WEEE recycling: A case study of Fincumet

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Mechanical engineering and production technology — Abstract

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Waste from electrical and electronic equipment or WEEE, is a broad category of waste involving electronics and e-scrap. Recycling WEEE can be made valuable by breaking down and reusing the waste, or processing it for individual material fractions. The field of WEEE recycling is fairly new and many innovative processes are being developed to deal with the waste. There are a lot of benefits in recycling WEEE especially when it comes to rare metals, it is also important to reuse and recycle waste for the purpose of the circular economy. Circulating materials and electronics to be reused will allow for the efficient use of resources, and hopefully limit the reliance on extractive processes.

This thesis provides a case study on how feasible industrial solutions for WEEE recycling might be developed. For this purpose a case study was used in the form of an industrial solution for a Finnish company which is trying to break into the field, this case study takes the form of an investigation. The background and theory on WEEE is discussed here, in conjunction with the case study to determine a conclusion. A detailed industrial operation is described within the thesis, acting as the primary concept for proving the feasibility of WEEE recycling. The thesis concludes by analysing the soundness of the proposed WEEE operation, providing a case study for developing such solutions. The thesis has was comissioned by Fortum.

Keywords: WEEE Recycling, industrial management, waste sorting, material processing

Pages: 1-37

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1 Introduction

The purpose of this thesis was to perform a research study for the company known as Fincumet, from this a case study on waste as to electrical and electronic equipment (WEEE) recycling was to be created. The study involved the author personally working within the small WEEE department at Fincumet. During this time observations were made on the state of the department from which a solution was ascertained. This solution involved proposing new industrial processes and providing operational improvements for the company, which resembled an implementation plan. The thesis was commissioned by Fortum, (Fortum owns and operates Fincumet) with the purpose of seeking out such a solution. Fincumet has had challenges with their WEEE department as it is a fairly new endeavour for their company, and this is why it had been deemed necessary to have it examined. The major purpose of the thesis can be summarised by posing a research question: How can WEEE recycling operations be setup feasibly?

This thesis starts by first explaining the theoretical framework, and defining the working methodology which was used. Background information on the commissioning company and on the WEEE recycling industry is covered, as an important piece of context. Information collected by the author is then summarised, and a set of requirements is drawn out from the collected information at the WEEE department. The proposed industrial solution for Fincumet is covered in great detail, using theory to back up the proposals. Thought is also given to implementing and managing this new operation, focusing on the practicalities of running a WEEE recycling site. Finally everything is summarised and a summary is drafted from the information presented in the text.

2 Background and theory

The theoretical framework that was used in this thesis is based upon the practices of industrial management. The information discussed in this thesis is framed within a conceptual model that provides structure, and a working methodology which provides clarity to the text.

2.1 Theoretical framework

This thesis primarily deals with the concept of industrial management. This thesis can be considered as a project which uses the concepts of industrial management to carry it through. These can be summarised as: production optimization, quality control, resource allocation and strategic planning. This thesis draws on these concepts to analyse and create solutions for the WEEE department. To clearly organize the project and to offer a frame of reference, a few steps can be setup in regards to the structure of the thesis:

1. Initiation phase
2. Planning phase
3. Implementation phase
4. Execution phase
5. Evaluation phase

The initiation phase can be considered the shortest, and it involves presenting the case and the desired outcomes by the comissioning company. This is of course crucial as it must be understood what it is that the company is looking for, the rest of the thesis rests upon this step. In the planning phase a plan on what to do is created, this was used to carry out the data collection in the implementation phase. In the implementation phase the plan is carried out and all the needed information is collected, the research study is carried out and everything is collated together. In the execution phase the actual solutions are created, and finally in the evaluation phase the solution is presented and a judgement is made upon it. The work is evaluated and assessed by the comissioning company and all the findings are delivered. This simple structure is fairly common within industrial projects, and throughout this thesis it will be referred back to (Lock, 2007, p. 8).

Throughout this entire project the relationship with the comissioning company Fortum, is very crucial. Close cooperation is key in any project and in this case it is no different, the

companies input was quite key especially in determining any solutions. As the comissioner of the project the company was responsible for providing requirements for the project. In the case where a solution was to be proposed, the direction for the industrial solution was set by the upper management. The author would collect more and more information and present this to the company, afterwards Fortum would update their requirements or the direction for the department would be altered. This would take the form of presentations, unstructured interviews and information exchanges.

2.1.1 Research methodology

The methodology used in this project relates to the collection of information. There were two main sources of information, research conducted at Fincumet, and research papers as well as other case studies. Searching for research papers was mostly done by going through online databases like Google scholar, and using key words to search for documents. Similarly case studies were gathered in this manner, looking specifically at studies which had been performed within other WEEE recycling operations. Most of the collected research was qualitative in nature, however, quantitative data was also used in the thesis process.

The research study that was conducted at Fincumet was the backbone of the thesis, and many practice-based methods were employed in carrying it out. The chief method of data collection was through direct observation by the author, these observations were collated by noting them down. Most of the time these observations involved the authors direct participation in the WEEE department’s operations. Information was also gathered through unstructured interviews with several members of staff at Fincumet. Many such interviews were conducted with the production manager, and other managerial staff within Fincumet. These unstructured interviews were conducted unformally by the author asking questions during daily discussions, and noting down the received answers. Almost all of this collected information was qualitative data in nature. The strategy adopted in collecting this information was pragmatic but methodical, notes were made by the author on what information was needed. The author would then actively seek out lacking information, through the previously mentioned methods of data collection. The aim was to gain a

complete picture of the WEEE department through an approach of inductive reasoning, which would later yield conlusions (Alasuutari, 2001).

2.2 Fortum and Fincumet

Fincumet (Fincumet, n.d.) is primarily a metal recycling company dealing with scrap and waste metal, as well as cables and batteries. The Fincumet site is located just outside of Ikaalinen (Pirkanmaa, Finland), where the company employs 43 people. Since 2018 Fincumet has been a part of Fortum (Fortum, n.d.) who handles most of the logistics and supply. Fortum is a large company operating in the Nordics and Central Europe, it is primarily an energy company but they also branch out into many fields of industry such as recycling. Fortum has been making headway into developing their recycling sector with a focus on batteries and plastics, with Fortum recently opening a battery breakdown facility at the Ikaalinen site. Fincumet handles its own management and daily operations, however most higher positions are filled by people coming directly from Fortum. Fincumet can be considered a subsidiary of Fortum and so for the purpose of this thesis, Fortum will be referred to as the managing company, whilst referring to Fincumet will refer to the specific site in Ikaalinen.

Recently Fortum has decided to branch out into WEEE recycling, and for this purpose a site has been setup in Fincumet to handle this operation. This WEEE department will be the focus of the thesis and it is also the reason for commissioning this thesis. Fortum wishes the department to be investigated and potentially expanded or reworked, Fortum wishes their department to recycle waste efficiently and in a manner which is sustainable and profitable.

2.3 WEEE recycling

WEEE recycling is the recycling or reusing electronic waste. Spent or used electronics can be collected and restored, or they can be broken down, and the components or even material fractions can be collected from the waste. WEEE is quite a broad category which includes any waste that possesses electronic components, this can range from refrigerators to phones. The term was originally put into use in the form of an EU directive on sustainablity,

put in place in 2003 but constantly updated ever since (EU, European Comission website, n.d.). The WEEE recycling industry is relatively new, but it is quickly becoming a profitable sector. New processes are being constantly developed to meet the challenge of recycling such a broad category of waste, new directives and regulations are also being introduced to attempt to incentivize recycling. The concept of the circular economy can be used to understand the direction of the industry, a focus is made on the sustainable recovery of raw materials (reusing/refurbishing). These are then fed back into the economy, and used to create new electronics. The intention is to supplement extractive processes such as mining, and also landfilling of waste which are considered harmful to the environment. Before this can be achieved it is important to first consider efficient and effective recycling methods, which are profitable for businesses. WEEE recycling can be seperated into: waste collection, sorting/processing, extraction/post-processing, selling. The industrial methods used in these 4 stages will vary greatly, depending on the intended goal and what materials may be recycled. Recycling of WEEE is generally very complex and so finding viable methods to recycle it can be quite difficult, especially on the smaller scale.

