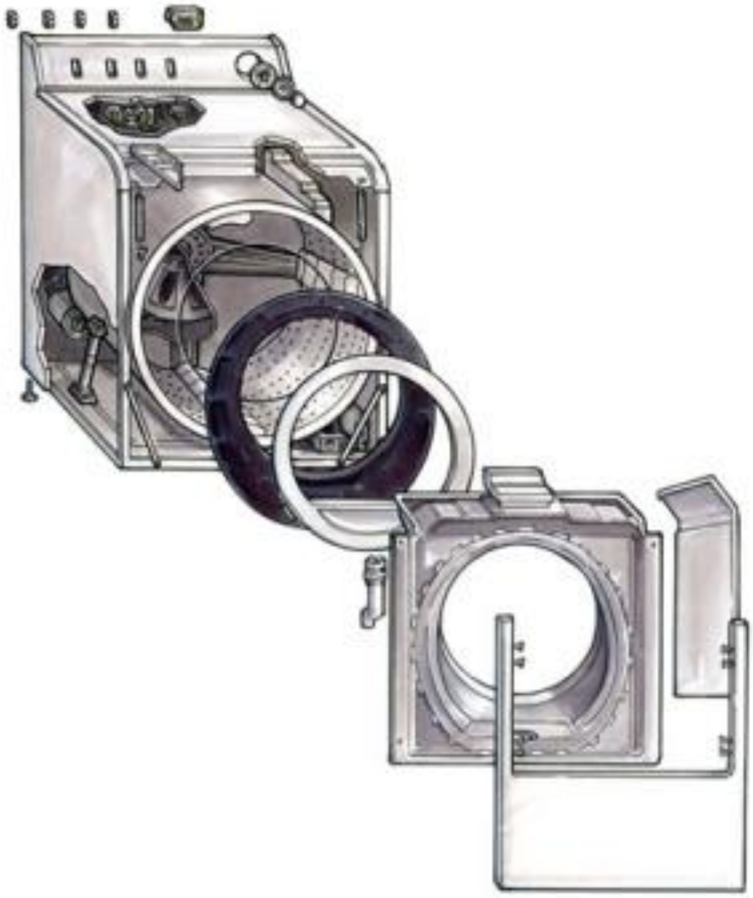

THE DISASSEMBLING PROCESS OF WASHING MACHINES

The valuable parts of the e-waste

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Academic Skills Premaster IEM – Group 2
27 January 2017

The disassembling process of washing machines

The valuable parts of the e-waste

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Preface

Before you lies the report "The disassembling process of washing machines", a report in which we conducted a research on how to get more value out of washing machines. It has been written as an assignment for the course Academic Skills in the Industrial Engineering and Management pre-master. The research started the 14th of November 2016 and is finished on the 27th of January 2017.

The project was undertaken at the request of waste-collector Twente Milieu and second-hand store De Beurs. These companies wanted to know how to get more value out of the e-waste they collect, both in terms of economic value and in employability. Therefore, we conducted research and present this in a report for the management of both companies.

We would like to thank Dr. Ir. S.J.A. Löwik for the support and feedback during this research, and also Mr. B. Assink and Mr. P. Wilderink for providing information that we needed.

We hope you enjoy your reading.

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Enschede, January 27, 2017

Management summary

Currently, Twente Milieu and De Beurs outsource many activities of the supply chain of the processing of e-waste to other companies in The Netherlands. Twente Milieu only collects the e-waste and sorts on a small scale and De Beurs collects e-waste on small scale and also does small disassembling and repairing activities to sell repaired goods in their second-hand store. The spare e-waste is sent to Omrin, a waste processing firm in Friesland. Both Twente Milieu and De Beurs would like to keep more work in the region Twente and get more value out of e-waste by performing more in-house activities. The goal of this project is to assess whether the business case is achievable and profitable.

To come to a suitable research question we fenced off the project and chose a specific issue: the disassembling of washing machines. To be able to assess the achievability of the case we drew up the following research question: “How can De Beurs and Twente Milieu redesign the individual employee disassembling process of washing machines in order to get more value out of e-waste and to achieve more work in the region?”

In order to answer the research question, we redesigned the disassembling process and created a flowchart to display this process. A flowchart is chosen because it gives a simple representation of how the process should be executed. This is important for Twente Milieu and De Beurs because they operate with social workers. Next, we defined variables which we used to answer the sub-questions that we set-up based on the research question.

From the calculations, the literature and the answers to the sub-questions we found that the most valuable parts of a washing machine are the engine, the PCB, and the metal cover. With this knowledge we made a flowchart for disassembling those valuable parts, we based the calculations that we made on this flowchart.

In potential Twente Milieu and De Beurs could collect 40 washing machines per day, if this is the case one employee can be put to work for the disassembling process. The revenue of the valuable parts of the disassembled washing machine is €40,- per washing machine, this results in a revenue of €1617,- per day. The variable costs are €322,- per day (transportation- and salary costs). This results in a profit of €1295,- per day. An initial investment for workplaces and materials of €166.897,- is needed, but with the daily profit, there is a payback time of 129 workdays.

These results lead to the conclusion that Twente Milieu and De Beurs can redesign the individual employee process of the disassembling of a washing machine according to the flowchart that we made in order to perform more in-house activities. According to the business case that followed the flowchart, these in-house disassembling activities will generate a small increase in employment, a huge increase in the value of the collected washing machines and is profitable in half a year.

Our recommendation is to look at the possibilities to expand the disassembling to other types of e-waste once a stable process for the disassembling washing machines is established. Our case showed that the in-house activities are profitable and by expanding to other types of e-waste the employment in the region can be increased further.

Management samenvatting

Op dit moment worden veel activiteiten van de supply chain van het e-waste verwerkingsproces van Twente Milieu en De Beurs uitbesteed aan andere bedrijven. De activiteiten die Twente Milieu zelf doet is het inzamelen van de e-waste producten en sorteren op kleine schaal. De Beurs verzamelt ook de e-waste, maar De Beurs ontmantelt en repareert een klein gedeelte en probeert het zelf te verkopen. De rest van de e-waste wordt ook naar Omrin, een afvalverwerkingsbedrijf in Friesland, gestuurd. Beide bedrijven zouden graag meer werk in de regio houden door meer activiteiten zelf uit te voeren in plaats van het uit te besteden aan Omrin, en ze zouden meer waarde willen halen uit de producten van e-waste. Het doel van dit project is om te kijken of dit mogelijk en rendabel is om activiteiten van de supply chain zelf te doen in plaats van het uit te besteden

Om tot een hoofdvraag te komen hebben we het project erg afgebakend, en hebben wij voor een specifiek onderdeel gekozen: het ontmantelen van wasmachines. Om te kijken of het doel te behalen is hebben we de volgende onderzoeksvraag opgesteld: ‘Hoe kunnen Twente Milieu en De Beurs het ontmantelingsproces van wasmachines herontwerpen om meer waarde te halen uit e-waste en om meer werkgelegenheid in de regio te houden?’

Om de onderzoeksvraag te beantwoorden wordt het ontmantelingsprocess herontworpen en wordt een flowchart voor dit proces gecreëerd. Er is gekozen voor een flowchart omdat dit een overzichtelijke weergave is van het process en in de flowchart is eenvoudig weergegeven hoe men het proces moet uitvoeren. Dit is onder andere belangrijk omdat Twente Milieu en De Beurs met social workers werken. Vervolgens hebben we variabelen gedefinieerd om antwoord te kunnen geven op onze deelvragen die we op basis van de hoofdvraag geformuleerd hebben.

Uit de antwoorden op de deelvragen, de literatuur en de gemaakte berekeningen is naar voren gekomen dat de onderdelen in een wasmachine die het meest van waarde zijn de motor is, de printplaat en de metalen achterkant. Aan de hand van deze drie onderdelen hebben wij de flowchart gemaakt en hierop zijn de berekeningen gebaseerd. Twente Milieu en de Beurs zouden in potentie 40 machines per dag binnen kunnen krijgen, in dat geval kan 1 werknemer extra aan het werk om de wasmachine te ontmantelen. De opbrengst van de waardevolle uit de ontmantelde wasmachine is €40 per wasmachine. Dit resulteert in een opbrengst van €1617 per dag. De variabele kosten zijn €322 per dag (transport- en arbeidskosten). Uiteindelijk levert dit een winst op van €1295. Met een eenmalige investering voor een werkplaats en materiaal van €166.897 geeft het een terugverdientijd van 129 werkdagen.

