E-waste at Twente Milieu and De Beurs

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Contents

Management summary

This paper describes the results of the executed research on how Twente Milieu and De Beurs can determine what e-waste to disassemble and what not.

First of all, the current situations regarding the handling of e-waste at Twente Milieu and De Beurs are analysed. This resulted in two flowcharts in which the processes are visualised. By combining this information with the information from the interviews at Twente Milieu and De Beurs, the aimed situation is composed. With this aimed situation, the scope of this paper is made clear. The main issue in the aimed situation is how to best organize the disassembling of the appliances to retain more value from the appliances and to create social workplaces.

To come to the core of the problem within the scope of the research, a problem cluster is made. The core problem is defined as the lack of knowledge about value of materials in e-waste. In order to provide Twente Milieu and De Beurs with a useful solution on how to organize the disassembling of the appliances, they first need a method for determining to which degree an appliance need to be disassembled. Therefore, the research question in this paper is the following: "*Which materials are profitable to extract out of the appliances by Twente Milieu and De Beurs based on cost-benefit analysis, in order to retain value of disassembling, and to create social workplaces?".*

Our analysis is based on four categories: big white household appliances, refrigerators and freezers, small household appliances and ICT and CRT TV's and monitors. Revenues consist of the worth of the materials extracted from the appliances, and the value that is given for the remainder. The materials considered are: metals, plastics, electronics, wood, and glass. The revenues should cover the costs of among others: wages, necessary tools, and the momentarily unknown disassembly location. We propose to execute a break-even analysis based on the selective disassembly methodology with priority for certain categories of appliances. This includes listing the components of the individual products, determining the disassembly time needed, and the additional profit that is obtained with extracting every further component. For this we have created an excel worksheet.

The conclusion with regard to which materials to extract should in the ideal case be based on the proposed break-even analysis. However, specific conclusions can be made for individual materials. The market value of wood is very low and the market value of glass is 0 in addition to the fact that extracting glass might be dangerous. It is recommended to not pay too much attention to these materials. Important materials in categories are metal for the big household appliances (50%-66%) and plastic for small electrical and ICT appliances. Despite of the fact that electronics do not account for big percentages within the contents of the appliances, electronics do have a relatively high market value. The break-even analysis results in an overview of the necessary employment. De Beurs and Twente Milieu have to decide on the actual employment because they consider social workplaces as a higher purpose.

Management samenvatting

Dit rapport beschrijft het onderzoek naar het demonteren van e-waste dat is uitgevoerd voor Twente Milieu en De Beurs.

Als eerste is de afhandeling van e-waste bij Twente Milieu en De Beurs geanalyseerd. Hieruit zijn twee flowcharts gekomen waarin deze processen worden weergegeven. Vanuit deze flowcharts, gecombineerd met de informatie uit de interviews bij Twente Milieu en De Beurs, is de beoogde situatie opgesteld. Op basis van deze beoogde situatie is de scope van de deze paper vastgesteld. Het probleem dat hierin centraal ligt, klinkt als volgt: "Op welke manier kan het demontage proces van e-waste zo ingericht worden dat er meer waarde uit de apparaten wordt gehaald en er sociale werkplekken worden gecreëerd?".

Om tot de kern van het probleem te komen, dat binnen de scope van het onderzoek ligt, is een probleem cluster opgesteld. Het kernprobleem dat hieruit volgt is gedefinieerd als 'het gebrek aan kennis van de waarde van de materialen in de e-waste'. Om Twente Milieu en De Beurs een bruikbaar antwoord te kunnen geven op de vraag hoe het demontage proces ingericht moet worden, moet er eerst bepaald worden in hoeverre een apparaat gedemonteerd moet worden. Hieruit is de volgende onderzoeksvraag gekomen: "Welke materialen uit de apparaten zijn winstgevend voor Twente Milieu en De Beurs gebaseerd op een kosten-baten analyse, ten einde waarde uit het demontage proces te halen en sociale werkplekken te creëren?".

Onze analyse is gebaseerd op vier categorieën: groot witgoed, koelkasten en diepvriezers, kleine huishoudelijke apparaten & ICT en CRT-tv's & monitoren. Opbrengsten bestaan uit de waarde van de materialen welke uit de apparaten gehaald zijn en uit de waarde dat het restant van het apparaat oplevert. De beschouwde materialen zijn: metalen, plastics, elektronische componenten, hout en glas. De opbrengsten moeten onder andere de volgende kosten dekken: loonkosten, benodigd gereedschap en de op het moment nog onbekende locatie voor het demonteren. Wij stellen voor om een break-even analyse uit te voeren die gebaseerd is op de selectieve demontage methode waarbij de prioriteit op bepaalde categorieën van apparaten ligt. Onderdelen van deze methode zijn het opsommen van de componenten van de individuele producten, het vaststellen van de benodigde tijd voor het demonteren en het vaststellen van de extra winst die verkregen wordt met het verder demonteren van het product. Hiervoor is een Excel werkblad gemaakt.

De conclusie waarin antwoord wordt gegeven op de vraag welke materialen uit de apparaten gehaald moeten worden, zou in de ideale situatie gebaseerd zijn op de uitkomst van de break-even analyse. Echter, deze conclusie kan nog niet gemaakt worden vanwege het ontbreken van cruciale data zoals precieze demontage tijden. Er kunnen wel enkele conclusies getrokken worden voor bepaalde materialen en productgroepen. Ten eerste hout, de marktwaarde hiervan is erg laag. Ten tweede glas, de marktwaarde hiervan is 0, daarbij komt dat werken met glas extra gevaar met zich meebrengt. Daarom is het aan te raden om zo min mogelijk tijd in deze materialen te stoppen wat betreft demontage. Ten derde metaal, 50% tot 66% van de grote huishoudelijke apparaten bestaan uit dit materiaal. Ten vierde plastic, kleine elektronica en ICT-apparaten bestaan voor het grootste gedeelte in dit materiaal. Tot slot de elektronica componenten, de hoeveelheden hiervan in de apparaten zijn relatief laag maar daarentegen is de waarde per kilogram relatief hoog. De break-even analyse resulteert, na het invullen van de benodigde variabelen, in een minimale hoeveelheid medewerkers die benodigd zijn om de demontage werkzaamheden uit te kunnen voeren. De Beurs en Twente Milieu kunnen vervolgens zelf bepalen hoeveel sociale werkers ingezet worden om, afhankelijk van het doel, een zo hoog mogelijk winst te maken of zo veel mogelijk sociale werknemers aan het werk te hebben.

1. Introduction

E-waste is described as discarded appliances that use electricity, such as computers, cell-phones and refrigerators (Robinson, 2009). Over the past couple of years, the global quantity of e-waste has increased incredibly. In 2010 the generated e-waste amounted to 33.8 million tons, whereas in 2014 the number had already increased to 41.8 million tons, and prospects for 2018 assume 49.8 million tons (Baldé, Wang, Kuehr, & Huisman, 2015). Due to this increasing number, a lot of scientific papers address the recycling of e-waste products which are also being referred to as 'waste of electrical and electronic equipment' (WEEE). However, e-waste does not only contain valuable metals and other materials, but it also contains potential environmental contaminants which increases the difficulty with which these products can be recycled (Robinson, 2009).

This paper considers two Dutch companies: Twente Milieu and De Beurs. The former being a company that collects the waste of households including e-waste and the latter being a second-hand shop also collecting e-waste (More information can be found in Appendix 1). Currently, these companies collect the appliances, after which other parties take care of the recycling process. However, Twente Milieu and De Beurs are both interested in doing parts of the recycling process themselves because of reasons that will be presented in this paper.

This paper aims to provide an analysis of the costs and benefits incurred in doing a part of the recycle process in-house and thus provides information on the profitability of in-housing these practices. We will first sketch the current situation and the contemplated situation after which the scope of the analysis is explained. This scope is necessary because recycling e-waste encompasses a very broad range of activities, a lot of which, Twente Milieu and De Beurs cannot execute because of special licenses or certifications that are needed. A lot of these activities are reserved for specialized companies. After the introduction to the problem and the introduction to our research questions, we will explain how we will find the answer. Chapter 4 presents all relevant information in order to arrive to multiple solutions. The solutions for Twente Milieu and De Beurs are presented in chapter 5. Finally, the conclusion and recommendations are presented.