2.3.1 WEEE industry

The WEEE industry is a growing sector, especially within Europe. Focus will be given to WEEE recycling in the EU and the Finnish domestic industry as this is most relevant to the thesis. The WEEE industry has grown rapidly in Europe with countries such as Finland recycling 48.2% of all their electronic waste. The electronic waste within the EU consists of: 52.7% large household appliances, 14.6% PV panels and consumer equipment, 14.1% IT and Telecommunication devices, 10.1% small household appliances, and the remaining 8.4% are miscellaneous items (EU, European Parliament news site, 2020). The categories for the waste are quite broad and they reflect the varied nature of WEEE, due to this it has been difficult to create a decisive and standardised strategy for dealing with the waste.

In large part the industrial processes used in WEEE recycling have come from innovative solutions in the private sector, a great example of this is Zenrobotics (Zenrobotics, n.d.). Zenrobotics have developed robotic pickers which are able to pick and sort waste quickly and accurately, these pickers can be purchased as self contained machines and they are

specifically made for the recycling industry. For this operation Zenrobotics has developed a machine learning algorithm which is able to identify waste with the help of dedicated software, and built in sensors (Lukka, Tossavainen, Kuijala, & Raiko, 2014). Another new potential process is pyrolysis, which involves thermal decomposition of materials with the lack of oxygen. This process involves smelting waste in large sealed chambers, through a continuous process known as reduction which can separate metal fractions from WEEE. Hazardous materials are dissolved or neutralized and plastic fractions are turned into fuel, this process is also very efficient. As an example from smelted down WEEE waste, a 98.3% copper yield was achieved, together with 93.1% yield for aluminium (Diaz, Friedrich, & Florez, 2015). The field is full of innovative solutions, however when it comes to small scale recyclers, they will often struggle to adapt to these innovations. Not to mention they often require significant specialisation and vast resources which are usually lacking in such businesses. In these cases companies may focus their efforts onto a specific part of the process, such as waste collection or partially dismantling certain items.

Currently WEEE makes up 4% of all municipal waste within the EU, however it is estimated that the amount of WEEE increases by 16% - 28% per year (Yla-Mella, Pongracz, & Keiski, 2004, p. 82). Within Finland there are a few large companies which recycle municipal WEEE such as Kuusakoski or Stena recycling, these however mostly focus on recycling mass waste and mainly handle large appliances. This strategy generally focuses on recovering the large metal or plastic fractions that are found in WEEE, this can be feasible as long as it is done on a large scale. A niche which is slightly overlooked is the recovery of rare metals from WEEE, metals such as Gold or Palladium are found in great quantities within WEEE, especially in circuit boards. Printed circuit boards (PCBs) are small rigid boards made primarily from plastic, they are used to electronically connect components using conductive pathways or tracks. Some PCBs are very small whilst others can be quite large, depending on their use. On average a PCB will contain: 317 ppm of silver, 142 ppm of gold, 14.2% copper content, 1148 ppm of cadmium, as well as many other metals and elements (Bizzo, Figueirido, & de Andrade, 2014, p. 4559). Recovering these metals is difficult but will usually be done through pyrometallurgical or hydrometallurgical processes, which are almost always done on a large scale.

Clearly there are a lot of opportunities within the WEEE sector and it seems that the industry is constantly growing, with this growth a demand for recycling and better processes will eventually develop. It is certainly worthwhile for larger companies to research this field as it can lead to good opportunites down the line. There has been a push for companies to manage their waste sustainably and with WEEE it is no different, a conference on Nordic waste collection summarised the key directions for the field of WEEE recycling (Kjorboe, Sramkova, & Krarup, 2015):

- Improving product design, making electronics more suitable for reuse and refurbishing.

- Increasing the volume of electronics which get reused and refurbished.

- Improving collection and logistics networks, which consider the hazardous nature of WEEE and protect the waste from being damaged.

- Creating innovative methods and profitable methods for the recovery of WEEE, fulfilling the idea of the circular economy.

2.3.2 WEEE waste

To oversimplify it, WEEE waste can be split into four types: general (small/large), specialised and hazardous waste. For the department at Fincumet these categories apply well to the waste that is brought to the site. The waste that gets delivered to Fincumet mostly consists of mixed items, which contain all manner of electronics, these can be categorized as small and large. Small waste is generally not very valuable, but will sometimes contain batteries which have to be taken out. Large waste may have large fractions of metal or plastic but also valuable PCBs inside of it, it is hard to determine how many PCBs are found in WEEE, again because of the immense variety of waste. However, it can be generally stated that IT and telecommunication equipment have the highest PCB content, these PCBs also have the highest rare metal content, due to the complex nature of the IT equipment.

To showcase an example, a Phillips 46'' 9000 series 2008 TV has a PCB content of 505g (this includes the entire board and components attached to it) which makes up roughly 1.73% of the TV's total mass, this TV is particularly large weighing almost 30kg (Nelen, Manshoven, & Peeters, 2014, p. 311). When considering large waste in this thesis, it will be referring to such items, any item that requires dismantling will be considered as large waste or part of the large fraction.

Specialised waste can be considered waste of a single type, this means that the waste will only be one specific product with only very small varieties between individual items. Within the Fincumet WEEE department the waste is very mixed, but there is some specialised waste, such as printers or medical equipment. A supply of printers will occasionally come, these printers are mostly plastic and metal with only a few PCBs inside them. The difference between the mixed waste and the specialised waste is significant, with the latter being much easier to process as the printers are all of the same build. This allows the workers to know what's inside the printers with decent accuracy. Mixed waste is much harder to identify, whilst specialised waste allows for simpler automatic processing since there is no need to identify items as they are mostly the same. The issue with specialised waste is that it can be hard to gather a reliable supply, since most specialised items aren't thrown out en masse.

Another thing to consider is hazardous waste, most WEEE, especially mixed waste is considered hazardous waste. In the case of Fincumet most WEEE containers have to be stored under a layer of double concrete so as to make sure that no hazardous substances seep into the soil (Finlex, n.d.). The more commonly found hazardous waste types are: flame retardants which are found mostly in PCBs, toxic organic compounds found in capacitors and PCBs, electrolytes found in batteries and hazardous metals, found in a lot of WEEE (Salhofer & Tesar, 2011). Most of these have to be dealt with when processing WEEE, this is especially made difficult with mixed waste, as one cannot be certain of their contents. However most of these hazardous materials come sealed in casings or in non-volatile forms, and so they only need to be dealt with during the processing and extracting of the raw material.

3 Project

Carrying out the planning and implementation phases was done by the author whilst working at Fincumet, methods discussed in the earlier methodology section (2.1.1) were used here. The collected information presented will later be used to determine a further direction for the department, and the move to the execution phase. The original scope of the project given to the author by Fortum, was to simply examine the WEEE department and to seek out innovative industrial solutions for it. This could be considered the initial phase of the project as it provided the author with an end goal, and outlined the companie's requirements.

3.1 Planning

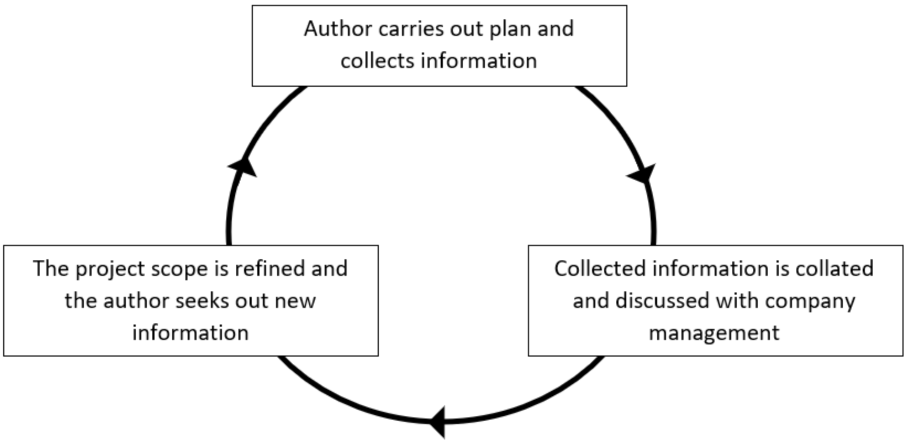
Once the project scope was given to the author by Fortum a plan was drawn out to collect information on the department. The plan was to observe the department's daily operations and to interview the staff to gather as much information as possible on the department. This was intended to be quite a loose plan, gathering information whenever possible with a pragmatic approach. The actual plan mainly consisted of simple check lists which would cover certain things that the author should look out for. Whilst carrying out the research study at Fincumet, it was also intended that research papers would be collected from online sources on relevant topics. The planning phase employed the methods discussed in the theoretical framework section (2.1). This plan was intentionally minimal due to the broadness of the project scope, with the idea of expanding upon it as information began to be collected.