Deze resultaten leiden tot de conclusie om het ontmantelen van wasmachines zelf te doen aan de hand van de flowchart in plaats van het uitbesteden. Volgens de business-case die we opgezet hebben zal dit een kleine toename van de werkgelegenheid genereren op dit moment, een enorme stijging van de waarde van de verzamelde wasmachines en de investering is in een half jaar terugverdient.

Onze aanbeveling is wel om op den duur te kijken of het mogelijk is om het ontmantelen uit te breiden naar andere soorten e-waste. We hebben gezien dat het erg winstgevend is en door het uitbreiden naar verschillende machines zal de werkgelegenheid ook verder stijgen.

Contents

1 Problem identification and problem-solving approach

1.1 Introduction

This assignment is written for the course Academic Skills for the premaster Industrial Engineering and Management. Within this business case, the goal will be to take a closer look at the processes of a second-hand organization and a waste collection company to see if a collaboration could make their processes more efficient.

Twente Milieu is a company that collects waste and manages public space in seven communities in Twente fully owned by the government. The seven communities are Almelo, Borne, Enschede, Hengelo, Hof van Twente, Losser, and Oldenzaal. At the moment, they serve 75% of the households of Regio Twente, they collect 32 types of waste with collection trucks and six locations for bulky waste and they recycle 95% of this waste. This means the materials are processed for reuse. In their vision, they state that they want to focus on declining the waste per person, want to innovate in recycling and that they want to invest in communication and education about waste.

De Beurs is a second-hand store located in Oldenzaal. They collect, process and sell used products from the surrounding communities. De Beurs has employees from social work companies. They are a 'Public Benefit Organisation', which means that 90% of their efforts are focussed on the general good.

This business case will take a closer look at the electronic waste (e-waste) of both companies. In the current age, mankind uses electronics such as phones, dishwashers, washing machines, refrigerators and televisions every day. This causes more e-waste coming into both companies, which is collected and shipped to a recycle company called Omrin, based in Leeuwarden.

For this business case, the two companies want to work together to reach two common goals. The first goal is to keep more work in Twente. At the moment both companies use a lot of outsourcing which takes work away from the region. The second goal is to get more value out of the e-waste, as well in terms of money as in terms of better recycling of waste.

This report will start with the current situation of the supply chain from Twente Milieu and De Beurs and the problem identification. After that, we will explain our research approach. Then we have done a stakeholder's analysis which is found in paragraph 1.4. In paragraph 1.5 the problem cluster can be found, the scope of our research and we have defined the core problem here. The research question and the sub-questions which follow from the core problem can be found in paragraph 1.6 and in paragraph 1.7 we will explain the research methodology and the concrete activities that we can conduct. Chapter 2 consists of the key constructs. In chapter 3 is our flow chart will show the redesign of the disassembling process. Chapter 4 consists of the variables and the answers to the sub-questions. Finally, chapter 5 consists of the solution and the recommendations.

1.2 Current situation

At the moment, De Beurs and Twente Milieu both outsource parts of the processing of e-waste. Twente Milieu only collects e-waste from households and local shops and separates it based on size, in order to effectively transport the waste. After these steps, the e-waste is sent to Omrin in Friesland for further processing.

De Beurs collects e-waste and also tests if the e-waste is still working, e-waste that works is sold in their store. For e-waste that is not working small reparations and specific disassembling is done. This all depends on available knowledge and capacity, both in workforce and space. The rest is removed of their sockets and send to Omrin. Both want to do more of the processing of e-waste in-house to reach the two common goals (Assink & Wilderink, 2016).

For this business case, Twente Milieu and De Beurs want to know which steps of the supply chain of collecting, sorting, disassembling, repairing and selling best can be done in-house and which can be best outsourced.

From the information, we get from Twente Milieu and De Beurs we have made a figure which shows the supply chain from both companies. Figure 1.1 shows these supply chains.

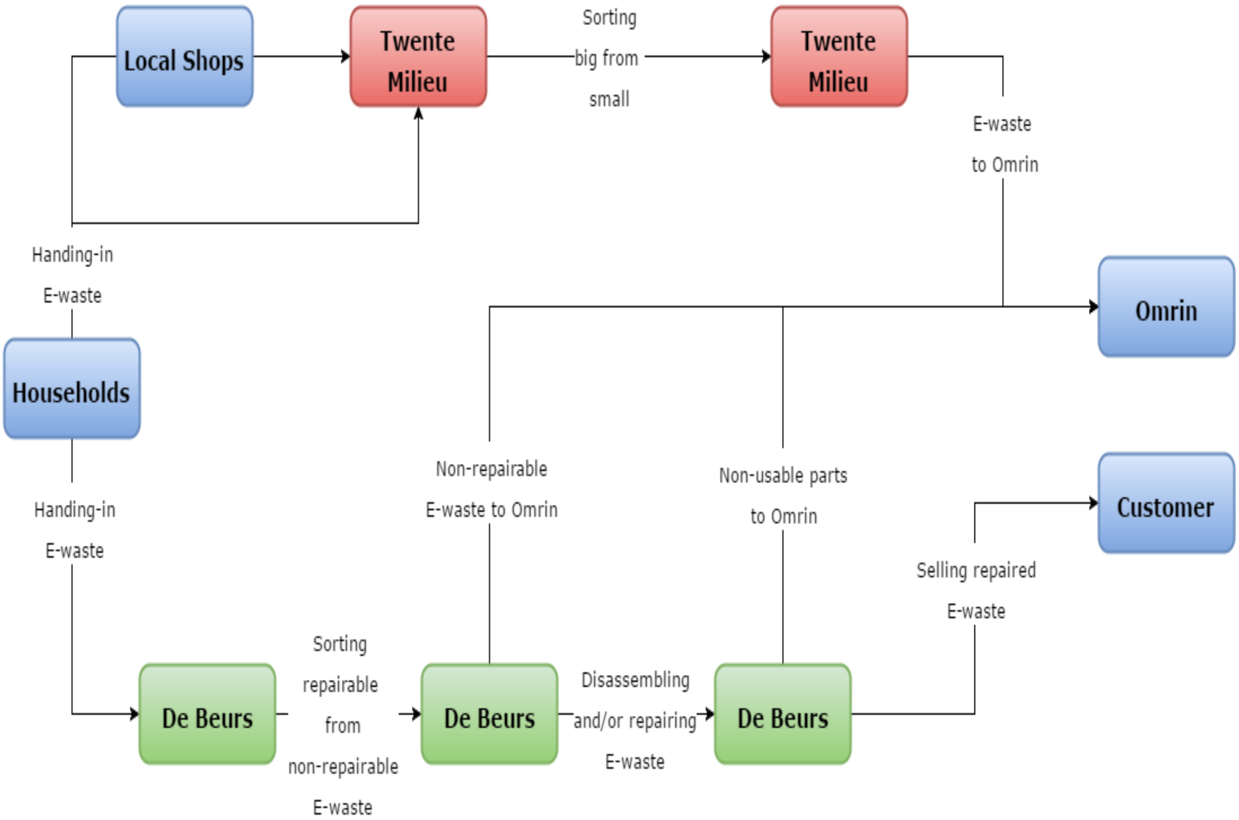

FIGURE 1.1 SUPPLY CHAIN TWENTE MILIEU AND DE BEURS

As shown in figure 1.1, both Twente Milieu and De Beurs collect their e-waste from the households in the region. Twente Milieu also receives some e-waste from Local shops. At Twente Milieu, the e-waste is sorted based on size: big appliances, such as washing machines and refrigerators, and smaller appliances such as screens and mixers. All the e-waste from Twente Milieu is transported to Omrin. At De Beurs, the e-waste is sorted by testing if it still works, if it can be repaired or if it can be disassembled. The e-waste that is useless to De Beurs is shipped to Omrin. The rest is sold to the customers.

So, De Beurs collects, sells, repairs and does a little bit of the disassembling process. At Twente Milieu, only the collecting and a little bit of sorting is happening at this moment at Twente Milieu. What Twente Milieu and De Beurs want, is to keep the work in Twente and try to get more value out of the e-waste. That is why we got the following assignment:

"Which steps of the supply chain of collecting, sorting, disassembling, repairing and selling can De Beurs and Twente Milieu best do in-house, and which can best be outsourced?"

1.3 Research approach

To come from the assignment we got from Twente Milieu and De Beurs to a solution, we will make several steps. The steps we will make to come to a solution are shown in figure 1.2.

The first step is to define the problem. To come to the core problem we will make a problem cluster for both firms and we define our scope. We will explain this step further in paragraph 1.5. We will also make a stakeholder analysis to see what the interests and the powers are in this project of the different stakeholders.