2. Problem statement

Twente Milieu and De Beurs are dealing with a lot of e-waste and are wondering whether improvements can be made in this area. Their aim is to extract more value from the products that are collected and additionally, create more work in the Twente area for disadvantaged people. In this chapter, we will analyse the current situation and the problem presented to us. At the end of this chapter our main question is determined. The answer to this question will support Twente Milieu and De Beurs in achieving their aims.

The problem with which the company presented us is: What is better to do? Organizing product flow for collecting, sorting, disassembling, repairing and selling based on processes by employees, or by yield in type of components? This problem is part of the bigger problem of the willingness to collect and recycle e-waste on location in order to extract more value from the e-waste and create workplaces. The current processes regarding the collection of e-waste at De Beurs and Twente Milieu are depicted in Figure 1 and Figure 2. Both companies collect the products, but De Beurs also checks whether products are broken, and if not they are sold. Moreover, they try to repair products that are easy to repair after which they can be sold again, only the products that are broken and cannot be fixed will be send to Omrin. Omrin collects, just as Twente Milieu, waste in the Northern region of the Netherlands, moreover they process the waste in order to recover raw material and produce renewable energy (Omrin, 2016). Twente Milieu does not check or repair products and all products that are collected are sent to Omrin if full truck loads are reached.

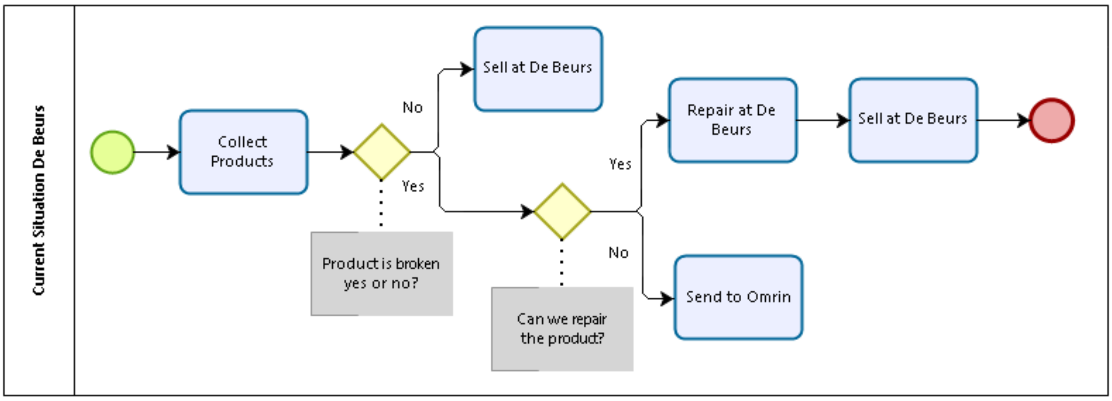

Figure 1 Current situation De Beurs

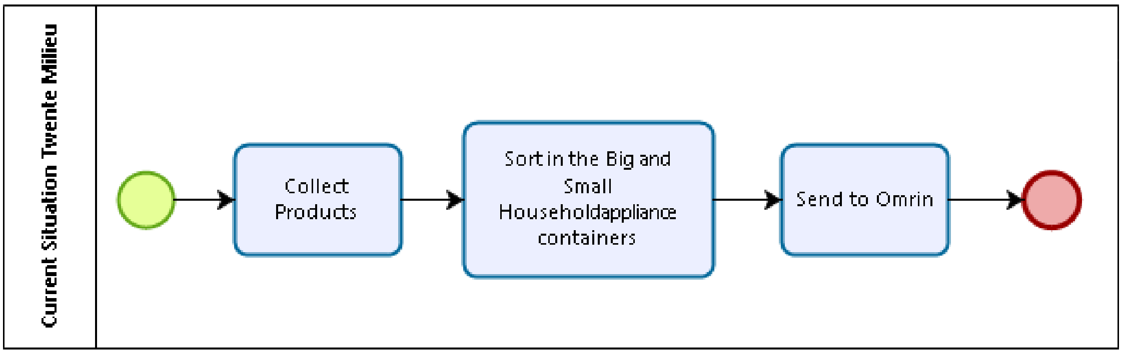

Figure 2 Current situation Twente Milieu

Figure 3 displays the interpreted aimed situation that would be most beneficial according to information provided by De Beurs and Twente Milieu. It shows the following: at the moment that the e-waste is collected it should be sorted into appliances that are either broken or not. Products that still work should be sold at De Beurs even when they arecollected at Twente Milieu. For broken products, the decision whether to repair the product or not should be made based on cost-benefit analysis.

Products that can easily be repaired should be repaired and sold at the Beurs. The other products should be evaluated on whether it is worthwhile to disassemble or immediately dispose of the product by sending it to Omrin. Up until this point, the companies are familiar with handling e-waste. However, they do not know how to organize the disassembling of the appliances.

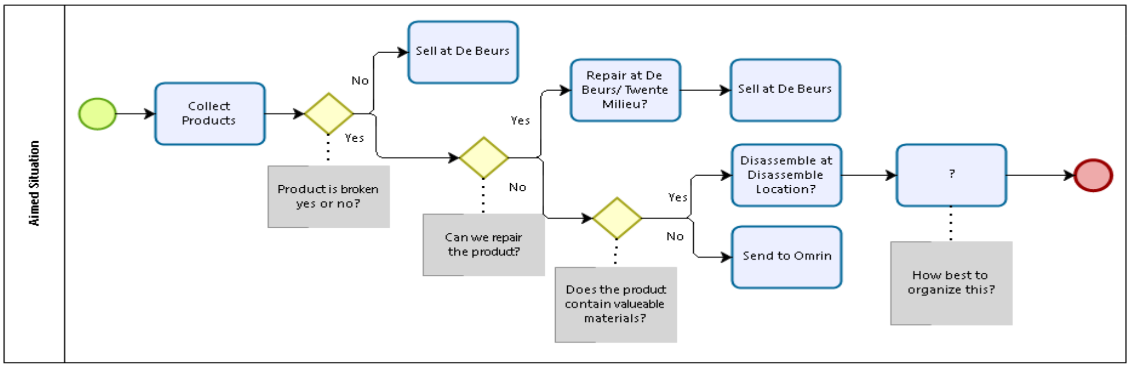

Figure 3 Aimed situation

The former consideration and the problem cluster that is included in appendix 2 jointly bring us to the scope of this paper. The problem cluster presents our view on the problem and reveals the underlying reasons why steps of the recycle process are currently not done in-house. In reality, not enough value is retained from broken e-waste and few jobs are available for social workers because of this outsourcing. The norm is to retain more value from broken e-waste and simultaneously create more work spaces for social workers in the Twente area. To achieve this, we want to find out which materials are profitable to extract from the appliances and sort this out per product group. According to us it is the lack of knowledge in this field that prevents the companies from doing steps of the recycle process in-house.

We choose to focus on the profitability of disassembling certain materials, because De Beurs and Twente Milieu already undertake collecting, sorting, repairing and selling to some degree. Despite of the fact that this is maybe not done in the most efficient way, it is more important for the companies to acquire knowledge on the subjects of disassembling and sorting. We want to clarify that we do not pay attention to the environmental impact of recycling. A lot of papers on e-waste pay lots of attention to ecological aspects, but it is the case that all of the actions that we will recommend to do in-house will otherwise be done elsewhere, having the same impact on nature. The only ecological benefit that might be achieved, by keeping parts of the disassembly process in the area, will be a reduced number of transportation kilometres as less trucks will have to drive to Omrin.

The question that we want to answer is:
Which materials are profitable to extract out of the appliances by Twente Milieu and De Beurs based on cost-benefit analysis, in order to retain value of disassembling, and to create social workplaces?

In order to answer this question, we derived the following sub questions:

1. *What is the economic value of the materials that the appliances consist of?*
2. *What are the costs related to extracting the materials out of the appliances?*
3. *Which categories of appliances are the most profitable to disassemble?*

By answering the main question, we will not immediately arrive at a solution to the problem with which the company presented us. However, in order to find a solution to this problem, our main question has to be answered. In the recommendations, we will try to bridge this gap, but first we will describe how we will find the answer to our main question.