3.2 Implementation

The beginning of the implementation phase was the beginning of the research study, which was taking place at Fincumet's Ikaalinen site. This initially followed the plan, the author began to work in the WEEE department and implement the previously outlined research methodology. The more information that was collected the clearer the picture became of what needed to be focused on. The research and collation of data took on an almost circular

pattern, with the author observing the department's operations and then discussing his findings with company experts. Figure 1 depicts this cycle.

Figure 1, Research and refinement cycle of collected data.



This process allowed for the company to provide their input, and allowed for discussion between the author and company staff on potential solutions. These discussions were again conducted as unstructured interviews, with Fincumet's production manager playing a key role in them. All the information that the author collected was noted down and turned into lists, or written up as notes. In conjunction with the research study, many research papers were collected and their information also played an important role in the cycle.

3.3 WEEE department

All the information that the author collected during the research study is presented here, and it provides an overview of Fincumet's WEEE department. The challenges and issues present are also covered.

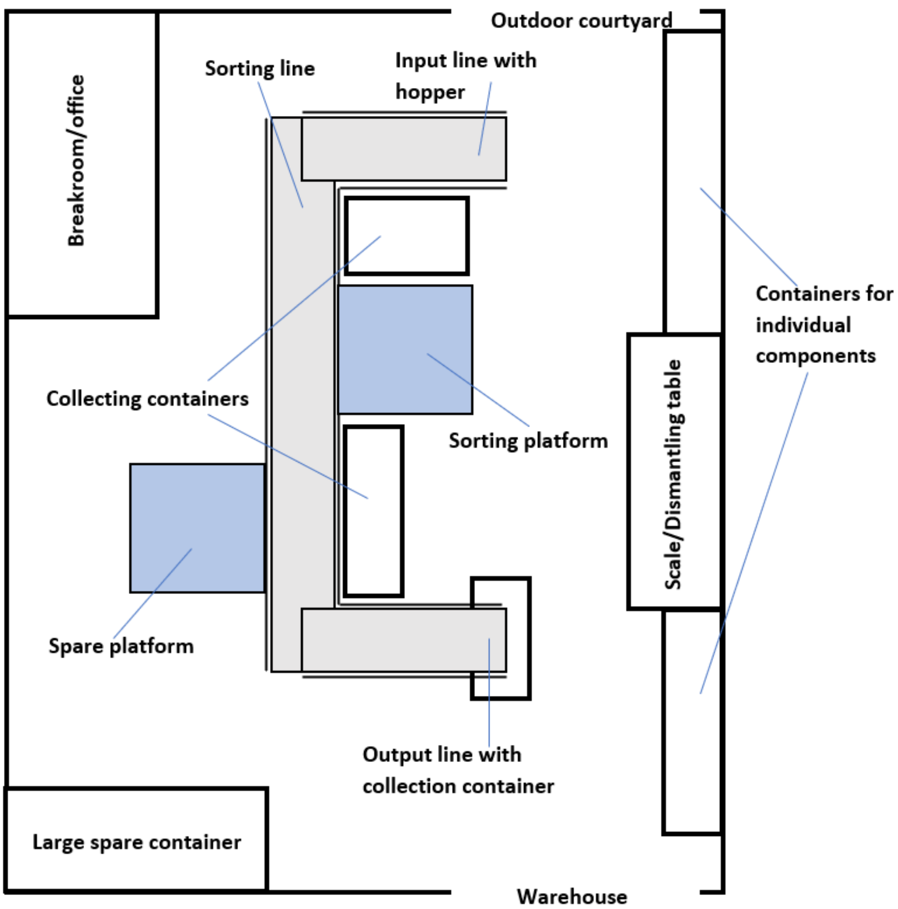
3.3.1 Overview of WEEE department operations

The newly set up WEEE department currently employs 2-3 people regularly, with this number increasing to 4-5 workers during the summer. The department is located within the Fincumet site in Ikaalinen, it sits in a single hall which is attached to a warehouse on one

end, and an outdoor courtyard on the other. Inside the hall there is one single machine referred to as the sorting line, this machine has a loading hopper on one end and a raised output line on the other. Waste is loaded into the hopper and when the line is turned on, the waste moves along it on a conveyor belt. In the middle of the line stands a platform upon which the workers stand over the line. From here the workers pick things off the line, small items are usually thrown into nearby containers or collected in boxes, whilst larger items are picked up and placed on the floor.

Inside the department there is a flurry of containers, some large and some small. Some of them are placed next to the sorting platform for the workers to easily throw items into them. In the case of items that are rare such as PC power boxes or cast-iron parts, the containers are placed alongside the wall of the hall, with the workers having to carry items to them. Moving containers, loading, and unloading is performed solely by one forklift with at least two workers trained in using it. Figure 2 shows the departments layout and where everything is placed.

Figure 2, WEEE sorting hall and its layout.



The inflow of waste to the department takes the form of a weekly delivery, sometimes another delivery comes during the end of the week but this is usually specialised waste. The deliveries come from suppliers that Fortum has signed contracts with, most of these will supply varied waste. Certain suppliers may also deliver specialised waste such as printers. Such waste or any very large waste, are usually packed into large cargo containers or they are just placed on pallets. The incoming waste is stored in its own warehouse, found outside near the outer courtyard. On occasion smaller containers will just be brought directly to the WEEE hall rather than the warehouse.

There are currently only a few contracts signed with supplying companies, however an effort is being made to bring in more waste. Almost all this waste is taken from the suppliers and brought to Fortum’s site in Riihimäki, this acts as the logistics hub and from here the waste is delivered to Ikaalinen. The workers main duty is to sort and collect valuable waste from the sorting line, this is done almost exclusively through manual means. Very large items that are packed on pallets will usually be stripped of any visibly valuable components (cables, batteries, etc.), whilst the rest is taken for crushing. Most of the time though, items are poured into the hopper at the start of the sorting line, and then the waste moves along the conveyor towards the workers. The workers are able to switch the line on and off from their sorting station, they can also control the speed of the conveyor. The workers then manually pick out any valuable items, any cables that are attached to devices or have power boxes are cut with pliers. Any items that are suspected to have batteries inside are taken out and stored for later dismantling, the same is done with large items that are deemed valuable. Cables and power boxes/plugs are the most common item to be collected, these will usually require cutting which can be time consuming as cables often come in large tangled bundles.

Outside of the sorting the most time-consuming operation is dismantling larger items, depending on the specific item the dismantling can be very time consuming. Items will usually have many screws combined with fittings and glue. The methods used in dismantling these items are entirely manual and involve the workers using hand tools such as: pliers, screwdrivers, hammers, drills, and wrenches. On occasion the large items are badly damaged and require the workers to use brute force to pry them open. The collected items are then taken to their respective containers with most of these being at an arm’s length away.

Certain items such as batteries are stored in special containers, this is due to their hazardous nature, however, most items are stored in normal open-air containers. The remaining waste that is not sorted gets taken to a large container outside. Once about 70 tons of this waste has been collected, it is taken to a crusher which crushes the waste into small parts. This waste is then processed by Fincumet in their metal sorting operation, or it is sent away to different Fortum sites. The remaining items that are collected, such as batteries, are sold off individually or again taken to different sites.

3.3.2 Department issues

During the research study at Fincumet, a few issues were identified that needed to be addressed. These issues are discussed in detail in this chapter, but to summarise and simplify, the following points cover the main issues in brief:

- Delivery timing and handling
- Waste identification
- Manual handling of waste
- Reliance on one forklift
- Lack of oversight and integration
- Lack of data collection
- Low volumes of waste

Starting with the the main delivery, it usually arrives at the beginning of the week bringing mixed waste to the WEEE department. Aside from occasional specialised deliveries which come infrequently, the weekly delivery is the main source of waste. The delivery will sometimes arrive late in the week, which makes it more inconvenient for the workers. The lack of a reliable delivery time, does not allow the workers to organise their time properly. This issue stems from how the deliveries are dispatched in Riihimäki, the delivery is only sent out once enough waste has been built up. This then depends on when waste is collected

from the contracted companies, this waste is collected weekly but it will vary in size and content greatly. The customer does not communicate to the company on what sort of waste is packed into what containers, and so everything is often heavily mixed. This also creates an issue with packing as under such conditions it isn't performed optimally. Ocassionally the containers will be filled with liquid, which cannot be poured out as it is considered hazardous since it mixes with the waste. Due to all these factors the volume of the delivery varies greatly, which ends up leaving the workers with too little or too much to do at times.