The step which follows from defining the core problem is deciding the research requirements. To solve the core problem, we have to decide what is necessary to know to create a solution. We have formulated some research questions which we think are necessary to solve the core problem. These research questions can be found in paragraph 1.6. From these research questions, we came to some key constructs which we have explained in chapter 2. Key constructs refer to the characteristics that are being evaluated.

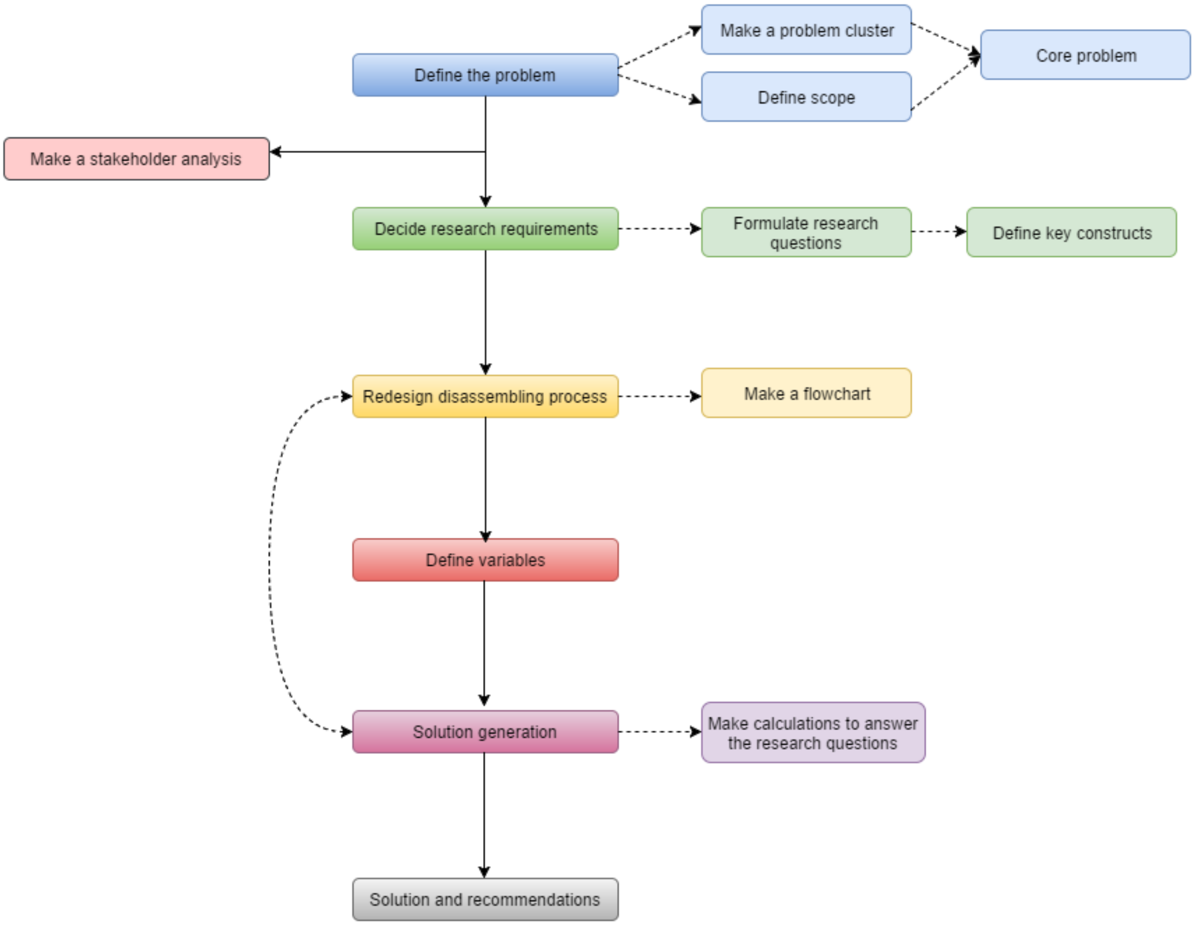

Figure 1.2 Research approach

The third step we will make is to redesign the disassembling process. We chose to make a flowchart, because a flowchart gives a consolidated view of the process and, using social workers, this provides a good view of how to conduct the process, so the social workers will understand it easily.

Then we will define the variables. These variables follow from the key constructs that we will elaborate in chapter 2. To make these variables measurable, we operationalize key constructs. Only when we have measurable variables we can give answers to our research question which is the next step in our problem approach. The variables are shown in chapter 4.1.

We will come to a solution to give answers to the research questions. We will have to make a lot of calculations to come to a possible solution and to see if the business case will be profitable. These calculations and answers can be found in chapter 4.2 to 4.6. In paragraph 4.7 a short summary is given.

In chapter 5 the Conclusion and Recommendations are given. Chapter 6 will show the discussion, Research limitations and our reflection on the research we conducted.

All these research steps and their deliverables are also shown in appendix 1.

1.4 Stakeholders interests and management

In order to further plan the problem-solving process, it is important to first determine the stakeholders of the companies and their interests within this project. In order to effectively identify and analyze the stakeholders, we have chosen to use the categorization of Bourne and Weaver (Bourne & Weaver, 2010) to identify the power/interest grid made by the Imperial College London in 2007 (Imperial College London, 2007).

Bourne and Weaver (2010) wrote that identifying stakeholders starts with brainstorming, but that the final activity in “Step 1: Identify”, is to categorize the listed stakeholders according to their direction of influence to, or from, the project manager (Bourne & Weaver, 2010). This will help us controlling the results of the brainstorm and check if no stakeholders are forgotten.

In their research, Bourne and Weaver (2010) suggest that there are two elements to consider.

1. Whether the direction of influence of the stakeholder is *upwards, downwards, outwards or sidewards.*
2. And if the stakeholder is part of the organization or external.

For this situation, we used the theory of Bourne and Weaver (2010) for the stakeholders of Twente Milieu and De Beurs.

Twente Milieu and De Beurs have several stakeholders. *Upwards* we identify the seven municipalities. External parties who have founded and funded Twente Milieu. These are formed by Borne, Enschede, Hengelo, Losser, Oldenzaal, Almelo and Hof van Twente. Normally, the government would be Outwards but since Twente Milieu is directly employed by the municipalities we believe they fit Upwards.

Sidewards we identify other companies embedded in recycling. From another second-hand store, like Het Goed in Enschede, to WeCycle, WEE, and Omrin, who are dependent on the waste that comes from Twente Milieu.

Outwards we found the inhabitants of the seven communities, the most important customers of Twente Milieu. They pay their municipalities for clean streets and want to get rid of their waste. Their interest is that they can bring their E-waste easily away at the lowest price. They also have an interest in the recycled goods that De Beurs offers in it stores. Other Outwards stakeholders are the social work companies, who supply Twente Milieu and De Beurs with employees and want to put their social workers to work. Their interests are to have as much work and therefore employability available within Twente.

These employees, together with the full-time employees can be found *Downwards.*

To analyze these stakeholders, we use a power/interest matrix, as suggested by the Imperial College London in 2007. The goal of this grid is to illustrate the potential impact each stakeholder may have on the project. The matrix for the stakeholders of Twente Milieu and De Beurs is shown in figure 1.3.

A	Communities
B	Social work companies
C	Households
D	Customers
E	Omrin
F	WeCycle
G	WEEE

FIGURE 1.3 POWER/INTEREST MATRIX BASED ON **(IMPERIAL COLLEGE LONDON, 2007)**

Because the communities have founded and funded Twente Milieu we think that they have a lot of power and interest because they are responsible for the well-being of the households. They have to be managed closely. The households, on the other hand, are less important because the communities take care of them. Twente Milieu and De Beurs do not have to pay a lot of attention.

Omrin, WeCycle, and WEE are dependent on the waste of Twente Milieu, so they do not have a lot of power but they are very interested in this project because if Twente Milieu and De Beurs do more in-house, they will get less e-waste.

The social work companies are very interested because there will be more employment for them if this project will succeed. And the customers are also very interested in the outcome of the project because there will be more e-waste for sale at De Beurs.

1.5 Scope, problem cluster, and core problem

1.5.1 Scope and problem cluster

To identify the problem further and to come to the core problem of the case we made two problem clusters, one for Twente Milieu and one for De Beurs. We started both clusters by defining the main problem of the case. For both companies, the main problem is: “too few activities from the e-waste process are done in-house”. After defining the main problem, we defined the causes of the main problem with respect to the five steps of the supply chain (collecting, sorting, disassembling, repairing and selling). This gave an insight on what the scope of our case should be and which parts are less relevant. The problem clusters are shown in figure 1.4 and in figure 1.5.