3. Research Methodology

This chapter describes how the research is carried out and what the key variables are.

3.1. Problem Solving Approach

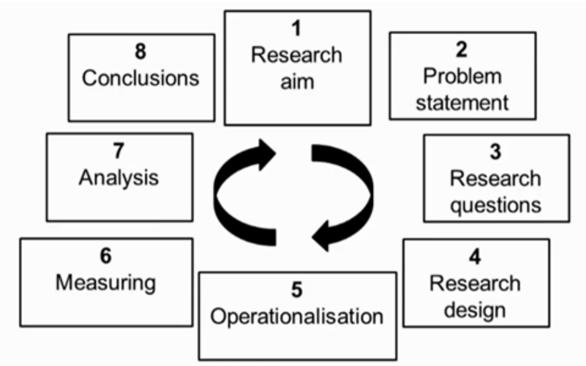

Figure 4 Research cycle

The main question that we have established relates to a knowledge problem. Therefore, we have decided to use the research cycle, shown in Figure 4, to obtain answers to our questions (Heerkens, 2016). Phase one, two and three are presented in the introduction and in chapter 2. We have determined the norm that the companies aim to achieve, and we found reasons that prevent them from achieving this. Subsequently, we came up with research questions that will, when answered, help them to change the current situation. In this section, we will describe the research design and operationalisation of key variables and constructs that we will use in chapter **Fout! Verwijzingsbron niet gevonden.**. Chapter **Fout! Verwijzingsbron niet gevonden.** focuses on real data and scientific knowledge that substantiate our conclusions presented in Chapter 5.

3.2. Research Design

Stakeholders that will benefit from insourcing some parts of the disassembly process are not only the social workers that will be employed. Additionally, the municipality of Enschede will save € 20.000,- per year for every person that is employed (personal communication, 24 November 2016). As these benefits are impressive, we agree with De Beurs and Twente Milieu that insourcing would benefit multiple parties and is thus something to explore.

To obtain answers to the sub questions established in Chapter 2, a lot of information and data is needed. A systematic literature review is conducted to find the most relevant scientific papers for all three sub questions. In appendix 3 we included an overview of our search terms and we explain how we eventually arrived at the sources that are mentioned in this paper (the bibliography). However, after we reduced the number of papers to a set of relevant and reliable papers, we found that we needed additional quantitative data to answer the questions. The separate sub questions needed different approaches. These approaches are explained below.

Sub question 1
'*What is the economic value of the materials that the appliances consist of?'* requires information on the economic value of raw materials and additionally requires information on the material contents of appliances. The value of raw materials can be found on Google by searching for the daily price of each material. This information is mostly not scientifically substantiated which reduces the reliability of the data. To increase the reliability (being the consistency of observations) we checked multiple sources on similarity within the quantitative data before using the data (e.g. material content of a washing machine). This is also referred to as triangulation (van den Berg & van der Kolk, 2014). Material contents of appliances can be found in reports on the specific products that are also found with the search engine Google. Whenever in doubt of the quality of information, multiple sources will be checked to confirm found data. An important player in the field of WEEE is WeCycle, this party will be used for general information about the collection of WEEE.

Sub question 2
'*What are the costs related to extracting the materials out of the appliances?'* focuses on the cost aspect of extracting materials. To answer this question, we need to know which costs should be considered and what the actual costs are. Common sense can help us to identify cost items after which we will use research papers to confirm these thoughts. The actual costs of the cost items can be found with Google and for this the notion on triangulation is valid again.

Sub question 3
'*Which categories of appliances are the most profitable to disassemble?'* does not only want to identify categories that are profitable to disassemble but also involves the search for a way to identify profitable disassembly. The first section focuses on available knowledge from products that have been disassembled by other parties, this information can be extracted from research papers on specific products or product category analysis. The second section is more general and can be found in research papers that propose a model for (profitable) disassembling.

Relation with steps of the research cycle
The key variables of the main research question are operationalized in the next section of this chapter. The sub questions do not have any other variables that have to be operationalized. Therefore, the sub questions relate to three steps of the research cycle: measuring, analysis, and conclusions. Measuring is done by doing desk research for each sub question in order to find quantitative information concerning e-waste. The data found is used to make an analysis in the next step of the cycle, which provides a basis for the direction of the solution. The final step is the conclusion. The conclusion includes the results of the analysis and thus the information from the sub questions.

3.3. Basic Concepts & Key Variables

In this paper, we talk about disassembling. Disassembling involves the removal of components and specific materials from products. A product can be partially or fully disassembled and this decision is often made based on the cost of disassembly, in which the costs are proportional to the effort employees take to extract components (Willems, Dewulf, & Duflou, 2006).

The decision regarding partial or full disassembly requires the disassembly sequence. This involves knowledge about every single component in a product and their connections with each other. Listing and levelling components is convenient to create a diagram that contains all possible disassembly sequences (Kara, Pornprasitpol, & Kaebernick, 2005)

Selective disassembly is the result of the cost/benefit analysis and should be based on the sequence of the components. Selective disassembly serves multiple purposes. It recovers valuable parts, assemblies, and valuable materials. It also removes harmful components and it increases the purity of the remainder of the product increasing the value of the remainder. This is similar to the notion of decreasing the shredder remainder. Finally, selective disassembly is useful when some valuable components can be extracted when other non-valuable components are removed (Lambert, 1997).

Value can be explained in multiple ways for different kinds of things. The obtained materials in the disassembly process are valuable. This value, for all kinds of materials, will be expressed in money. Value is also delivered to the social workers who will disassemble the e-waste in the Twente Region. For them, value means that they have a place where they can work, and in some cases, they have a place to make steps to reintegrate into the labour market. Also, the salary they will receive is value for these social workers in terms of money. More jobs will be available when the disassembling of e-waste is done in the Twente Region, mainly for social workers. This means that municipalities can save money on the expenses for social benefits. A decrease in unemployment in the Twente Region will stimulate the image of the region in a positive way.

In-housing a part of the disassembly process results in an unquantifiable value for the society. On the one hand, it saves the municipality money, but on the other hand, Twente Milieu and De Beurs might have increasing expenses as a consequence of the creation of these workplaces. The worth that is assigned to these workplaces has to be determined by Twente Milieu and De Beurs. However, as they already state that one of the aims is the creation of work places, we feel that they are aware of this unquantifiable value.

3.4. Relationships

To be able to evaluate the stream of e-waste and to decide what to disassemble and what not, relationships between the variables need to be sorted out. For the break-even analysis, it is important to have an overview of:

- product groups with material proportions within the appliances,
- material groups and their current value.

4. Data analysis concerning e-waste

This chapter considers the value and costs of disassembling and proposes ways to identify a break-even situation.

To be able to make a decision for Twente Milieu and De Beurs with regard to which materials to extract from the e-waste stream, we propose to execute a break-even analysis. According to Lambert (1997) there are two aspects that influence the break-even point; costs and revenue. Cafferky (2010) explains break-even thinking as 'a way of comparing the amount of incoming value that an organization needs in order to serve its customers by delivering outgoing value of an equal amount'. A break-even situation is thus a situation in which no losses are borne, nor profits are made. The total cost method of Cafferky (2010) uses the following formula:

Total costs for a period = total revenue for a period = break-even

However, total costs can be split into fixed costs and variable costs changing the formula into:

Fixed costs + variable costs = total revenue = break-even

According to Koetzier & Brouwers (2015) total revenue can also be divided into fixed revenue and variable revenue. An example of fixed revenue would be subsidies (Koetzier & Brouwers, 2015).

Fixed costs are costs that are always there whether the process is stopped or not, e.g. lease of the workshop and machinery. Variable costs depend on the amount of work and can variate in a certain time period. The same goes for the constant and variable revenues. In order to conduct a break-even analysis, it is necessary to get data of these aspects.

According to our own insight the operation has the costs and revenues as shown in Table 1.