Another issue is the large variety of waste, the waste varies in types and sizes greatly which makes identifying valuable waste difficult. The workers must rely on their built-up knowledge of what items are valuable, this works for the more common items such as PCs, but rare items may leave the workers uncertain of their true value. It can also be difficult to identify hazardous materials, especially when it comes to items with batteries inside. There is no reliable method for determining if something has a battery or not. Valuable items may also be passed by, whilst useless items are picked up for dismantling, only to end up having nothing useful inside. This is especially an issue when it comes to larger items, since a large portion of the workers time is spent on dismantling said items.

Certain items can also be very difficult to dismantle even if they have valuables inside, and so a lot of time is spent on them with the return value not being worth it in the end. This is perhaps a limitation caused by working exclusively with simple hand tools. Tangled wires are a very common occurrence in the waste containers, and the workers must painstakingly deal with these. Untangling and cutting these bundled cables takes up a lot of time, and it also makes it harder to see things on the sorting line.

The department currently relies on only one forklift to move around any containers, this is fine for now but in the future if the workload is to increase then this may become a bottleneck. There is also always the concern of the forklift breaking down. This overreliance is an issue when the delivery arrives, as the workers are left to wait for the forklift to unload the delivery first before anything can be placed on the sorting line. The hopper into which the waste is loaded, is placed high up which only allows items to be loaded via the forklift. The workers also must carry a lot of items to containers which are on the other side of the

hall, although this is only the case with rare items which are generally not that heavy. However, this may prove to be an issue if the volumes of waste increase in the future.

The WEEE department is very small as compared to the rest of the site at Fincumet, and so there are not any dedicated specialists or managers to handle the departments minute operations. This may result in a lack of quality control and long-term assurances for the department, this is especially the case with data collection. The data that is collected lacks detail, which prevents any proper analysis especially in terms of how much time the workers spend doing what. Having such data would be crucial for making any impactful decisions on the department. It is also clear that the original plan for the department has somewhat changed and thus the need arises for setting a new direction. Another problem for the department is the low processing volume, simply put, not enough valuable waste is collected and processed to turn a profit. To ensure success a new direction has to be set for the department with either a focus on specializing into a single waste type, or to try and increase the volume of the waste.

4 Results

The overall direction is to make the department work efficiently and turn a profit. After the implementation phase, a few solutions were created for the department. These are based upon earlier findings and input from the company, these can be summarised as:

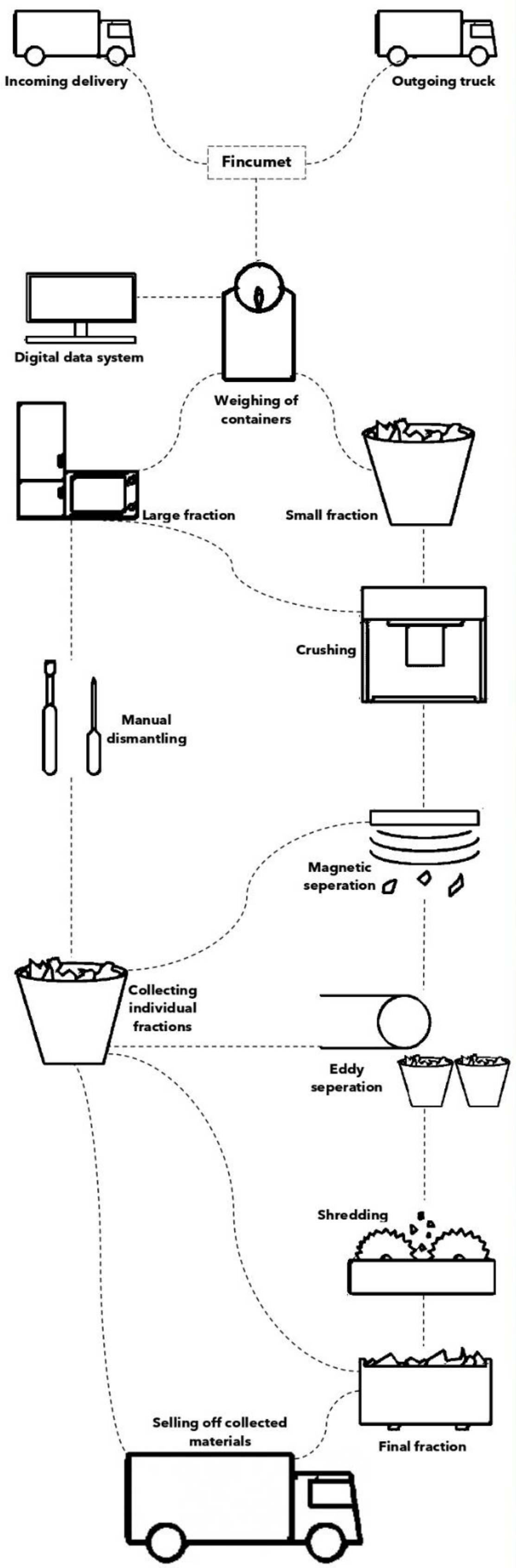
- Shifting the department’s focus to collect PCBs
- Creating a sorting line with new machinery
- Optimizing the running of the department

These processes are intended to make the department run efficiently, and to extract as much value as possible from the waste. A focus was also made on keeping this new overhaul limited in scope, mostly due to financial constraints and practical concerns. The execution phase covers these solutions in great detail, which can be found in the following chapter.

4.1 Technical solutions

Developing a new process and direction was key in Fincumet’s WEEE department. A lack of any set purpose or consensus in regard to dealing with waste, was a hindrance to the entire operation. Through the author’s personal findings in the department (as discussed in the previous chapter) it was concluded that a new process and goal was crucial, upon reviewing the department through extensive discussions, this view was adopted by the upper management. Originally a complete overhaul of the entire process was planned, with the goal of recycling specialised waste with specialised equipment, however, this was deemed too costly and unrealistic. Thus, the new conception attempts to minimize the costs as much as possible, and it aims to integrate the department into Fincumet’s other operations.

Figure 3, New industrial process with the material flow for the entire process.



An incoming delivery is attended to by a forklift driver, after checking with the driver he begins to unload the containers. He brings all containers one by one to the WEEE department where each one is weighed.

Every container brought in is weighed and this information is tallied up on a notepad. The weight of the containers is subtracted to get the real number. The total weight of the delivery is later inputted into a digital system, together with the date and who the delivery has arrived from. Most containers are then taken to the warehouse for storage.

With the forklift, one by one the containers are poured onto the sorting line, if there are any particularly large items then these are placed on pallets and later crushed separately. Valuable items are then picked from the line and any larger items with valuable internal components, are also picked off the line.

Larger items which need to be dismantled are dealt with manually once the sorting line has been cleared. The remaining waste which isn't collected get's taken into a large container, and after enough of the has built up it is taken to the crusher. Attached to the crusher is a magnet which will separate any larger ferrous metals, these can be directly given to Fincumet.

Further onwards the now crushed material is taken to an eddy current separator which separates out any remaining ferrous and non-ferrous metals. These are also taken directly to Fincumet, any other components taken from the dismantled items are also given to Fincumet. Specific components such as PC power boxes, or plugs are sold off individually.

After the waste has been put through the eddy current, it is taken to the shredder which crushes the waste into even smaller pieces. Afterwards the final fraction is complete, it consists of plastic and circuit rich waste. If the volume of circuits is low, then loose circuits or collected ones can be used to enrich the fraction. Finally, this is sold off together with any other individually collected items.