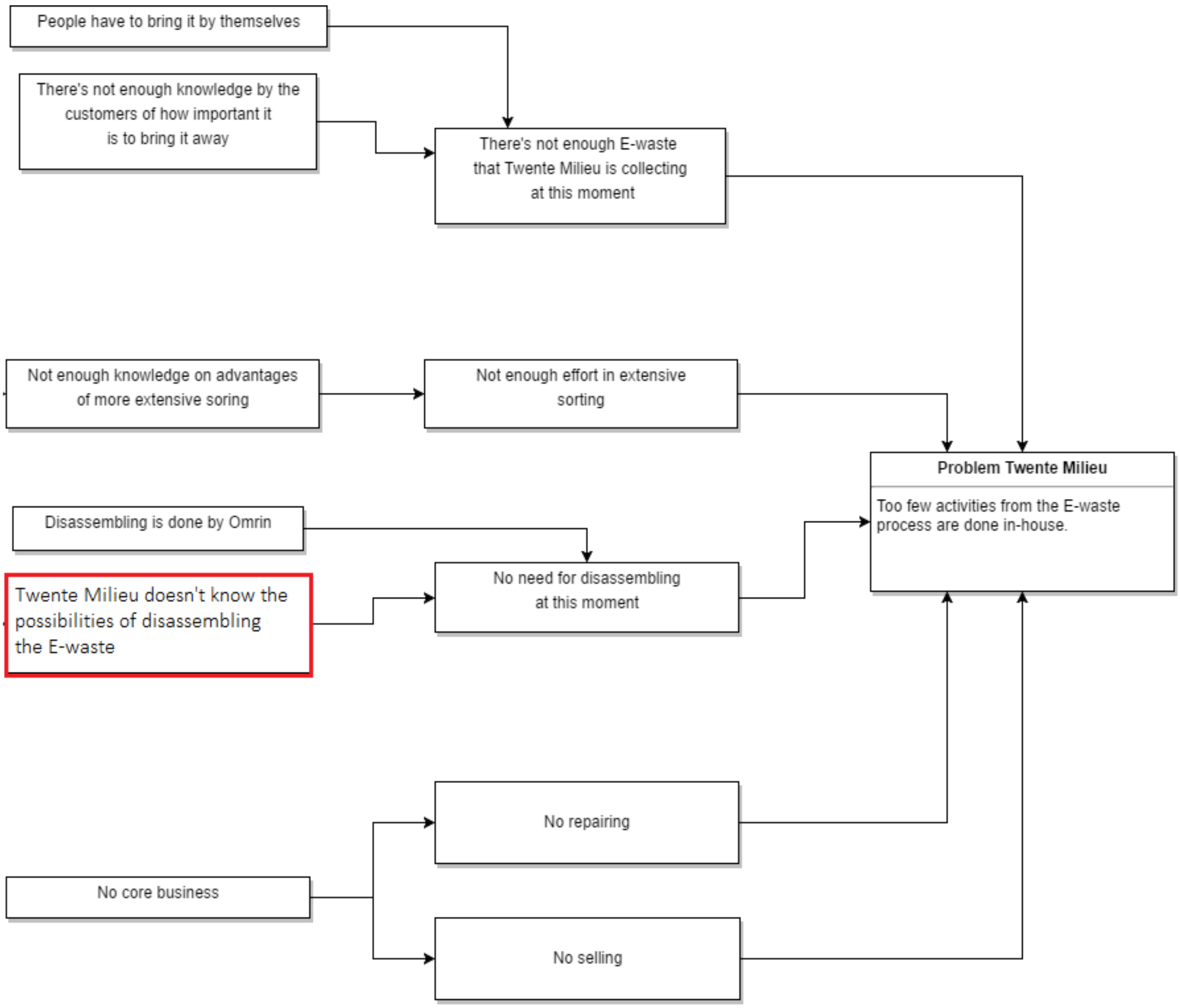

FIGURE 1.4 PROBLEM CLUSTER TWENTE MILIEU

Figure 1.4 shows the problem cluster from Twente Milieu. First, we looked at the 5 steps of the supply chain, which are collecting, sorting, disassembling, repairing and selling. Then we defined the problem for each step. The problem in the red box is according to us the main problem from Twente Milieu and we will describe this problem further in paragraph 1.5.2.

In figure 1.5 the problem cluster from De Beurs is shown. We will describe the main problems (problems in red boxes) also in paragraph 1.5.2

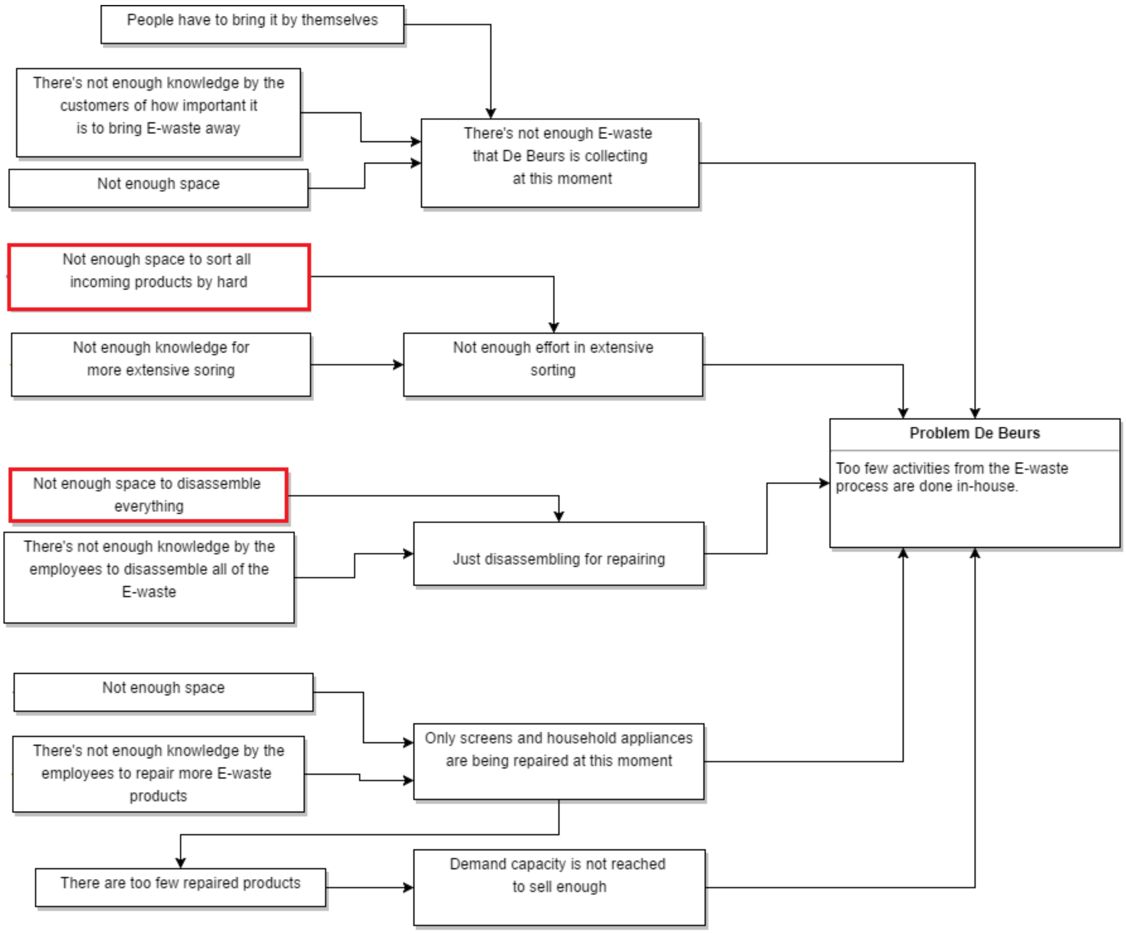

Figure 1.5 Problem cluster De Beurs

For collecting, we looked at which problems could occur at Twente Milieu and De Beurs when collecting e-waste. The main problem can be that Twente Milieu and De Beurs do not get enough e-waste to really use it or gain value from it. At this point, it is unclear however whether this will be the case. From the interview with Twente Milieu, we did learn that it would be relatively easy to get more e-waste from surrounding communities and we know that right now more e-waste is collected than De Beurs can handle. So, if at the end of this case the problem would be that there is not enough e-waste, it is an easy problem to tackle and therefore collecting is out of the scope of this research.

Secondly, the steps repairing and selling at Twente Milieu are irrelevant to investigate further. This is because these steps are no core business for Twente Milieu and fall outside the scope of the company. Selling would be even impossible for Twente Milieu to do in-house because the allocation plan of the local authority does not allow Twente Milieu to sell at their properties. Putting those two steps in the research would create a whole new business element for Twente Milieu, which is also out of the scope of this research.