Fixed costs	Operation costs such as workshop, tools, machinery & energy
Variable costs	Labour costs
Fixed revenues	Subsidies
Variable revenues	Value of the extracted materials and the remainder of the disassembled appliance

Table 1 Costs and revenues

The fixed revenues are subsidies that can be granted to the organization for employing disadvantaged people. The variable revenues of the extracted materials come from the basic materials of which a product consists. For instance: electronics, glass, metal, plastic, and wood.

To get a better overview, we decided to set-up the analysis per product group. The product groups are a compilation of appliances/e-waste of the same kind that are brought in at Twente Milieu and De Beurs. The product groups, the costs incurred, and the revenues obtained that will be used in this paper will become clear in the next sections of this chapter.

4.1. Economic value of the materials

This section aims to answer the question: what is the economic value of the materials that the appliances consist of? We will first determine categories of appliances and their material content, after which we will provide information on material values and thus the value of the appliances.

4.1.1. The materials of each category

In the Netherlands, a lot of e-waste is collected. WeCycle is the only non-profit organisation in the Netherlands responsible for collecting and recycling e-waste (WeCycle (a), 2016). As shown in Figure 5 below, WeCycle collected 32.1 million kilos of big white household appliances, 22.8 million kilos of refrigerators and freezers, 33.2 million kilos of small electrical appliances and ICT, 16.0 million kilos of CRT TVs and monitors, 2.0 million kilos of flat screen TVs and monitors, 1.7 million kilos of energy saving lamps, and 1.9 million kilos of fixtures in 2015 (WeCycle, 2016). The latter two categories will be left out of consideration as these appliances are small and contain few valuable materials, additionally the total volume of these categories is small. The flat screen TVs and monitors category should be considered because the collected volume will increase over the next couple of years. The appliances that are collected in a certain year reflect what has been bought several years ago, and therefore, the category of flat screen TVs will increase. CRT TVs are old fashioned, but are still handed in a lot compared to flat screen TVs. We will use the numbers of WeCycle as a basis for our material analysis.

Figure 5 Collection of e-waste Source: (WeCycle (b), 2016)

For big white household appliances, refrigerators and freezers, small electrical appliances and ICT, and CRT TVs and monitors an overview about the material composition is made. These overviews are shown in appendix 4. The material composition of flat screen TVs is difficult to establish because few information is available, therefore this category is not shown in the overview.

The materials are divided into five groups: electronics, glass, metal, plastic, and wood to show which material groups are the most important for each of the appliances. We did have to make some assumptions. For example, we assume that the proportion of electronics, glass, metal, plastic, and wood in a washing machine are similar to the proportion of these materials in a tumble dryer. An overview of the average percentage of electronics, glass, metal, plastic, and wood in each of the categories of appliances is given in Table 2.

Material	Big white household	Refrigerators and freezers	Small electrical appliances and ICT	CRT TVs and monitors
Electronics	4%	1%	7%	8%
Glass	2%	1%	0%	54%
Metal	50%	66%	26%	14%
Plastic	11%	23%	60%	14%
Wood	3%	0%	0%	0%

Table 2 Proportion of materials per category

As you can see in the table, big white household appliances and refrigerators and freezers consist of metal for a large part; 50% and 66%. In the other categories, metal can be found as well. Different kinds of metals are found, such as aluminium, brass, copper, iron, and steel (figures and sources can be found in Appendix 4).

The small electrical appliances and ICT appliances contain the most plastic, namely 60%. In other categories, plastic can be found as well. To give an impression of this category, three different types of appliances are analysed. These appliances are coffee machines, inkjet printers, and vacuum cleaners. It turns out that the average proportion of electronics, glass, metal, plastic, and wood are pretty much the same in these appliances. There are a lot more different types of appliances, but the general proportion of the four materials will be the same. The plastics in the products are a composition of all kinds of plastics.

CRT TVs and monitors consist of glass for more than half of the product, namely 54%. The glass that needs to be extracted, mostly comes from the vacuum tubes. These tubes could implode if they break. Since the tubes can break, the TVs and monitors must be disassembled with care.

Electronics can be found in each category. Electronics consist of printed circuit boards (PCBs), cables, and power supplies (sources can be found in Appendix 4). The percentage of electronics is not very high, but as will be explained in section 4.1.2 the value of these materials is relatively high.

The final material, wood, is not present in most of the appliances and if wood is present, it is a very small amount. Therefore, wood will be left out of further consideration.

4.1.2. Value of the materials

Employees should know how to disassemble a system, which components they should extract based on the value and which components should be handled with care. To maximize economic value, the disassembly process should start with the most valuable parts and finish with the parts that have the lowest value (Kang & Schoenung, 2005). Additionally, within this range one has to decide where to stop the disassembly process based on a cost-benefit analysis. Twente Milieu and De Beurs will not be recycling the spare product and therefore they do not have to extract any hazardous materials or components themselves, they can leave this task up to the party that will recycle the spare product.

Plastic is found in all appliances, but since an appliance consists of 8 - 12 different basic types of plastics it is difficult to work with the unknown compositions. As a consequence, the market value of unsorted plastics is very low which should be taken into consideration (Electronic waste recycling: A review of U.S. infrastructure and technology options). The presence of, for example, flame-retardants is a technical constraint to the extraction of plastics in certain products (Huisman, Stevels, & Stobbe, 2004). Additionally, it is found that recycling plastic is only eco-efficient for large housings of appliances from which also other valuable materials can be extracted (Huisman, Stevels, & Stobbe, 2004). In general, the fraction including iron, copper, aluminium, gold and other metals in e-waste is over 60%, while pollutants comprise 2.70% (Widmer, Oswald-Krapf, Sinha-Ketriwal, Schnellmann, & Böni, 2005).

After disassembly, every resulting component comprises an output flow. A decision must be made on what to do with these output flows and the following alternatives are possible: reuse, material recycling, incineration and landfill (Willems, Dewulf, & Duflou, 2006). Incineration and landfill are no possible options in this case because Twente Milieu and De Beurs are not concerned with these kinds of practices and moreover, these options can often be eliminated because of legal restrictions (Willems, Dewulf, & Duflou, 2006). Reuse will most probably also involve a lot of work and thus the most viable End-of-Life strategy is material recycling. Material recycling is done by other companies and Twente Milieu and De Beurs will receive money for every kilogram of material that they offer. The prices per kilo of the different kind of metals are given in Table 3.

Metal	Price per kilo in euros
Aluminium	0.70
Cupper	4.00
Lead	1.40
Brass	2.60
Unsorted iron	0.11
Stainless steel	0.70
Zinc	1.45

Table 3 Metal prices Source: (Oudijzer-prijs.nl, 2016)

Table 4 shows the price per kilo of plastics and moreover the prices of electronics. The electronics have a relatively high price per kilo. These parts could be extracted from the appliances to gain extra revenue.

Part	Price per kilo in euros
PCBs	3.20
Cable (without plug)	1.10
Power supply (without cable)	0.40
Mobile phone PCBs	20.00
Plastics	0.15
Low grade cable (inside appliance)	0.25

Table 4 Part prices Source: (Bishoen, 2016); (Nederlandse Recycle Bank, 2016)

According to our contact person at Twente Milieu, they hand in glass for free at the recycler. This means that it is not worth it to dedicate work to extracting glass from the appliances (personal communication, 17-1-2017). Important to consider are the values of the materials. If materials increase in value (partial) disassembly is more attractive, if materials decrease in value, disassembly becomes less attractive (Willems, Dewulf, & Duflou, 2006).

4.2. Costs related to extracting materials

This section is concerned with the costs of extracting materials. We will determine which variable and fixed costs must be considered to eventually answer the question: what are the costs related to extracting the materials out of the appliances?

Costs are very difficult to determine. However, the largest variable expense will be the wage of the employees who are going to execute the disassembly. De Beurs determined the average hourly wage to be 5 euros (personal communication, December 21, 2016). Social workers are subsidised which reduces the cost for De Beurs and Twente Milieu to employ these people.

The higher the disassembly time of a product the more workhours are needed and thus the higher the total amount of wages is. It is difficult to determine how many products an employee can disassemble in an hour. We assume that products will be disassembled manually with tools. This assumption is made because automatic disassembly will not provide more work in the Twente area. Creating more workplaces was said to be one of the aims of keeping work in-house. The disassembly time will be considered as a variable.