The concept of the new process is not too dissimilar to the original operation, but with the order of operations reworked and with a completely different goal. The new model assumes that the current supply and labour requirements are kept the same, with only the addition of an eddy current separator (STEINERT, n.d.). Together with a significant restructuring of the operations, as seen in Figure 3. The crusher and shredder are already in the possession of Fincumet; however, the shredder remains at a different site and is yet to be brought to Ikaalinen. The largest difference for the workers is that their labour will be shifted towards sorting and forklift operating, whilst the dismantling will be kept to a minimum and only to the most valuable of items. The focus will be shifted towards collecting PCB rich waste which is found in a vast amount of electronics, (Cucchiella, D'Adamo, & Koh, 2016, p. 5) especially in IT and telecommunications equipment. With the addition of the shredder and eddy current the PCBs together with their casing, may be shredded into smaller parts after which the eddy current separates out any ferrous or non-ferrous fractions (Yazici, Yazici, Deveci, Alp, & Greenway, 2010, p. 4). The remaining fraction would consist of small pieces of plastic and shredded circuitry, with some potential bio-waste mixed in. This final product can be sold off to companies such as Boliden who are able to extract rare metals from the shredded PCBs and use the plastic as fuel. Any other collected items such as batteries and cables can be sorted and sold off to Fortum for processing, whilst any loose PCBs can be used to enrich the final product.

The operation begins with the arrival of a delivery, this usually takes place in the main courtyard at Fincumet, and the delivery is unloaded with forklifts. The deliveries vary often in the amount of waste that is brought in, and thus the unloading times will also vary. Generally, any larger containers will be taken to the outside warehouse, whilst the smaller ones will be taken directly to the sorting hall. Anything that is brought to the sorting hall is weighed immediately and the numbers are noted down on paper, later on being inputted into Fortum’s digital system. There is little need to change the delivery process as the deliveries usually come once a week and even if this increases, it should not significantly impact the operation. Thus far the operation remains the same as there is no real need to change the unloading aspect, since it does work effectively even with large deliveries. However, time management during the deliveries could certainly be improved, but this will be discussed later.

Once the delivery has been handled, the items are ready to be poured onto the sorting line, this is again done with the forklift. The sorting line's speed can be adjusted by the workers who are positioned at their workstation, this layout is already quite optimal and there even exists a spare workstation later down the line (see Fig. 2). Once the waste reaches the workers, they must begin to sort out any valuable loose items. Some items are necessary to pick out such as cables and batteries, this is because Fincumet already processes these items. Within the Fincumet site there is a cable stripper used to collect copper from cables and the batteries are sent to another site. Thus, it is at least worthwhile to collect these items, however, it will no longer be necessary to collect metal casings or loose metal plates. Since all of the waste is put through magnetic and eddy current separation, the ferrous and non-ferrous fraction can be easily collected in this manner. This will also make the collection much more efficient as it will now be done automatically as compared to the current manual methods, there is an especially large number of ferrous metals which can be collected. As an example, 9 WEEE recycling sites in Austria were able to collect 496kg per ton of iron and steel on average from IT waste (Salhofer & Tesar, 2011, p. 1485). Not having to collect metals anymore will free up labour to be used elsewhere, in the case of very large items (individually delivered on pallets; fridges, solar panels etc.) it should also not be necessary as the crusher is capable of handling items as large as car bodies (Hammel, n.d.). These can also be handled by the large trucks in possession of Fincumet, their grippers are capable of lifting and crushing most larger WEEE, this is already done with printers.

Observably the most common valuable items handled by the workers are cables, batteries, PCs, and large modems. It is difficult to ascertain what the compositions of WEEE waste are but generally estimates for processing within the EU can be considered somewhat accurate. A Swiss company estimated that 2% of all WEEE consists of cables, by mass (Charles R. G., 2017, p. 6). This number will vary greatly depending on the type of WEEE, to cite the Austrian example once more, 65 kg/ton of cables was collected from small household appliances (vacuum, toaster, kettle, etc.) (Salhofer & Tesar, 2011, p. 1485). Observing the waste at Fincumet, it can be seen that a lot of time is spent on untangling and collecting cables, due to the nature of the loading, the cables will often be very tangled. This is further complicated by the fact that the cables will often be attached to small and large appliances, meaning the workers have to cut the cables with pliers. Measuring exactly how much time

the workers are spending on dealing with cables is made very difficult as the waste deliveries vary so greatly, this would have to be done over a long period of time to get accurate data. If a solution is found which ensures the cables are collected quicker (such as having them spaced out on the sorting line, rather than tangled) then it may remain viable to collect them, as long as the labour isn't needed elsewhere.

Items containing hazardous substances must also be considered for collection, luckily the most common ones are fairly easy to remove and collect. Batteries are already being collected and processed at the Fincumet site and so collecting them makes sense and it usually isn't very time consuming. Batteries will contain an estimated 12,700 mg/kg of Lithium hexafluorophosphate, as well as 85,500 mg/kg of Cadmium and 156,000 mg/kg of Nickel, together with smaller fractions of hazardous metals (Salhofer & Tesar, 2011, p. 1485). Another commonly collected hazardous item is the printer cartridge or ink cartridge, the ink "dust" (small particulates) within them is considered hazardous (Salhofer & Tesar, 2011, p. 1485) and thus they have to be collected. This is quite simple and the worker merely needs to pull the cartridge out of the printer, this is then deposited into a container and later these are sold. LCDs or liquid crystal displays are also hazardous as they contain small particulate crystals as well as mercury within cathode lamps (Jang, Hong, & Park, n.d., p. 1). This however isn't much of an issue, as long as the displays are kept within closed off containers which will prevent any mercury gas from leaking out. Monitors and TVs are already collected separately and no dismantling is done on them, this removes the issue of having to deal with the hazardous substances overall. In general, most other hazardous substances can be found in PCBs in the form of flame retardants or hazardous metals, these are also not a problem as they will form part of the final fraction. The flame retardants come in non-volatile forms and so they aren't an issue unless they are being melted or processed. Once the circuits are incinerated the hazardous materials are safely removed, this process is used by Boliden in their smelters (Boliden, n.d.). To conclude on the hazardous materials, they should not pose a significant burden as long as storage practices are up to standards, this will mostly involve sealing certain containers. More information on specific local legislation and hazardous waste can be found here (Finlex, n.d.).

The small fraction that is shown in Figure 3, will mostly consist of cables, batteries, as well as loose PCBs or plugs. Most of these items don't require much from the workers to collect, but to ensure it is financially viable it will be necessary to collect data on this matter (discussed later). It is now time to consider the larger items that the workers may come across. On occasion very large items will arrive, these will be packed separately on pallets and usually these are not dismantled but simply taken away to be crushed. This is because larger items are usually difficult and very time consuming to dismantle, mostly due to the very large casings and significant amount of screws or fittings on them. A lot of the workers time is spent on dismantling larger items, this is regarded as being very wasteful as it is very obvious that most of these items take too long to dismantle and have too little value inside them. Cutting down on the number of items that are dismantled will greatly improve efficiency and will free up time which can be used elsewhere.

The most common items to be dismantled are PCs, modems, control boxes, and aluminium strong boxes. These are dismantled mostly for their circuits but with the new eddy current these circuits will be separated out automatically, making dismantling these items mostly redundant. However, it may still be worth recovering certain circuits such as processors or RAM memory as these are very valuable due to their high gold content. A detailed breakdown of PCB materials can be seen here (Cucchiella, D'Adamo, & Koh, 2016, p. 758). To demonstrate the value, we can take a single Samsung 128MB PC2100 RAM memory; the value of a single module is about 0.7 EUR with >90% of the value coming from the gold content, per tonne the value would be around 42,000 EUR (Charles, Douglas, Hallin, Mathews, & Liversage, 2017, p. 515). An average RAM module contains an estimated 18 mg of gold (Charles, Douglas, Hallin, Mathews, & Liversage, 2017, p. 512), the value in collecting these is immense however they do come in very small numbers. Thus, their usefulness comes in being used for enriching the final collected fraction. Determining how much gold is contained in the final collected fraction is important for companies like Boliden, who later collect it. Since it is almost impossible to estimate how much gold will be found in the final fraction, it becomes difficult to guarantee a minimum amount to the buyer. To ensure the fraction has sufficient gold content, adding some RAM modules and processors will make this more certain. Nevertheless, this will still remain a rough estimate, it seems that

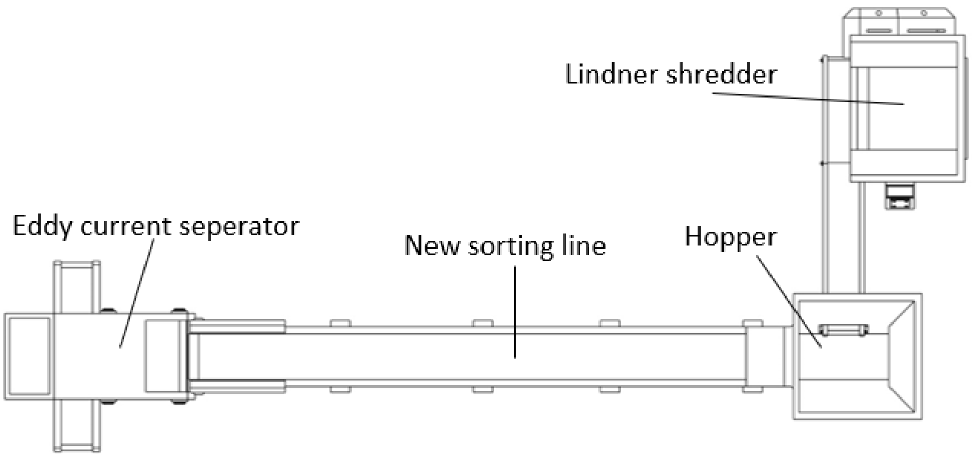
experience in this field is crucial and having an expert make an estimate will still be somewhat valuable.