Repairing at De Beurs is also an irrelevant step in the supply chain for us. We have found that the product life cycle of e-waste is sharply decreasing (Ahmad, 2013). So, we should not focus of the repairing on e-waste, but rather on recycling by disassembling.

The last irrelevant part to investigate is the step selling for De Beurs. At the moment, only a limited number of products is repaired and sold at De Beurs. More repaired products and valuable disassembled parts will automatically lead to more sales, but since the sales capacity of De Beurs is not reached and the demand for second-hand electronics is high they are able to cope with this possible increase in sales. Therefore, also this part does not fit the scope of this research.

With this elimination of irrelevant steps, the scope of the research is more clear. This scope is now limited to the steps sorting and disassembling for De Beurs and Twente Milieu.

Furthermore, we would like to focus our scope even more by a specific product area. In an interview with Bas Assink from Twente Milieu, we argued for a more specific scope and he suggested to focus on the process of washing machines. This because the washing machines are easier to disassemble than other products since they all are similar in components and structure. They also do not include toxic or dangerous materials and have not been through rapid technical changes in the past couple of years. This would also make sorting a lot easier, Twente Milieu and De Beurs would only need to sort the washing machines separately from the rest of the e-waste.

That is why our scope is on the disassembling process of washing machines. From our scope we try to identify the core problem.

1.5.2 Core problem

In the problem cluster, we have shown that the core problem can be found in the disassembling process of Twente Milieu and De Beurs. Twente Milieu does not know what the possibilities are to disassemble a washing machine and De Beurs does not have the space to have an expanded disassembling process.

At this moment Omrin takes all the e-waste from Twente Milieu and De Beurs and recycles it in Leeuwarden. The problem owners identify a problem in this: every week a truck will move the containers of e-waste to Friesland (*reality),* while the managers of Twente Milieu and De Beurs would like to keep the value in these containers, both in work and in money, in Twente (*norm)*.

For Twente Milieu, this means that little sorting and no disassembling is done since they do not know how to gain (more) value from disassembling. Their core problem, retrieved from the problem cluster, is that Twente Milieu does not know what the possibilities are to disassemble the e-waste.

De Beurs is already doing some form of sorting and disassembling. However, they are very limited by one main factor: there is no available space. Their core problem, retrieved from the problem cluster is that De Beurs has not enough available space to further expand their activities in sorting and disassembling the e-waste.

So, the core problem of this project will be: The disassembling process of washing machines is non-existing at Twente Milieu because they do not know what the possibilities and advantages are of disassembling washing machines. De Beurs does not have enough space to optimize the disassembling process. The core problem defines the main reason for this project. The main goal is to get more value out of the e-waste, in form of money and employability. To achieve this goal, we focus us on the re-design of the disassembling process of the washing machines, as we have explained in paragraph 1.5.1.

To achieve the main goal, we need to assess a business case to find out if it is possible for the two companies to collaborate in designing a new way of processing the washing machines. The collaboration can consist of the space of Twente Milieu and the employees from De Beurs.

1.6 Research question

In this chapter, we will determine a research question and some sub-questions which will try to solve the core-problem of Twente Milieu and De Beurs. We have defined the following research question: 'How can De Beurs and Twente Milieu redesign the individual employee disassembling process of washing machines in order to get more value out of e-waste and to achieve more employment in the region?'

The sub-questions are the following questions:

1. Which parts of the washing machines are valuable enough to disassemble instead of transporting them to Omrin?
2. How many washing machines could Twente Milieu and de Beurs collect in the seven municipalities in which it operates?
3. How many full-time-equivalents (FTE) are necessary for Twente Milieu and De Beurs in order to perform activities on disassembling of washing machines?
4. Do Twente Milieu and De Beurs need a conveyor belt or individual stations in order to have a continuous disassembling process?
5. What kind of investments are required and what are the variable costs for Twente Milieu and De Beurs in order to perform activities on the disassembling of washing machines?

1.7 Research methodology

In order to successfully answer the research question, it is necessary to obtain the right information.

For all sub-questions separately we will have to search in the existing literature base and critically assess what we find. To find the correct information from the literature we start making a literature review. The core steps are the following:

1. Define the key constructs:
   For our questions, we have to define key constructs. We will explain these key constructs in Chapter 2.
2. Define search strings:
   To define the search strings we have to determine keywords to guide or search and find a relationship between these keywords.
3. Determine inclusion and exclusion criteria:
   From the previous steps, we can collect a lot of articles. To find the right information we include and exclude several outcomes. This is different for each construct. We will work this out in Chapter 2.
4. Make a concept matrix:
   In this step, we will make a table in where you can see which concepts are in the different articles.

For the different sub-questions we evaluate the articles found out of the literature review. With the concept matrix, we can find the right article for each sub-question and use that article to solve that sub-question.

We will explain now what we think is necessary for each sub-question:

- Which parts of the washing machines are valuable enough to disassemble instead of transporting them to Omrin?
  →We have to know what the value of e-waste is and we also have to know what kinds of parts are inside of a washing machine.

- How many washing machines could Twente Milieu and de Beurs collect in the seven municipalities in which it operates?
  →We have to know what the life-cycle of a washing machine is and we have to know what the number of inhabitants are.

- How many full-time-equivalents (FTE) are necessary for Twente Milieu and De Beurs in order to perform activities on disassembling of washing machines?
  →We will need to know how much time it costs to disassemble a washing machine and we have

to know how much FTE is available for the disassembling of washing machines.

- Do Twente Milieu and De Beurs need a conveyor belt or individual stations in order to have a continuous disassembling process?
  → We have to know what the incoming numbers of washing machines are

- What kind of investments are required and what are the variable costs for Twente Milieu and De Beurs in order to perform activities on the disassembling of washing machines?
  →We need to know what steps we have to take to disassemble washing machines, what kind of tools are needed, and how much space is necessary.

To come to these answers, we will define variables and search in the literature we have found among other things in chapter 2.

Besides the literature review, we will also have an interview with Twente Milieu and De Beurs to guide us to our process and to provide us with more information.

Finally, in order to provide reliable results and proper source mentioning, the APA style will be used. The validity of the results will be determined by the amount of assumption we will have to make in order to find our results. A number of assumptions we will have to make is determined on the available time and information the companies are willing to provide. When we think we found a good article, we will look at the impact factor. When the impact factor is greater than one, we can conclude that this is a good article. The impact factor means the yearly average amount of citations.

2 Key constructs

In this chapter we will explain our key constructs. To define the key constructs we did a literature review. These key constructs will eventually lead to measurable variables. In this paragraph we will elaborate the key constructs Value of e-waste, Knowledge of disassembling and Continuous Processes. The different steps of the literature review are worked through and the most important aspects of the literature review will be elaborated. In the appendices 2 to 4 the rest of the literature review is showed.

2.1 Value of e-waste

One of the constructs that followed the problem identification is 'value of e-waste', since value is an abstract concept it is good to find out what exactly the value of e-waste is. A brief internet research showed that value of e-waste can be divided into two categories; societal and economic value of e-waste. This brief search is displayed in figure 2.1.

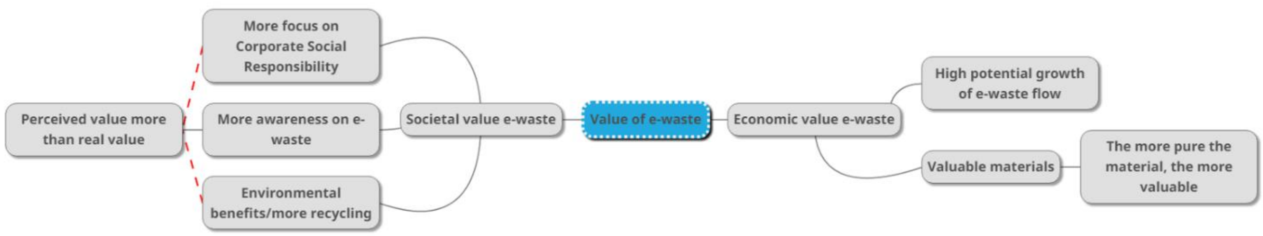

Figure 2.1 Results brief internet research

Because of the scope of the case we chose to focus on the economic value of e-waste. After defining the inclusion and exclusion criteria and the search strings we selected relevant articles which we read extensively and which are summarized in a concept matrix. This extensive literature review (table 1 and 2) and the concept matrix (table 3) can be found in appendix 2. From this review we found that the economic value of e-waste can be derived from the valuable components in the e-waste, where we define economic value as the profit - revenue minus costs - that can be made per washing machine. A valuable component that can be found in almost all sorts of e-waste is a Printed Circuit Board (PCB). This PCB is rich in precious metals but also on hazardous substances. Deriving a PCB from a Waste Electrical and Electronic Equipment (WEEE) is not difficult but recycling a complete PCB is hard because of the complex composition and physical structure. The materials that are found to be most valuable in e-waste are gold, copper, palladium, platinum, silver, rhodium, aluminium, tin, barium and cobalt. The value of a material is assessed on the following variables; market price of the materials, electronic design, material's weight within a product, volumes of generated waste, percentage of collected versus generated e-waste and the materials purity level obtained. The purity of material is an important factor in the value of a material. There is no homogenous data on what the exact relation is between the purity and the price of the material, but the purer the material, the higher the price. The articles reviewed did not specifically investigated washing machines but since there is also a lot said about raw materials, the data is applicable to this case.