To make it possible to disassemble the appliances, tools are required. The tools are a drill and a big toolset. These tools are needed for each workstation where the disassembling process takes place. The cost of an industrial quality drill is €275.00 and a big toolset costs €295.00 (Manutan (a), 2017); (Manutan (b), 2017). Other investments such as hand trucks, work benches and protective work clothing are also fixed costs that should be considered, estimated costs are €125.00 for a hand truck and €519.00 for a work bench (Manutan (c), 2017); (Manutan (d), 2017). The costs for protective work clothing are extremely variable and it is thus better to be filled out by De Beurs and Twente Milieu. The biggest fixed cost is the cost for the location of the disassembly activities, because these costs cannot be estimated these costs will be considered as an unknown cost.

4.3. Profitability of the appliance categories

This paragraph is about to come to answer the question: Which categories of appliances are the most profitable to disassemble?

It will only be profitable to disassemble products if the benefits outweigh the costs and thus a break-even situation is achieved. To accomplish profitable disassembling, it is necessary to determine the optimal degree to which a product should be disassembled. Disassembling is also referred to breaking down a product into individual parts. Parts can either be reused, remanufactured or recycled (Duflou, et al., 2008). In this case study, parts will only be disassembled for recycling. Reusing and remanufacturing are not an option because both companies are not concerned with these kinds of practices. Easy to repair products will be repaired before disassembly takes place.

Multiple articles explore how products should be treated after entering a recycling facility. Willems et al. (2006) propose to have varying levels of disassembly ranging from option 1: no disassembly to option n: full disassembly. Willems et al. (2006) distinguish 8 profiles of products. They used a water kettle, coffee maker, iron, video cassette recorder, mobile phone, vacuum clear, personal computer and a washing machine as a representative sample of e-waste products. They found that high-value products required a disassembly time-reduction of 65-75% to make partial or full disassembly profitable. Although we do not have any information on the disassembly time for the various products, we can conclude that (partial) disassembly for high-value products is profitable but only if they have a low enough disassembly time. The paper does not conclude on specific disassembly times, but we do assume that the wage of social workers will be lower than the wage that is used in the calculations of the paper. Willems et al. (2006) conclude that only mobile phones, vacuum cleaners, personal computers and washing machines should be considered for disassembly. Whereas, for the other categories, it is better to dispose of the product after the easiest valuable component is extracted.

With knowledge of the yields of the materials and the employment costs of the employees, the only information that is still required, is to which degree an appliance should be disassembled. For this multiple models have been designed. Kara et al. (2006) propose the selective disassembly methodology as shown in Figure 6. This model first requires knowledge of all components in the appliance after which all connections are written down. The third step is to find out which connection has to be taken care of before the next one can be disconnected. This results in a disassembly - sequence diagram. The more complex a product, the more subassemblies and components it will involve. For convenience, a bill of materials can be used, to keep track of the number of levels and the depth of the various subassemblies (example in appendix 5). Kara et al. (2006) proceed with multiple steps to determine the optimal selective disassembly sequence, but at this point we would like to include the cost-benefit analysis. At this point all components are linked and the sequence for disassembling is established. Now, the information of the value of the materials and the employee costs come into play. Every connection involves further costs and benefits and thus represents additional profit that can be gained by removing the connection (Kara, Pornprasitpol, & Kaebernick, 2005).

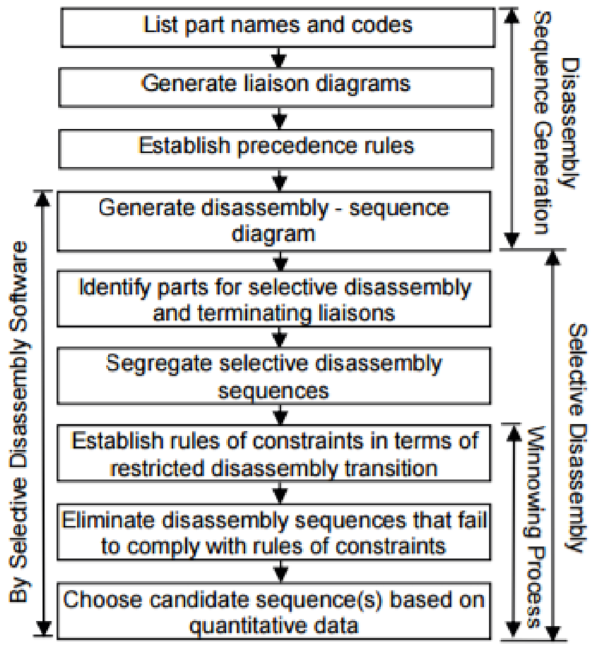

Figure 6 Selective disassembly methodology Source: (Kara, Pornprasitpol, & Kaebernick, 2005)

5. Direction for solution

The solution we propose is a combination of using the selective disassembly methodology introduced in Chapter 4 and the founding of Willems et al. (2006) that only high-value products are profitable to disassemble. The method of selective disassembly will require quite some time, but will result in a reliable solution in terms of costs and revenues. Disassembly times are unknown and are of great importance for the determination of the disassembly degree. Therefore, we recommend Twente Milieu and De Beurs to collect information on the disassembly times and the former presented data.

Based on the outcome of the research paper of Willems et al. (2006), not all appliances should be examined with the selective disassembly methodology, but only the ones in the high-value category: mobile phones, vacuum cleaners, personal computers, and washing machines.

The break-even point will be calculated by comparing the fixed costs and the profit per product. In this case, the variable costs are already subtracted from the revenues per product. At first, the profit per product will be determined for each of the high-value appliances. After that, the profit per product can be multiplied such that it will be higher than the fixed costs.

Profit per product

For this, we have designed the following action map.

1. Let the employed social workers disassemble various products that are collected often.
2. Fully disassemble the products, but do not break any dangerous parts or subassemblies that are too difficult to disassemble.
3. Fill out a break-even analysis per product that looks like Table 5 below, and can be found in the Excel file. The green cells have to be filled out.

Product	Mobile phone
Disassembler	
Date	

Break-even analysis per product						
Component	Level	Material	Value	Weight	Time	Profit
			(€/kg)	(Kg)	(Min.)	Yield - costs (€)
						€ -
						€ -
						€ -
						€ -
					Total profit (€)	€ -

Table 5 Profit per product

It is important that the analysis is done for all components, because an earlier extracted component might result in a negative solution, whereas the next component results in a profitable solution due to being a valuable material. The final component that results in the highest profit, marks the point up to which subsequent products of this category should be disassembled if a maximum profit is desired, because then a new product can be disassembled again until this point.

Because of the fact that creating workplaces is an important value for De Beurs and Twente Milieu, it could be valuable to disassemble until the last profitable component. In this case, more workplaces will be created than disassembling until the highest profitable component. So, if it turns out that sacrificing a bit of net profit provides a lot of workplaces, it will be a valuable decision. This has to be taken into account during the determination of the break-even point.

Determine the break-even point

If the former tables per product category are filled out, the sheet that contains the calculation for the break-even calculation, also depicted in Table 6, automatically returns the calculated values. Additionally to these values, the green cells still require actual data on costs and collected appliances. This results in the total costs and revenues that can be compared.

Another way to fill out this sheet can be done by determining how many products are needed to break-even. Comparing these numbers with actual data will show if it the break-even point is met.

Number of employees	10

Fixed costs	**(€) per year**	**Revenues**			**(€) per year**
Tools per employee	€ 2.428,00	Subsidies			
Location		Profit from products	Number of products	Amount per product	
Energy		Mobile phone		€ -	€ -
Overhead		Vacuum cleaner		€ -	€ -
		Personal computer		€ -	€ -
		Washing machine		€ -	€ -
		Scrap of products			
Total	**€ 2.428,00**	**Total**			**€ -**

Table 6 Break-even calculation

6. Conclusion and Limitations

This chapter describes the conclusions and limitations from the research that is done.

6.1. Conclusion

With help of the problem cluster and the current product flow at De Beurs and Twente Milieu, the main research question and the sub questions are defined. The main research question to be answered in this paper is: *'Which materials are profitable to extract out of the appliances by Twente Milieu and De Beurs based on cost-benefit analysis, in order to retain value of disassembling, and to create social workplaces?'.*

The materials of which appliances consist are divided into five groups: electronics, glass, metal, plastic, and wood. This is done to show which material groups are the most important for each of the appliances. It turned out that wood is almost not present in e-waste and that glass is not profitable to extract out of the e-waste, since it has no economic value if you turn it over to a recycler.