It seems reasonable to assume that it will be only worth dismantling items which possess such valuable PCBs, this is again difficult to determine as the waste varies greatly. However, from the experience that has been collected in the department thus far, it is agreed upon that PCs and large modems will likely be worth dismantling. PCs have a lot of useful components, they contain power boxes, cables, processors, RAM modules and circuit boards (Vermesan, Tiuc, & Purcar, 2019, p. 3). Meanwhile the modems are very quick to dismantle and have a few large PCBs inside them, these however do vary a lot in size making it difficult to quantify their value but also easy to identify them. It will be necessary to collect data on these items so that their proper value can be analysed. To conclude the large fraction will likely end up being very small and most items will just be sent to crushing as it isn't worth dismantling them. It at least can be certain that this will free up time, which can be used for sorting and collecting items within the small fraction.

To carry on with the process described in Figure 3, it should be looked the remaining waste that wasn't picked off from the line. At the end of the sorting line there is a container which captures all the outgoing waste, once it is full this waste is taken to a large container with a forklift. Once the container or substitute containers have been filled sufficiently, (this will usually be around 70 tons but this depends on the crushers availability) they are taken to the crusher. The crusher is used for a lot of other things at the Fincumet site and so it is only used with the WEEE on occasion. The crusher is also very powerful, capable of crushing 45 t/h of industrial waste (Fig. 4). The crusher also has a magnet attached to it which will be able to collect any larger pieces of ferrous metal from the crushed waste, the remaining waste is then taken to the new sorting line.

Figure 4, Hammel VB 750 D crusher which is in possesion of Fincumet (Hammel, n.d.)

Figure 5, Potential layout of the new sorting line.



The new sorting line would be a compact set up, Figure 5 shows how it might be layed out. The purpose behind the new sorting line is to act primarily for sorting metals, this is what Fincumet does extensively and having an automatic eddy current separator for it would make things much faster, as compared to manual sifting. However, purchasing an entire new eddy current separator will not be worth doing for the purpose of sorting metals and WEEE waste, as the volumes are just simply too low. With the Steinert example (STEINERT, n.d.) we have an eddy current which can be attached to a truck and be moved around, effectively

becoming mobile. This would be very useful for Fortum overall as they can move the eddy current to different sites, and have it used whenever and wherever it might be necessary.

This design for eddy separators is quite common and very versatile. Eddy current separators are quite capable of separating circuits from metals, it is even possible to calculate the trajectory for the PCB. The eddy current works by inducing a magnetic field through powered revolving magnets that will cause items with different mechanical properties to react, this works through Lorentz forces that push different items along different distances. This of course depends on the item's mechanical properties, such as it's density and electrical conductivity but it is entirely possible to calculate the trajectories of these items (Yazici, Yazici, Deveci, Alp, & Greenway, 2010, p. 1208). Pre-made eddy current separators are usually programmable and can be used to separate out multiple fractions. In the case of WEEE the ferrous and non-ferrous fraction will have to be removed by the separator, these fractions can later be taken by Fincumet and processed at the rest of the site. This will offer a very efficient way of extracting metals from WEEE waste, which contain large amounts of ferrous metals as mentioned previously. The sensitivity of most eddy currents can also be calibrated to ensure that it doesn't pick up the PCBs, since these have some metals on them.

The final fraction that remains will be a mixture of plastics, some biowaste and crushed circuitry. This is where the value is found, a ton of such waste can be sold for 700 EUR (production manager's estimate), if it is deemed that the gold fraction is too small then the collected circuits from the PCs and modem's can be used to enrich the fraction. This fraction now has to be shredded with the Lindner shredder; this shredder is already in possession of Fincumet but it hasn't been brought to the site yet. There is a lack of any technical data on the shredder and so it is difficult to ascertain what particle sizes it can produce from shredding the waste. Although this shouldn't be too great a concern as the particles required by a company such as Boliden, are usually around ranges of 10mm, which most shredders are capable of achieving. This shredded waste can be readily sold and presents the final product. What is later done with this varies from company to company, but the more common process is to use smelting and leaching (Nakamura, 2018, p. 19). This involves burning the waste in large furnaces which turn the plastic and the biowaste into fuel, whilst the valuable metals are later extracted through leaching. This process is becoming quite

valuable, to demonstrate, the copper content found in PCBs is between 12% and 29%, whilst the copper content found in raw copper ore is only about 0.5% to 3% (Bizzo, Figueirido, & de Andrade, 2014, p. 4560).

With other metals it is quite similar, and so as the electronics market grows and it's corresponding waste, it will overtime become more valuable to mine PCBs as compared to ores. This of course is highly dependant on developing effective extraction methods for the PCBs, which could be considered as efficient or even more efficient than mining processes. To summarise, the new process will involve creating a new sorting line which will primarily serve as a metal sorting line, but also used for the sorting of WEEE. An eddy current separator which is mobile will have to be purchased and leased around Fortum's different sites. The labour currently being performed at the WEEE department will have to be shifted towards sorting and moving the waste around. It has already been agreed that this process is technically sound and can work for Fortum, but due to the limitations present it is much more difficult to ascertain its financial viability.

4.2 Operational standards

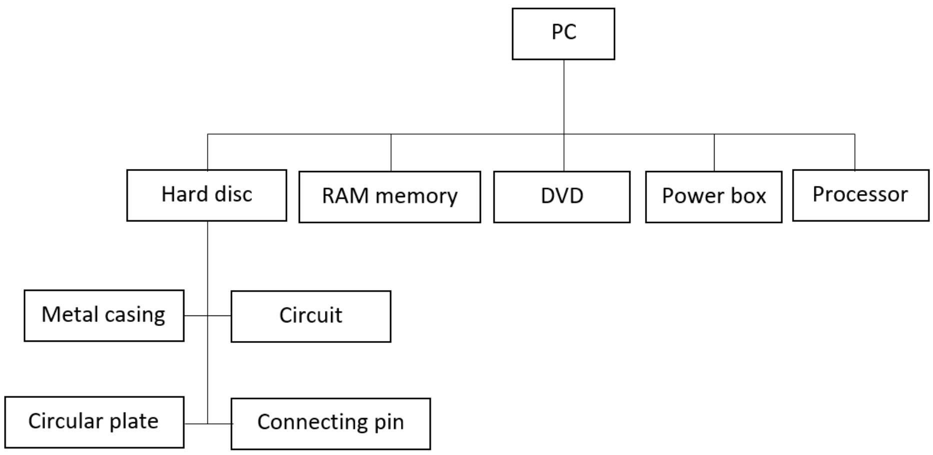
Although implementing an entirely new industrial process may be successful. Thought should still be given to operating the WEEE department, and how this may be done efficiently and up to a high standard. To do so previously known issues within the department should be looked at, and solutions should be considered for implementation. As long as a high operational standard is maintained, then it can be expected that the department will operate effectively.

The first thing to consider may be the logistical aspect of the operation, having a smooth and timely logistical operation will be important for the rest of the operation. The waste is collected from customers by sending them containers, and providing them basic information on what to put in them. Providing the customer with more information may be a useful way of easing the later processing of the materials. For example, the customer could be given information on hazardous waste and given special containers exclusively for such waste. The customer may also be instructed to pack small and large items seperately, which would

make the dismantling process easier since the workers can just pick out any larger items from the containers, rather than waiting for them on the sorting line. Storing the waste in a dry area would also be to an advantage, as the workers then don't have to deal with disposing of the contaminated water, that collects in the containers. Setting up a clearly defined schedule or improving communication between the site at Ikaalinen and Riihimäki, may also benefit efficiency. Letting the workers know what waste they should expect, even if it is a quick glance into the containers, would allow the workers at Ikaalinen some time to prepare for the delivery. Knowing exactly when the delivery will come will also allow for effective time management, this would let the workers prioritise important jobs first as compared to less important ones such as cleaning.