2.2 Knowledge of disassembling

Another construct is the knowledge of disassembling. According to Kaya (Kaya, 2016) disassembly/dismantling is the systematic removal of components, parts and/or a group of parts from e-waste. Based on the assembly of PCB's, there are two forms of dismantling e-waste: selective and simultaneous disassembly, whereby selective disassembling can be performed manually or mechanically. Mechanical dismantling can be done in an automatic or a semi-automatic way. Manual dismantling aims to heat the solder above melting point and resell the reusable electronic components. Manual dismantling uses chisels, hammers and cutting torches to open solder connections and separate various types of metals and electronic components. In the simultaneous disassembly method, the whole product is heated and all the components are wiped of simultaneously. Then, the components are identified and sorted by geometrical and physical criterions. Selective disassembly is also called the “look and pick” principle, and the simultaneous disassembly method is also known as the “evacuate and sort” principle.

Habib Al Razi (Habib Al Razi, 2016) confirms this theory, saying that the disassembling of computer cases, monitors and displays is done in a manual way, using simple tools such as screwdrivers, air drivers, hammers, tongs, and conveyor, in order to separate the materials and components into different categories.

Also, the author states that manual dismantling is not possible in developed countries, because of the unavailability of workers and high wages.

Ilgin & Gupta (Ilgin & Gupta, 2011) have designed a washing machine disassembly line using a multi-Kanban system. This disassembly line consists of 3 stations, which is schematically represented in figure 2.2 “Disassembly process of washing machines. At the first station, the metal cover is removed. At the second station the circuit board is taken out and at the third station, the motor of the washing machine will be removed.

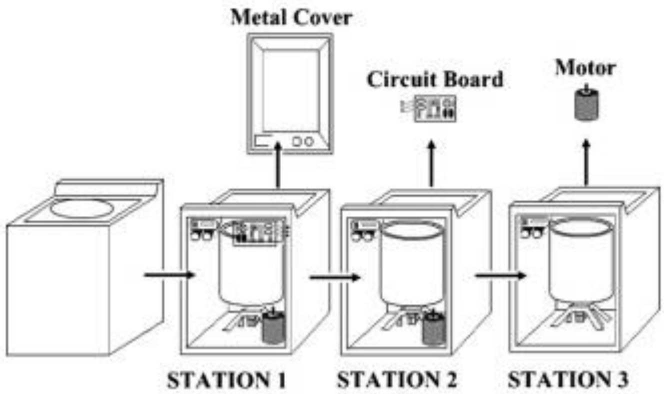

Figure 2.2 Disassembly process of washing machine **(Ilgin & Gupta, 2011)**

Manual disassembly of washing machines is preferred, according to Baylakoglu & Yüksel (Baylakoglu & Yüksel, 2007). However, the authors state that the best results can be obtained by developing optimization of automatic-manual methods. The disassembly cost per washing machine is €0,225. The cost parameters are used depending on the Turkey’s local conditions in 2007. The disassembly time is 150 seconds per washing machine.

2.3 Continuous processes

In order to gain more value out of e-waste, it is important to suggest a process that can do so. To determine whether Twente Milieu and De Beurs should use an automatic disassembly line or an individual station disassembly line, we need to know what the bottlenecks will be so we can compute what profit Twente Milieu and De Beurs can make.

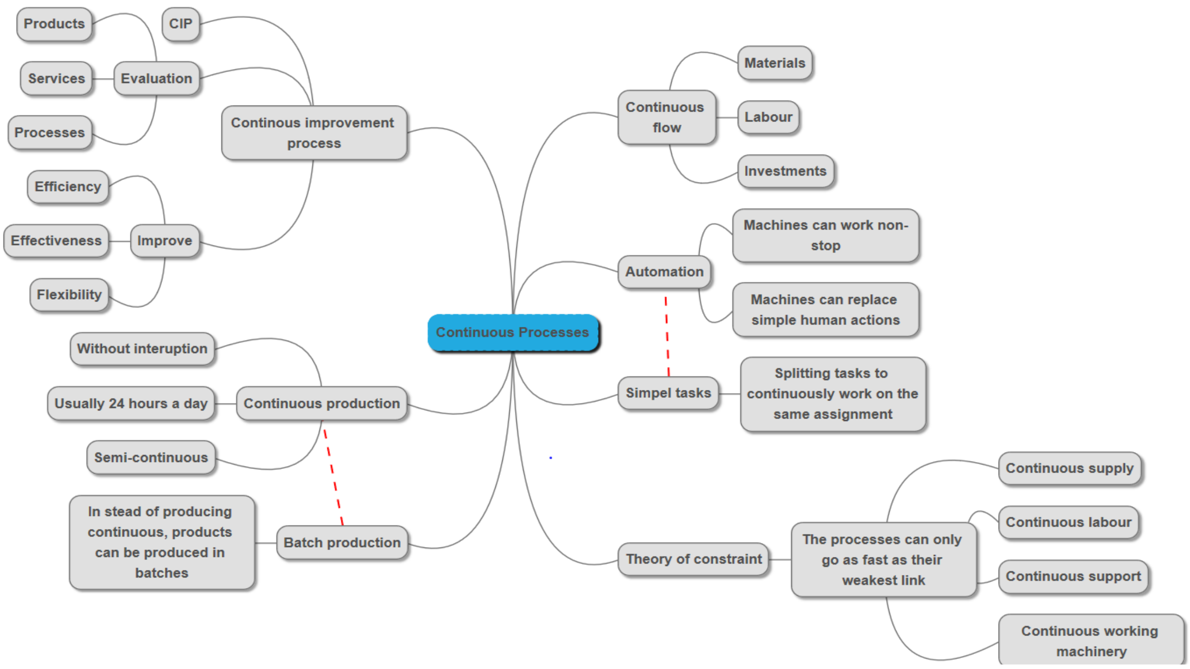

FIGURE 2.3 RESULTS BRIEF INTERNET RESEARCH CONTINUOUS PROCESS

Our brief search displayed in figure 2.3 showed that “continuous process” is a broad keyword. That is why we have selected “Continuous production” and “Theory of Constraint” as our keywords. These, and the other in- and exclusion criteria, as well as the extensive literature research, can be found in appendix 4.

From this literature review, we found that in order to create a continuous process we need to identify possible bottlenecks and keep cycle time low. Furthermore, we found two possible continuous processes we could implement.

Bottlenecks are defined by Sims and Wan as: “the weakest link of the manufacturing system” (Sims & Wan, 2015). Bonal et al suggested a methodology deal with these bottlenecks (Bonal, et al., 1998). Using the following steps:

- Calculate a buffer for every step.
- The capacity of the bottleneck determines the output/shipment given that the material is available.
- Every product family has its own bottleneck, the differences between the product lines can be managed through Drum-Buffer-Rope method.

Following the three articles, we have made the following definition of cycle time: the longest time we expect a product to be in the disassembly process. In order to create a continuous process, we will need to design the process around the bottleneck, in order to minimize the cycle time so that we can maximize the throughput.

Sims and Wan (2015) suggested in their article two ways we could implement a continuous process. The first is by using a moving assembly line, and the second through automatic stations (Sims & Wan, 2015). The advantage of a moving assembly line is the simple work and fast throughput. But automatic stations are less perceptual by fluctuating supply or variance in the specifications of the incoming units.

2.4 Reliability and validity

In this paragraph, we will assess the reliability and validity of the articles which were read in order to perform this research.

The reliability is mostly assessed based on the import factor of the journals the articles were published in. The impact factor is defined as the "average number of citations received in a particular year by papers published in the journal during the two preceding years" (Elsevier, sd). When the impact factor is larger than 1.0, the article can be assessed as reliable, according to information provided during the lectures of the course Academic Skills (Löwik, 2016).

The assessment of the external validity is based on the degree of agreement of the sources. Articles which do not contradict, we assume are valid.