The conducted research shows that the e-waste categories big white household appliances and refrigerators and freezers consist of metal for a large part, respectively 50% and 66%. The categories small electrical appliances and ICT appliances contain the most plastic, namely 60%. Electronics consists of PCBs, cables, and power supplies. Although this material group is relatively small, it is recommended to extract these components, since the research shows that they are valuable.

The research shows that only mobile phones, vacuum cleaners, personal computers and washing machines should be considered for disassembly. Therefore, it is recommended to prioritize these products for disassembly.

It turned out that it is very difficult to conclude in this paper which materials are profitable to extract out of the appliances due to unknown cost and revenue variables. Therefore, we came up with a tool with which De Beurs and Twente Milieu can decide to which degree a product needs to be disassembled. It is possible to choose for profit maximisation or it is possible to emphasis the creation of social-workplaces.

6.2. Limitations

We are aware that the collected information might not represent the exact material content of the various appliances. Mainly because these contents are subject to technological changes and variance across brands and types. This might also be the case for other data (e.g. the number of appliances that an employee can disassemble in an hour). Whenever we could not find reliable specific data, we explicitly state that we make an assumption. However, these assumptions will of course be based on various sources. Due to the fact that we are not experienced with disassembling appliances and the inner constructions of these appliances, we rely on scientific papers for information on what can and what cannot be extracted from the appliances. People with more knowledge on the subject or people that have more time to explore the inner workings of these appliances, will most likely propose adjustments for the extraction of components.

7. Recommendations

First, we want to stress that it should be kept in mind that repairable or resalable items or parts will generate more revenue than disassembling into separate materials (Electronic waste recycling: A review of U.S. infrastructure and technology options). Options to obtain value from repairing and reselling should therefore be explored before products are selected for disassembly.

However, when products are selected for disassembly our developed method can be used to determine the disassembly degree. We would recommend Twente Milieu to buy NEN-EN 50574:2012 - Collection logistics and treatment requirements for end-of-life household appliances containing volatile fluorocarbons or volatile hydrocarbons. This report explains which materials are dangerous to extract and gives in-depth information on the treatment of various materials.

Moreover, we identified a knowledge problem as the basis for our solution. We think that data about the collection of the appliances will be very important to establish the most efficient operation. We recommend creating a database in which the number of collected appliances is stored per category to keep track of changes in the composition of the collection. Moreover, we recommend a periodical review of the disassembly time needed by employees to disassemble up until the required disassembly degree. This is recommended because employees experience a learning curve, execute work with different tools and work executed by people is a lot more variable than work executed by machines. Calculating an average disassembly time could, therefore, also be considered.

To bridge the gap between our research question and the question that was initially presented to us we recommend to first execute the analysis and store the data. Based on this information decisions about the organization of the product flow should be made. For example, if it is the case that big household appliances comprise the majority of the collected appliances, it might be interesting to create a product flow specifically for this type of components. Within this product flow employees can get the task of extracting specific components from the products. However, small categories, that are not big percentages of the total collection, could maybe better be taken apart by one single employee because this is not a routine job. The answer to the question: 'What is better to do? Organizing product flow for collecting, sorting, disassembling, repairing and selling based on processes by employees, or by yield in type of components?', should be a product of the solution to our main research question to create the most efficient product flow.

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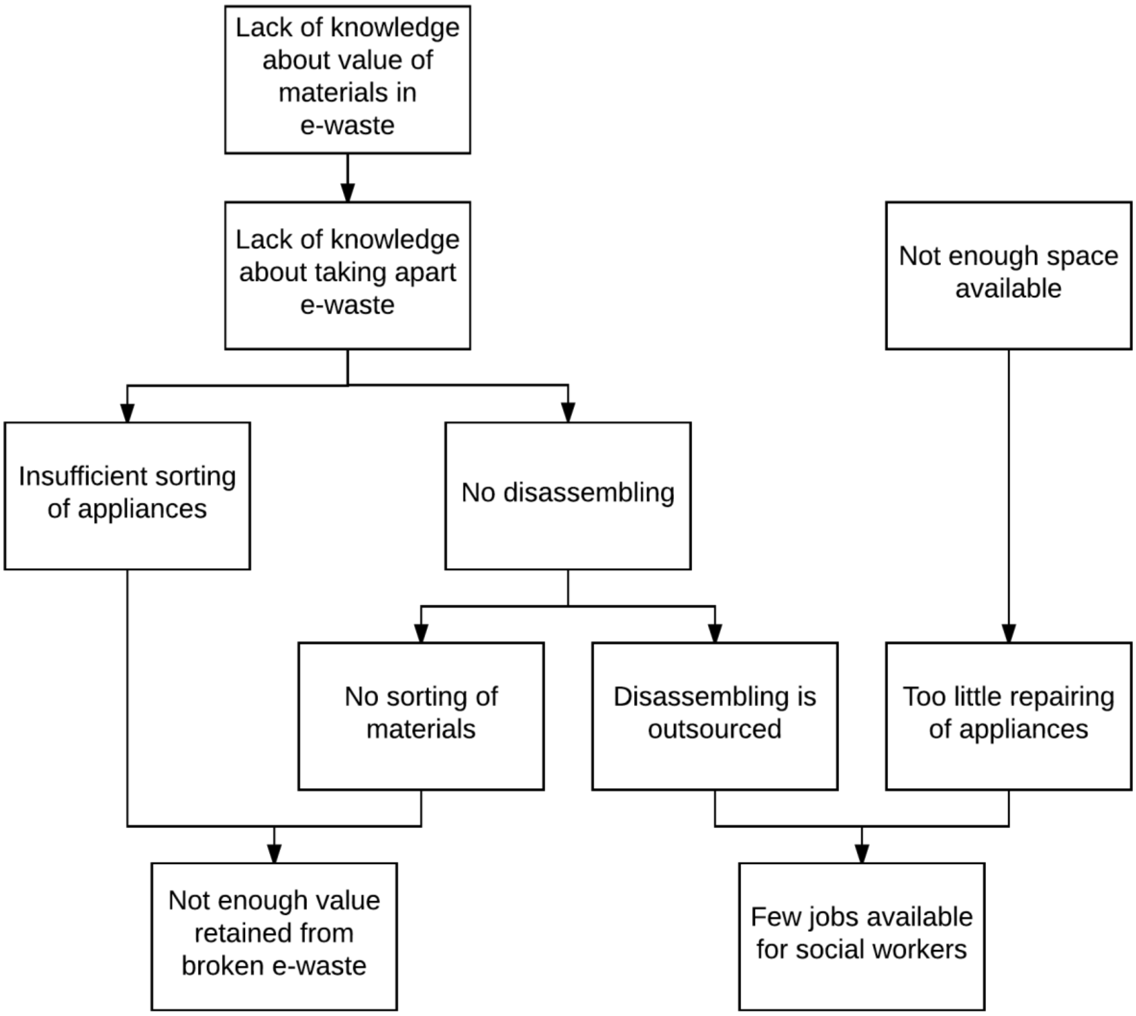
1. Appendix 1: Company Profiles

Second hand shop De Beurs was founded in 1982 by four environmentally conscious people. Currently, the Beurs has establishments in Oldenzaal, Tubbergen, Losser & Denekamp and it works closely with a number of municipalities. A lot of the work is done by volunteers and social workers. Foundation De Beurs is designated to be an ANBI 'algemeen nut beogende instelling' which translates to a public benefit aiming institution.

Twente Milieu is a public limited liability company from which all of the shares are held by seven municipalities in the Twente area. The tasks of Twente Milieu are collecting household waste, managing waste streams and managing public spaces. Twente Milieu employs 350 employees from which 20% exist of people that have a distance to the labour market. For the employment of these people, they work in close collaboration with regional social work companies.