It may be considered that the current sorting line inside the WEEE departments hall, may need to be moved or potentially refitted. Setting up a new sorting line (see Fig. 8) may be costly and so an alternative to this would be to use the existing line, for this the line would have to at least be moved closer to the outside door. This is to allow the eddy current to be placed close by, however moving the entire line and using it for multiple operations (metal sorting and WEEE sorting) would require extensive coordination, and may prove difficult to implement. The loading hopper at the start of the line is located high up, only allowing forklifts to load items into it, having it lower would be very difficult but the hopper could be entirely removed in favour of a line that simply goes all the way from the floor, decreasing reliance on the forklift.

Figure 6, Dissasembly tree of a PC (the tree only displays a few PC components).



The identification of valuable items has to be done properly, valuable material shouldn't be thrown away and time shouldn't be wasted on valueless items. Common items should be analysed for their value, this can be done with the use of a dissasembly tree as illustrated in Figure 6. Items are picked from the line and dismantled, the time taken and the value of the components is compared to determine if it is worthwhile to dismantle them in the first place. The individual components are then collated as a dissasembly tree, allowing a clear analysis of individual items. If such data is collected then identifying valuable items on the sorting line should be made much easier, the data can also be used to analyse what the optimal dismantling rate is. It may only be worth taking out the circuit from a modem and then leaving the rest, partial dismantling may be the case for a lot of items and the optimal state should be discovered for them (Wang, Huisman, & Korevaar, 2008, p. 47). It is expected that this will result in a significant reduction of time spent on dismantling, a focus should also be made for collecting PCBs as these are intended to be sold. As long as the amount of larger items is kept minimal then manual dissasembly methods will be sufficient and will effectively collect any valuable internal components.

It is also evident that the workers spend a lot of time on untangling waste that has clumped inside the containers, this mostly happens with cables into which smaller items get mixed in. Having a method for spacing items out on the line would make the sorting significantly faster as well as make items easier to see. This can be done for example with an adjustable lever which holds back waste by blocking larger items, a comb could also be used in this regard. Having a slower loading system could also fix this, with the forklift everything is dumped in one go, but if the container is slowly tilted and only a few items are allowed through at a time, then everything would remain neatly spaced out. Such systems can be found even in garbage trucks which can load containers automatically and do so at an adjustable rate, however this might be difficult to implement at Fincumet since the containers vary in size.

Another small thing that can be done to improve efficiency is to plan and zone out space within the WEEE department hall. Currently there is plenty of space inside the hall but nevertheless it would be good practice to make sure the space is used effectively. Since there is so much space in the WEEE hall some of it could be utilised for storage, the collection containers inside the hall could also be placed closer to the line so that the

workers do not have to carry items very far. This would also mean that the forklifts don't have to travel too far, to pick up the waste. Some redundant containers can be removed and replaced with bins or even boxes, this could be done with items that are collected on a very low volume. For example PC processors are very small and collected rarely, rather than having an entire 500L container for them, it may be wise to simply put them in a small box or plastic bin.

The WEEE department has remained self-contained and somewhat isolated within the site at Fincumet and it is important to integrate it into the organizational hierarchy. If the new sorting line is introduced then this will be made much easier as it will require better coordination between the metal and WEEE operations. Having dedicated staff for the department would still be very valuable, but with it's current size this would be too unrealistic. For the time of the new expansion, a project manager should head the expansion to make sure everything runs smoothly. The WEEE department should also be able to have access to the expertise within Fortum, this would be especially useful in terms of quality control. Having someone check the final fractions before they are sold, would be a good practice to introduce, ensuring the sold off product is of a higher quality for the buyers.

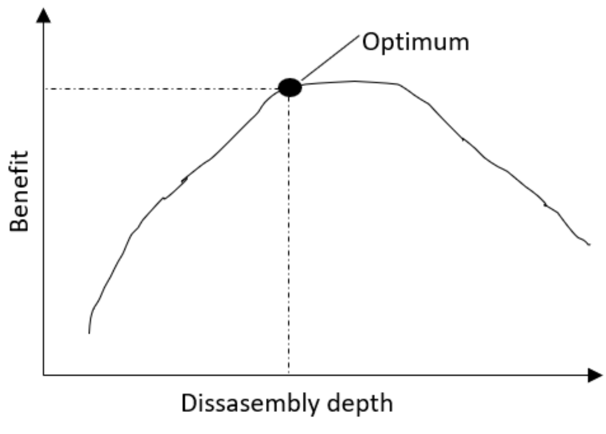
To get a good idea of how the WEEE department can be made profitable, it must first be identified what waste is valuable and how to extract the value out of it, in an efficient manner. The first thing that should be done is to see how much time is spent on what, assessing how the workers spend their time will be important to know. Being able to see a breakdown of how the workers time is spent can be used later to assess their productivity. To assess the value of the workers time, it would firstly be important to identify how much waste is collected, during times when the workers are sorting and pulling items from the sorting line.

A lot of items that are taken off the line have no dismantling time, and so they only require the worker to deposit them into their correct container (these will be loose batteries or circuits, cables, etc.). Weighing the collected items will be key as the weight (and value) can be later compared with the total time spent to collect it. In the end this can be used to determine how much time was spent at the sorting line, and how many items were collected

during that time. This would give a very crude estimate as it does not consider a multitude of factors. However, it would be useful in showing whether time being spent at the sorting line is at all worthwhile, later on this can be done with specific waste types to see which items are most worthwhile to sort. This will probably be unnecessary as simply seeing the total value of individual items will probably give this information anyway.

The same can be done for when the workers are spending time dismantling items, however here it would be useful to analyse individual items so as to see what is worth pulling from the line and dismantled, as previously mentioned with the dismantling tree. This would be simple to do and would require the workers to pick out common items, such as computers, phones, printers, etc. The workmen should note how much they are spending on dismantling certain appliances. The value of the collected items from said appliances should then be compared to the time spent on dismantling them, this can then be used to determine if the item is worth dismantling or not. This can later be refined by studying whether partial dismantling may be worthwhile or by looking at singular items and fully disassembling them.

Figure 7, Crossing the benefit with the depth of dismantling provides the optimum point. (Opalić, Kljajin, & Vućković, 2010, p. 52).



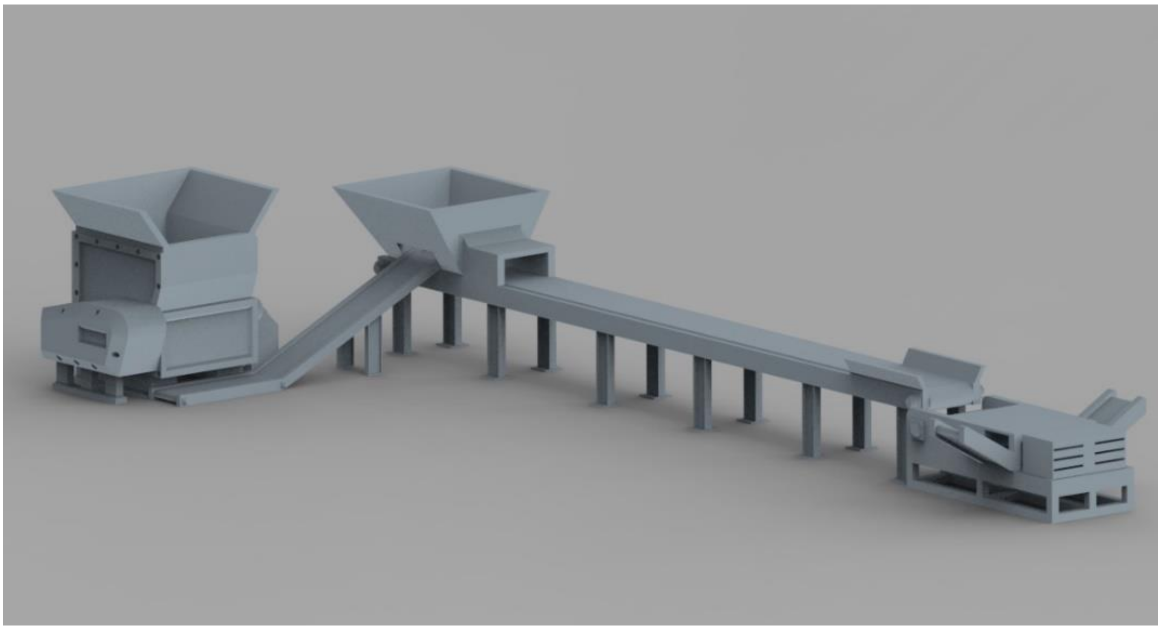
If the workers begin to collect the afformentioned data then it can later be used to determine the optimum dismantling depth for a certain item, as shown in Figure 7. It may not be worthwhile taking apart every item fully, it may only be viable to take out the circuit

or battery and the rest to be left alone. This can only be determined if the workers begin to collect information on how they spend their time and if individual items are analysed with the dissasembly tree method. Collecting this data will be extremely crucial in providing a realistic financial view of the department, as currently this information is lacking, causing the analysis to be largely speculative. Data that is collected should be inputted into Fortum's digital system for safekeeping and for allowing easy access to the information, this will be especially useful on the business side of things. Overall as long as good practices are followed and everything is performed with care, then the department should be working efficiently.