2.4.1 Value of e-waste

In the table below, the impact factors of the journals used for the key construct Value of e-waste are presented:

Article	Journal	Impact factor
E-waste as a source of valuable metals	Archives of materials science and engineering	2.647
Solving/understanding/evaluating the e-waste challenge through transdisciplinary?	Futures	1.242
Recycling of WEEE's: An economic assessment of present future e-waste streams	Renewable and sustainable energy reviews	6.798

TABLE 2.1 IMPACT FACTORS VALUE OF E-WASTE

All the journals above have an impact factor above 1.0 and therefore we assume that the selected articles from these journals are reliable.

For the three selected articles, we assessed the external validity. We did this by looking at the agreement of the articles of the concepts of the concept matrix. We decided that if the outcomes on the concepts are at least not contradicting we can say that there is enough validity to further use these articles. In the concept matrix, it can be found that the outcomes agree or complement each other. They do not contradict each other so there is enough external validity.

2.4.2 Knowledge of disassembling

The impact factors of the journals used for the key construct Knowledge of disassembling are presented in the table below.

Article	Journal	Impact factor
Recycling of Electrical and Electronic Equipment, Benchmarking of Disassembly Methods and Cost Analysis	Proceedings of the 2007 IEEE International Symposium on Electronics and the Environment	-
Resourceful recycling process of waste desktop computers: A review study	Resources, Conversation, and Recycling	3.280
Recovery of sensor embedded washing machines using a multi-kanban controlled disassembly line	Robotics and Computer-Integrated Manufacturing	2.077
Recovery of metals and non-metals from electronic waste by physical and chemical recycling process	Waste Management	3.829

TABLE 2.2 IMPACT FACTORS KNOWLEDGE ON DISASSEMBLING

Most of the journals have an impact factor which is much higher than 1.0, so they can be assessed as reliable (Löwik, 2016). The article in the journal Proceedings of the 2007 IEEE International Symposium on

Electronics and the Environment is a conference paper. It is difficult to assess the reliability of a conference paper, but if we look into the authors, we see one of them was responsible for environment and energy within the Arçelik Group. This company is a big household appliances manufacturer from Turkey. The other author was Chief Researcher at a research institute in Turkey. Based on this we can conclude that this paper is also reliable (Löwik, 2016).

According to the articles which were found, manual disassembly is a labour-intensive process, using simple tools to separate components. One of the articles does not provide information about manual disassembly, but the other three provide similar information about manual disassembly.

There is more disunity about automatic disassembly. Some of the papers say it increases the costs a lot, because the automatic disassemblers are expensive, and decreases the material quality. Other papers say automatic tools improve the efficiency of the disassembly process, and say that it is the most suitable layout for disassembly operations. We can say that the validity of the papers on this point is at least doubtful, but we decided to use them because of the crucial information in the articles.

2.4.3 Continuous processes

The impact factor of the used articles can be found in the table below:

Article	**Journal**	**Impact factor**
Constraint identification techniques for lean manufacturing systems	Robotics and Computer-Integrated Manufacturing	2.077
Management of multiple pass constraint	IEEE/SEMI Advanced Semiconductor Manufacturing Conference and Workshop	-

Table 2.3 Impact factors Continuous processes

Here we see that the first journal has an impact factor higher than 1.0. The second article is a conference paper. As stated above, it is rather difficult to assess the reliability of the article. The main author of the article, Javier Bonal, has published 4 more papers and has been cited 5 times, according to Scopus. Currently, he is Research Programme Officer at the European commission. We decided to use the articles after all because of their overlap in findings. Their definitions for Theory of Constraint and Bottleneck are almost identical which indicates that validity of the research they have done (Löwik, 2016).

3 Disassembling process of washing machines

3.1 Initial solution

According to the literature on the constructs “value of e-waste” and “knowledge on disassembling” we can make a few assumptions. The PCB’s inside a washing machine are one of the most valuable components. Also, a lot of metals are valuable. The engine inside a washing machine can also be very valuable when it is still working and can be used to repair or recycle washing machines (Ilgin & Gupta, 2011). Furthermore, these parts are quite easy to remove and considering the kind of employees (Social Work) it is preferable to use an easy disassembling process. In order to provide a view on how we think the disassembling process of a washing machine can be done by Twente Milieu and De Beurs, we created a flowchart with the input, processes, and output of the disassembling process, shown in figure 3.1.

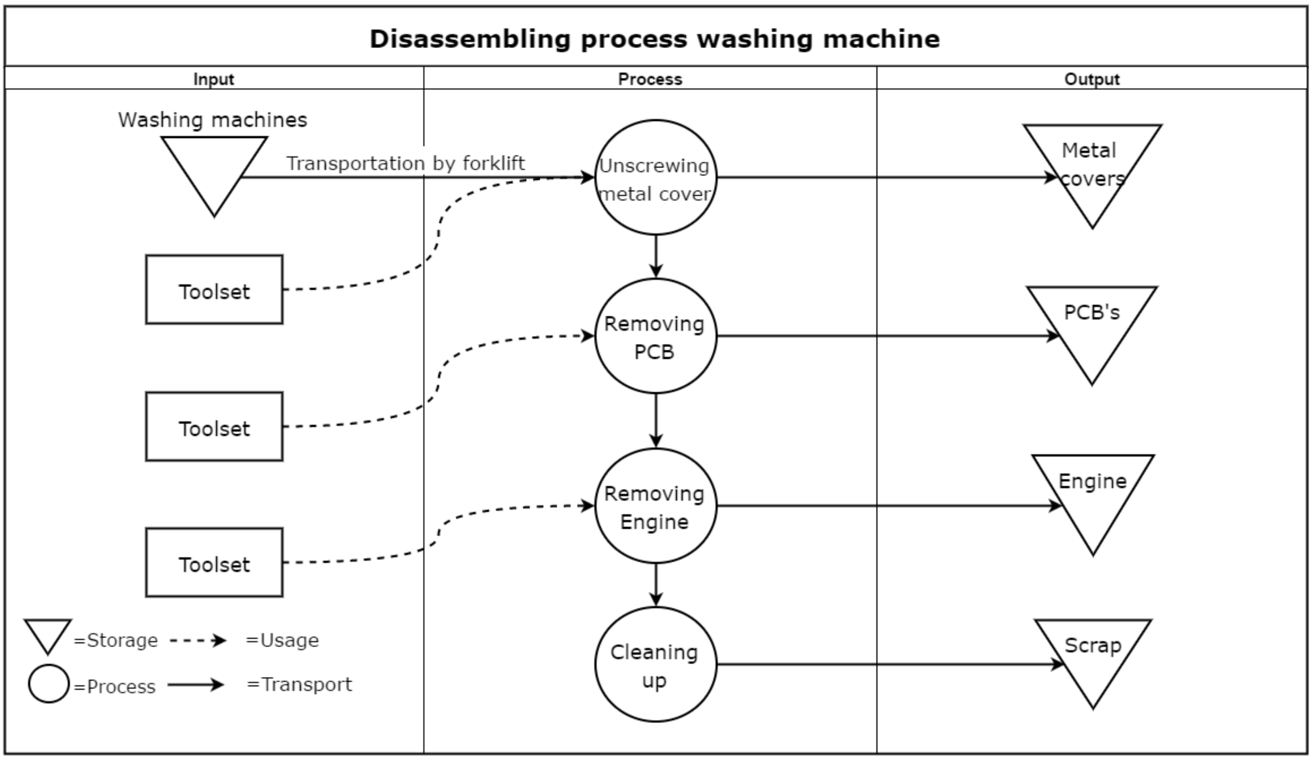

FIGURE 3.1 FLOWCHART DISASSEMBLING PROCESS OF WASHING MACHINES

It all starts with the input of washing machines into the disassembly process. The washing machines are transported onto the workbench or the conveyor belt, using a forklift. In chapter 4 we will review what kind of production environment is more suitable for the disassembling process.

The first step is to unscrew the metal cover. To do this a specific toolset is needed. In chapter 4 we will elaborate what kind of tools are needed for the disassembling process. The output of this first step are the metal covers of the washing machines. These can be collected in bins or containers, so it is easy to sell them all at once. The next step is to remove the PCB from the washing machine. This can be done by unplugging the wires and removing any screws or bolts. Also, the PCB’s can be collected in bins or containers. The engine can be removed by removing any screws and bolts and loosening the fan-belt. The scrap that is left can be moved using the forklift.

Concluding: for the disassembling process there are a few requirements. These requirements are the equipment for disassembling/transporting the washing machines, the disassembling staff, the production/storage areas and other additional matters. These requirements also follow from our sub-questions in paragraph 1.6. In chapter 4 we will define variables to use to assess whether the business case is profitable enough for Twente Milieu and De Beurs.