2. Appendix 2: Problem Cluster



The current process concerning the e-waste is simple. At De Beurs, incoming products either work or don't work. Well-functioning products are placed in the shop for sale. From the broken products, De Beurs only repairs a very small part. The remainder of the broken products are placed in a container transported to Omrin, without any further processing at De Beurs or Twente Milieu. At Twente Milieu, people place their appliances in the container by themselves. Twente Milieu does not test the products to check whether a product still works and Twente Milieu doesn't disassemble them. All the products are directly transported to Omrin. Because disassembling of e-waste presumably realizes value for De Beurs and Twente Milieu, and due to the fact that only a very small part of the products is being repaired, the following problems are the starting points of our problem cluster: 'not enough value retained from broken e-waste' and 'few jobs available for social workers'. From these starting points, the problem can be clustered in such a way that underlying problems become clear, thereby revealing the core problems.

The fact that not enough value is retained from e-waste has two reasons. One reason is that there is no disassembling of e-waste and therefore no sorting of materials. The other reason can be found in the sorting of appliances. At the moment, incoming e-waste at De Beurs is placed in a single container without sorting it and at Twente Milieu it is only sorted in big household appliances (e.g. washing machines) and small appliances. This means that Omrin needs to sort the appliances at their plant and that Twente Milieu and De Beurs do not process the appliances themselves.

There are few jobs available for social workers because the disassembling of appliances is outsourced and that very little appliances are repaired in-house. At the moment, the repairing of appliances is at its maximum capacity due to the lack of available space.

Two problems have been determined to be the initial causes of the inefficient product flows that are currently existing within both companies. The relevance rule and pneumonia rule help us to determine which problem is the most important one to solve (Heerkens, 2016). When considering the costs and benefits of the problems, the most relevant problem to solve is the lack of knowledge about processing e-waste. Only having space will not result in a more efficient organization of processes, whereas knowledge can help to determine which steps can be done to keep the value within the company. Moreover, space to execute activities is not relevant to the problem as the location and capacity of the workspace are outside of the scope of the problem.

There is a gap between the identified core problem and the problem that the company wants to resolve. The action problem that follows from the company problem is designing the best way to organize the product flow. However, it became clear that the company does not have enough relevant knowledge of how to process e-waste, which should thus be resolved in advance. With the information on how e-waste can be processed it will be possible to make useful recommendations on the organization of the product flow for disassembling.

3. Appendix 3: Scientific Literature Review

This Appendix consists of an overview of our search terms, our inclusion and exclusion criteria and a concept matrix.

Search terms & Analysis

Search string	Scope	Date of Searc	Date range	Number of hits
Search protocol for Google Scholar				
"E-waste" AND "recycling"	Title of the article	11-16-2016	2000 - 2016	308
"E-waste" "global"	Title of the article	16-11-2016	2000 - 2016	87
"End-of-life" AND "electronics"	Title of the article	14-12-2016	2000 - 2016	54
"E-waste management systems"	Title of the article	11-16-2016	2000 - 2016	10
"WEEE" AND "Disassembly"	Title of the article	12-14-2016	2000 - 2016	8
"Efficiency" AND "Disassembly"	Title of the article	12-14-2016	2000 - 2016	16
"Optimal" AND "Disassembly"	Title of the article	12-20-2016	1990 - 2016	54
"Disassembly electronic products"	Title of the article	12-20-2016	2000 - 2016	17
"Selective disassembly"	Title of the article	12-24-2016	2005 - 2016	66
Search protocol for Scopus				
"E-waste" AND "processing" AND "Netherlands"	All fields	12-14-2016	2010 - 2016	118
"Disassembling" AND "e-waste"	Title of the article, abstract, keyword	12-14-2016	-	7
"Disassembling" AND "e-waste" AND "Recycling"	All fields	12-14-2016	2010 - 2016	47
Search protocol for FindUT				
"Disassembly scheduling" AND "waste" AND "suppl	Keyword	12-14-2016	2010 - 2016	101
"WEEE" AND "selective disassembly"	Keyword	12-14-2016	2005 - 2016	224
"Sorting" AND "WEEE" AND "appliances"	Keyword plus full text	12-20-2016	2000 - 2016	128
"ECMPRO" AND "waste"	Keyword plus full text	12-20-2016	2010 - 2016	29
"waste management" AND "end-of-life strategies"	Title of the article	12-20-2016	2005 - 2016	11
Total in endnote				**1285**
Excluded due to criterion 1				-871
Excluded due to criterion 2				-85
Excluded due to criterion 3				-27
Excluded due to criterion 4				-35
Excluded due to criterion 5				-27
Excluded due to criterion 6				-5
Excluded due to criterion 7				-43
Excluded due to criterion 8				-138
Excluded due to criterion 9				-28
Excluded due to criterion 10				-2
Total selected for review				**24**

Inclusion and exclusion criteria

Number	Criteria	Reason for exclusion
1	We will only check the articles on the first two pages of Google Scholar and FindUT	The articles are sorted based on relevance and we assume that the most relevant articles are included in the first two pages.
2	The number of articles on Scopus is restricted to the first 40 articles	The articles on Scopus are sorted based on the number of citations. Articles that are cited more often are assumed to be more valuable.
3	Duplicates	
4	Citations & Conferences	These are not full papers or published papers
5	Article is too specific/difficult	The articles that will be excluded because of this rule contain a lot of information on too specific contents of e-waste. For example: polybrominated diphenyl ethers (PBDEs) and polychlorinated biphenyls (PCBs). This is irrelevant for our analysis.
6	Automatised or semi-automatized disassembly	Twente Milieu and De Beurs want to create work, manual disassembly is preferred
7	Article is focused on environmental aspects	Irrelevant for our analysis as explained in paper
8	Article is irrelevant based on the title/first sentences displayed in the search engine	Despite of having the search terms in the title or abstract, it is immediately evident that we will not be able to use this information for our purpose.
9	Removed after reading the abstract, introduction & discussion	Not relevant enough.
10	Impact factor is not high enough	Our threshold is 0.5, we want to exclude articles that do not have enough scientific value.
	Criteria	**Reason for inclusion**
1	The article describes a process of disassembly sequencing	This information is needed to solve our core problem
2	The article is about selective disassembly	We want to determine the break-even point. This information is required
3	An article including 'optimal' or 'economically viable' or anything that implies a break-even situation	This information is needed to determine which activities should be insourced

Concept Matrix

Articles	Concepts				
	Disassembly (General)	Disassembly Sequence	Selective Disassembly	Break-even Analysis	Material Contents
A chance constrained programming approach to determine the optimal disassembly sequence	X	X			
A hybrid approach to selective-disassembly sequence planning for de-manufacturing and its implementation on the Internet		X	X		
A selective disassembly methodology for end-of-life products			X		
An integrated approach to selective-disassembly sequence planning		X	X		
Can large-scale disassembly be profitable? A linear programming approach to quantifying the turning point to make disassembly economically viable			X	X	
Design for disassembly: a methodology for identifying the optimal disassembly sequence				X	
Determination of the optimal disassembly sequence using decision trees		X		X	
Determining optimal disassembly and recovery strategies				X	
Disassembly factories for electrical and electronic products to recover resources in product and material cycles	X		X		
Disassembly layout in WEEE recycling process	X			X	
Eco-efficiency considerations on the end-of-life of consumer electronic products			X	X	
Efficiency and feasibility of product disassembly: a case-based study			X	X	
Environmentally conscious manufacturing and product recovery (ECMPRO): a review of the state of the art			X		
Evolutionary sequence planning for selective disassembly in de-manufacturing		X	X		
Global perspectives on e-waste					X
Key drivers of the e-waste recycling system: Assessing and modelling e-waste processing in the informal sector in Delhi	X	X			
Mathematical model and solution algorithms for selective disassembly sequencing with multiple target components and sequence-dependent setups		X	X		
Optimal disassembly configurations for single and multiple products				X	
Optimal disassembly of complex products				X	
Optimal disassembly sequencing strategy using constraint programming approach		X		X	
Recovery of metals and nonmetals from electronic waste by physical and chemical recycling processes			X		
Simultaneous selective disassembly and end-of-life decision making for multiple products that share disassembly operations			X		
Selective disassembly and simultaneous end-of-life decision making for multiple products			X		
Selective disassembly sequencing: a methodology for the disassembly of end-of-life products		X	X		

4. Appendix 4: Material Contents

The tables below show the proportion of different materials in the different categories of appliances. This is done in grams or in percentages. The materials are divided into five groups: electronics, glass, metal, plastic, and wood. The percentage of each of the four groups is calculated.