4.3 Implementation of concept

The WEEE department will generally maintain it's look but it's function will change. The workers will now only spend time on sorting and little time on dismantling. The volume of incoming waste will increase and more time will be spent on managing inventory and moving containers. The new sorting line will be constructed near to the WEEE hall, it may also be possible to re-zone space in the nearby warehouse or rework the sorting line in the WEEE hall, for an even simpler solution. Before implementing any such solution it will be important to collect the afformentioned data, as well as assign specialists to the department. The new sorting line may look as shown in Figure 8.

Figure 8, Conceptual design of the new sorting line.



Before going on to create a sorting line it will first be important to allocate space for it, the line will have the shredder attached to it, combined with a hopper and a line which leads directly to the eddy current seperator. This line will be used for sorting out ferrous and non-ferrous fractions from Fincumet's metal operation, and will also be used to remove metals from the circuit rich WEEE fraction. Going on to implement such a concept will require dedicated specialists to organise the new line and to integrate it into the hierarchy, and operations currently taking place in Fincumet. The new solution will require new space to be organized for the line, as well as the purchasing of a new short sorting line and a mobile eddy current seperator. I have already talked about the benefits of this, setting up this operation shouldn't be a great challenge for an organisation like Fortum, nor should the resource expenditure be too great.

5 Future Potential

Looking into the future of the WEEE industry can grant a better view of the potential found within it, specifically looking at innovative industrial methods of which some are already being implemented. An interesting development to showcase is the automated monitor dismantling machine from Votechnik (Votechnik, n.d.). This machine is a large self-contained device. The machine can dismantle up to 80 monitors per hour, and it is able to collect close to every material fraction and component from the monitors as the dismantling is done mechanically. Mechanical arms with tools and suckers are used to pull apart the monitors. It also deals with any hazardous waste. In the case of monitors this is mercury leaking from cathode lamps found inside them. The Votechnik example is an interesting machine as it has every aspect of WEEE recycling already integrated into it, essentially meaning that no pre-treatment or post-treatment is required unless the aim is to recover raw materials. A company interested in recycling monitors can simply purchase the machine and bring it to their site; the machine can then begin to recycle monitors without the need for specialists or costly setup operations. Votechnik has clearly discovered a niche in monitor recycling which they have exploited. Fully automated solutions are rare in the WEEE field and so this development may pose a standard for companies in the future.

Another interesting development is that of solar panel recycling, currently such panels are a very uncommon item to be recycled with only a few companies, such as Veolia currently recycling them. Since 2010 the average annual growth of solar panel installations has been 25% worldwide, with the solar panel industry expected to become the fastest growing industry within the energy sector (Lehtomaki, Jonsson, Roscher, & Rautiainen, 2020, p. 7). Solar panels or photovoltaic panels usually contain aluminium, glass, steel, plastic and some rare materials, notably silver. Solar panels do also vary in type, with silicone based panels being the most common, consituting 90% of all solar panels (Kusch & Alsheyab, 2017). Only about 10% of solar panels are currently being recycled worldwide, making them a very niche item for recycling, this is likely due to solar panels having a lifespan of 25-30 years and only having been introduced to the market in the 90s (Lunardi, Gaitan, Bilbao, & Corkish, 2018). Most industrial methods for dealing with solar panels involve mechanical seperation of components, this is usually done through a mixture of manual and robotic means. Since the panels are a growing niche, they might be an interesting example of a growing and yet unexplored sector. This niche is ripe for being exploited by innovative and ambitious companies.

Another interesting development is the robotics which are being integrated into WEEE recycling. Robots are very useful due to their precision and versatility, the previously mentioned example of Zenrobotics demonstrates well how robots can be used to sort waste automatically. Similarly packing facilities use pick and place robots which are fast parallel robots, cabale of picking items off conveyor belts and placing them into containers. Alternatively robots can be used to dismantle items quickly and safely, as compared to humans performing the sometimes dangerous labour. Hyperspectral imaging has also been used in conjunction with robots, to help identify waste accurately and quickly allowing for smooth automated operations that require little human involvment (Raptopoulos, Koskinopolou, & Maniadakis, 2020). In theory such an operation could be setup in a WEEE recycling facility, hyperspectral cameras could be used to identify waste on a sorting line. The line would have to be well lit and the waste on it would have to be neatly spaced out, the line would also have to move at moderate speed. Such a camera could identify up to a few items and relay this information to a robot picker which could pick up the desired item. This may be a good alternative to manual sorting especially if specific items are being looked

for, such a robot could sift through tons of waste and pick out a few desired items. The speed of such operations is highly dependant on the algorithm used to identify waste, the computational power would have to keep up with the camera and robot to quickly identify the waste. There is so much potential in developing robotic solutions for WEEE, but the limitation is that such solutions are often very expensive and require extensive research to implement them. Due to this it is very difficult to break into this sphere, however as the technology develops, it is likely that this field will become more significant in the future.

6 Conclusion

Concluding the thesis the author summarises the findings and analyses the quality of the collected information. This is effectively also the evaluation phase.

6.1 Limitations

There are some limitations to the information found in this thesis, which are addressed here. Economic analyses is excluded from the study due to the lack of data relating to finances in the WEEE department at Fincumet. There are also limitations to the observations made by the author at Fincumet, since these are subjective observations and may be biased. There are of course limitations to the industrial process proposed in the thesis as it is assumed that Fortum has a need for the eddy current separator elsewhere, this also applies to Fincumet's need for metal sorting. This still does not affect the case study overall. The study conducted by the author at Fincumet was just under three months, thus results found in more long term studies may be different.

Since the field of WEEE recycling is quite new, there is a lack of literature on certain topics which may cause limitations to the theory presented. Most of these limitations can be addressed by conducting more long term studies and carrying out practical experiments, which Fortum should be able to perform in the WEEE department.

6.2 Summary

The findings of this thesis can be summarised as a case study for the developing field of WEEE recycling. It acts as an example from which many conclusions can be made. WEEE is difficult to deal with and even supplying it can pose a challenge, not to mention trying to organise automated solutions for it. Perhaps the most significant finding here is that when attempting to recycle WEEE on a small scale, it is best to focus on a niche or to specialize into one specific process. A practical example of this is laid out in the new solution for Fincumet's WEEE department. With some reworking and a few new purchases a transition can be made from recycling mixed waste to extracting specialised waste.

The process will now specialise in to gathering plastics and PCBs, which are intended to be sold for further processing. Many other fractions are also collected along the way and the process is significantly less wasteful. It also shows how new innovative solutions can be created to address the issue of WEEE, these can then be perfected and eventually become standard practice within the industry. Small companies may become overburdened with the demands of recycling WEEE and so specialising into niches should be their primary concern, as opposed to trying to recycle every type of waste en masse.

New solutions by nature will be crude, and thus it is important to test them in practice, and in a way which is both technically and financially sound. To answer the initially posed research question, it seems that it is entirely possible for companies to recycle WEEE in a feasible way, hopefully the case of Fincumet demonstrates this. As long as thought is given to what value can be extracted from the waste and how to do so efficiently, then innovative processes can be soundly introduced into the field. Especially when it comes to exploring niches within the WEEE market. To conclude, WEEE recycling is a difficult field for companies to get into, but it also presents many opportunities as a new sector of industry within the increasingly circular economy.

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