The last table under 'Small household appliances and ICT' provides an average amount of the four material groups for this category. The average is calculated by using the percentages of the tables of the vacuum cleaners, the inkjet printers, and the coffee machines.

The table under 'Proportion of materials per category' provides an overview of the amount of materials in percentages for each category of appliances.

Big white household appliances

Material	Washing machine type						Average	Electronics	Glass	Metal	Plastic	Wood
	Type I	Type II.1	Type II.2	Type II.3	Type III	Type L						
Unit	Gram											
Acryl-Butadien-Styrol	1.228,0	1.851,0	1.863,0	1.850,0	1.196,0	1.850,0	1.639,7				P	
Aluminium	2.313,0	3.209,0	4.124,0	5.211,0	3.608,0	5.021,0	3.914,3			M		
Brass	73,0	20,0	20,0	20,0	0,0	20,0	25,5			M		
Cable	781,0	286,0	302,0	303,0	952,0	303,0	487,8	E				
Carboran	0,0	10.574,0	11.505,0	11.289,0	775,0	0,0	5.690,5					
Chipboard	2.057,0	2.350,0	2.350,0	2.350,0	2.468,0	2.350,0	2.320,8	E				
Concrete	22.740,0	18.680,0	18.680,0	18.910,0	0,0	17.090,0	16.016,7					
Copper	925,0	579,0	747,0	765,0	1.027,0	765,0	801,3			M		
Cotton	525,0	198,0	378,0	999,0	1.620,0	999,0	786,5					
Electronic components	362,0	482,0	537,0	968,0	1.929,0	968,0	874,3	E				
Ethylen-Propylen-Copolymer	2.220,0	2.673,0	2.942,0	2.981,0	2.960,0	2.981,0	2.792,8				P	
Glass	1.931,0	1.688,0	1.688,0	1.688,0	1.476,0	1.688,0	1.693,2		G			
Gray cast iron	1.304,0	1.400,0	1.920,0	3.140,0	28.780,0	7.860,0	7.400,7			M		
Polyacryl	17,0	77,0	59,0	65,0	0,0	65,0	47,2					
Polyethylen	0,0	0,0	0,0	6,0	27,0	6,0	6,5				P	
Polymethylmethacrylat	3,0	0,0	56,0	47,0	185,0	47,0	56,3				P	
Polyoxymethylen	0,0	58,0	46,0	49,0	25,0	49,0	37,8				P	
Polypropylen	175,0	859,0	1.055,0	1.060,0	489,0	1.060,0	783,0				P	
PP 20% mineral filler	421,0	0,0	0,0	0,0	41,0	0,0	77,0				P	
PP 40% mineral filler	8.012,0	0,0	0,0	0,0	1.410,0	11.288,0	3.451,7				P	
Polystyrene	219,0	0,0	0,0	0,0	0,0	0,0	36,5				P	
Steel	24.320,0	26.045,0	26.470,0	27.935,0	44.733,0	27.935,0	29.573,0			M		
Other materials	2.118,0	1.152,0	1.188,0	1.434,0	3.350,0	1.434,0	1.779,3					
Wood	422,0	1.100,0	1.100,0	1.100,0	1.100,0	1.100,0	987,0					W
Corrugated cardboard	499,0	1.300,0	1.300,0	1.300,0	1.300,0	1.300,0	1.166,5					W
Polystyrene	192,0	500,0	500,0	500,0	500,0	500,0	448,7				P	
Shrinking foil	77,0	200,0	200,0	200,0	200,0	200,0	179,5				P	
Polyacryl	38,0	100,0	100,0	100,0	100,0	100,0	89,7					
Paper	58,0	150,0	150,0	150,0	150,0	150,0	134,7					W
								4%	2%	50%	11%	3%
Total	**73.029,0**	**75.530,0**	**79.278,0**	**84.421,0**	**100.402,0**	**87.130,0**	**83.298,3**					

Source: (Rüdenauer, Gensch, & Quack, 2005)

Refrigerators and freezers

Material	CRT TVs	Electronics	Glass	Metal	Plastic	Wood
Unit	Percentage					
Plastics	13,0				P	
Polyurethane	10,0				P	
Other	7,0					
Copper	3,0			M		
Aluminium	3,0			M		
PVC (cables)	1,0	E				
Glass	1,0		G			
Refrigerant fluid	1,0					
Oils	1,0					
Steel	60,0			M		
		1%	1%	66%	23%	0%
Total	**100,0**					

Source: (The Institute ENSAM of Chambery (a), 2017)

Small household appliances and ICT

Material	Vacuum cleaner type					Average	Electronics	Glass	Metal	Plastic	Wood
	Domestic canister	Commercial canister	Domestic upright	Commercial upright	Battery/cordless						
Unit	Gram										
Bulk plastics	4.188,0	5.880,0	3.927,0	4.995,0	3.035,0	4.405,0				P	
Tecplastics	695,0	0,0	894,0	1.494,0	426,0	701,8				P	
Ferro	1.467,0	1.450,0	1.048,0	1.308,0	1.120,0	1.278,6			M		
Non-ferro	478,0	2.250,0	440,0	711,0	1.428,0	1.061,4			M		
Coating	8,0	0,0	0,0	0,0	0,0	1,6					
Electronics	29,0	0,0	0,0	20,0	0,0	9,8	E				
							0%	0%	31%	68%	0%
Total	**6.865,0**	**9.580,0**	**6.309,0**	**8.528,0**	**6.009,0**	**7.458,2**					

Source: (AEA group, 2009)

Material	Inkjet Printers	Electronics	Glass	Metal	Plastic	Wood
Unit	Percentage					
ABS	4,0				P	
HIPS	39,0				P	
Various plastics	15,0				P	
Others	4,0					
Electronic	14,0	E				
Steel	19,0			M		
Aluminium	4,0			M		
Copper	1,0			M		
		14%	0%	24%	58%	0%
Total	**100,0**					

Source: (The Institute ENSAM of Chambery (b), 2017)

Material	Coffee machines	Electronics	Glass	Metal	Plastic	Wood
Unit	Percentage					
ABS	22,0				P	
PP	18,0				P	
PA	3,0					
Various plastics	14,0				P	
Ferrous	14,0			M		
Non ferrous	10,0			M		
Electronic	6,0	E				
Others	13,0					
		6%	0%	24%	54%	0%
Total	**100,0**					

Source: (The Institute ENSAM of Chambery (c), 2017)

Material	Big white household	Refrigerators and freezers	Small electrical appliances and ICT	CRT TVs and monitors
Electronics	4%	1%	7%	8%
Glass	2%	1%	0%	54%
Metal	50%	66%	26%	14%
Plastic	11%	23%	60%	14%
Wood	3%	0%	0%	0%

CRT TVs and monitors

Material	CRT TVs	Electronics	Glass	Metal	Plastic	Wood
Unit	Percentage					
Glasses from vacuum tubes	54,0		G			
Others	10,2					
Printed circuit boards	7,8	E				
Ferrous metal	12,3			M		
Non-ferrous metal	2,1			M		
Plastics	13,6				P	
		8%	54%	14%	14%	0%
Total	100,0					

Source: (The Institute ENSAM of Chambery (d), 2017)

Proportion of materials per category

Material	Big white household	Refrigerators and freezers	Small electrical appliances and ICT	CRT TVs and monitors
Glass	2,0%	1,0%	0,0%	54,0%
Metal	50,7%	66,0%	26,5%	14,4%
Plastic	11,4%	24,0%	60,2%	13,6%
Wood	2,7%	0,0%	0,0%	0,0%

5. Appendix 5: Example Bill of Materials

Level	Component	Unit	Quantity
0	Table	-	1
.1	Top Assembly	-	1
..2	Table Top	Piece	1
..2	Drawer	Piece	1
.1	Leg Assembly	-	1
..2	Leg	Piece	4
..2	Side Rung	Piece	2
..2	Connecting Rung	Piece	1