3.2 Alternative solution

To be sure we made the right decision by making a flowchart, we will create an alternative solution and compare it to the flowchart, so we can see which solution is best.

Another possibility for describing the disassembling process of washing machines is by making a work instruction. A work instruction is documented where the whole process is described in words. The goal of this instruction is that everyone that reads it can understand and perform the process that is stated in the work instruction.

For the disassembling process of washing machines the following work instruction can be made:

Requirements:

Screwdriver set
Hammer
Socket Wrench set
Forklift
Workstation/conveyor belt
Bins/containers

1. Transport the washing machine from the storage to your workspace, using a forklift.
2. Grab the right screwdriver and hammer from your screwdriver set
3. Unscrew the metal cover of the washing machine
4. Place the metal cover in the right bin/container
5. Unclip the wires from the PCB and remove the PCB from the washing machine
6. Place the PCB in the right bin/container
7. Grab the right socket wrench from your socket wrench set
8. Loosen the fan-belt
9. Removing the bolts and screws that are holding the engine
10. Remove the engine and place it in the right bin/container
11. Put back all your tools in the right place
12. Put all the scrap in the right container
13. Start over

3.3 Solution choice

When choosing a solution we need to consider the employees that are going to work with the solution. In our case, these are the social workers from Twente Milieu and the Beurs. Social workers are employees with a distance to the labor market. Since we are dealing with social workers, the main goal for the solution is to be clear, simple and visually supported.

When we are comparing the two solutions we think the Flowchart will be the most suitable for our process, considering the social workers. It gives a clear visual view of the steps that need to be taken by the social workers.

4 Solution generation

In this chapter, we will define the main requirements needed for our final solution. At first, we will define the variables we think are necessary to assess whether the business case is achievable and profitable. These variables can be used to measure and calculate the requirements stated in chapter 3 and the requirements that follow from our sub-questions. Furthermore, in this chapter, we will provide answers on the sub-questions, based on the calculations with the variables, the literature review from chapter 2 and other sources we found necessary. Therefore we made an Excel sheet called "Calculation_Disassembling_Process" with all the calculation, courses and references of the calculations used in this chapter. This Excel Sheet will be provided with the report.

4.1 Variables and relations

For every sub-question we generated variables that we think are necessary to provide an answer to the sub-questions. In the following figure, we will show that the variables have a link with the sub-questions. Furthermore, we operationalized these variables, shown in the figure with the symbols between brackets.

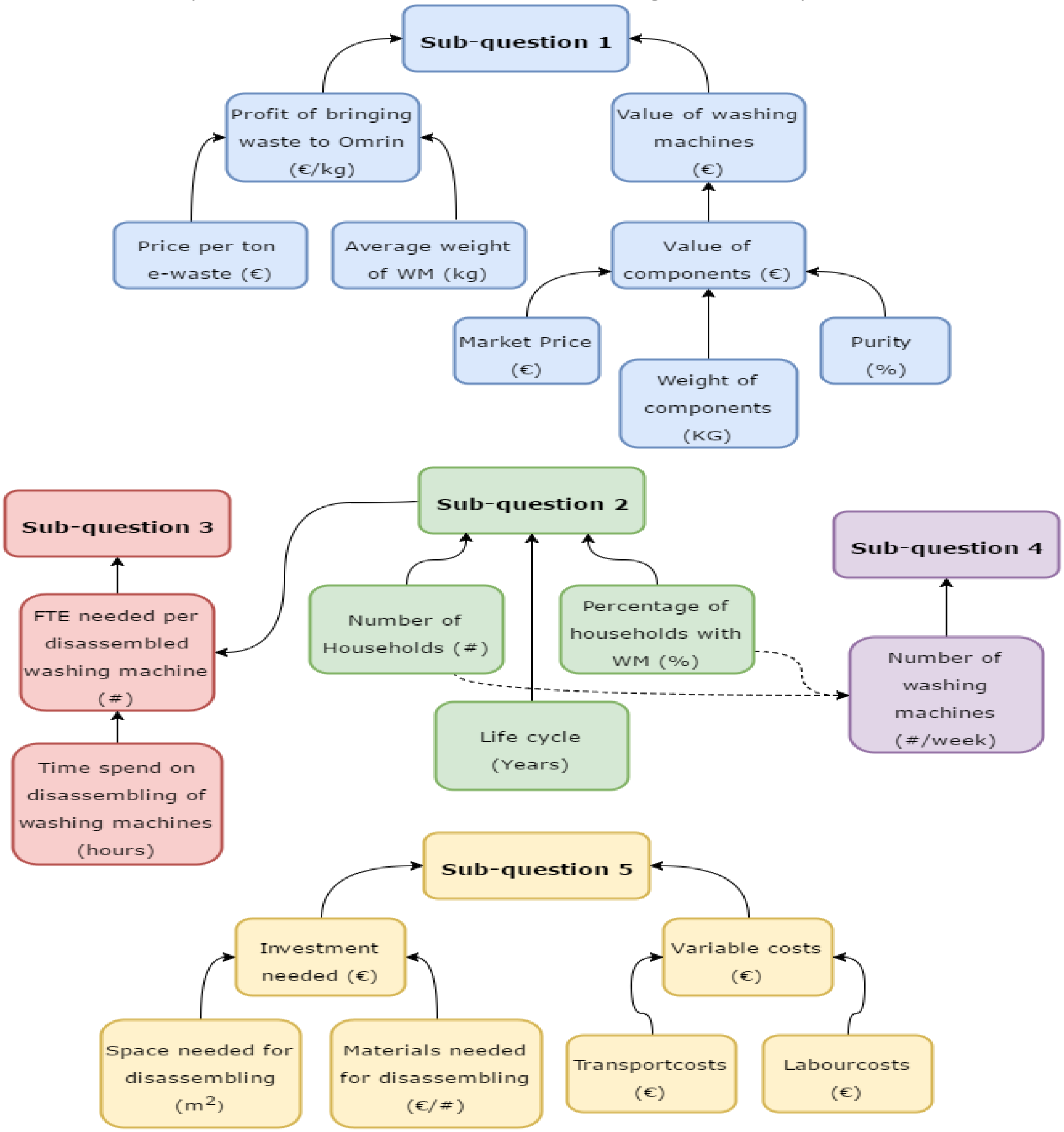

FIGURE 4.1 VARIABLES IN RELATION TO SUB-QUESTIONS

Sub-question 1 is about the value of the washing machines. For Twente Milieu and the Beurs, there are, in the scope of this research, two options for gaining value out of the washing machines. The first option is to bring the washing machines to Omrin. A set price per kilogram is given by Omrin. Therefore this price and the average weight is needed to calculate the profit. The second option is by gaining value by disassembling the washing machines. Therefore the value of all the disassembled components is needed. The value of these components can be calculated with the market price (sometimes per kilogram), the weight and the purity of these components.

In sub-question 2 we want to know how many washing machines can be collected by Twente Milieu and De Beurs. Therefore we need to know the number of households in the seven municipalities, the percentage of households that use a washing machine and the average amount of years that a washing machine will work (life cycle).

The number of FTE needed by Twente Milieu and De Beurs, to answer sub-question 3, can be derived from two things. Namely, the number of washing machines collected, derived from sub-question 2, and the time spent on the disassembling of washing machines.

The fourth sub-question is about the form of the disassembling process. The main variable here is the number of washing machines that come in every week. If the inflow of washing machines is big enough, a conveyor belt can be more efficient, otherwise, a workstation can be more efficient.

Sub-question 5 will give a view on the monetary requirements for this disassembling process. There are two types of costs, the investments needed to start the process, and the variable costs. The investments consist of an investment in space (ground, building) and materials (e.g. tools). The variable costs split in transportation-/ and labor costs.

4.2 Valuable parts of washing machines

According to the literature review we did, we know which parts of the washing machines are more valuable than just selling the washing machine to Omrin. The average weight of a washing machine is around 65 kg (Ilgin & Gupta, 2011). This means that one washing machine will yield €5,20 (on average) when shipped to Omrin (Assink & Wilderink, 2016).

The most valuable parts of the washing machines are the metal components and the PCB’s (Kaya, 2016). Also, the engine can be valuable and is easy to remove (Ilgin & Gupta, 2011). To remove these components no high technical skills are needed and they do not contain hazardous material.

In the following table, the weight and prices of the valuable components are given according to Ilgin & Gupta (2011) and some field research. Since Ilgen & Gupta (2011) assume all products can be reused, we compared the market price they proposed to the current field. The price for metal we retrieved from the Metaal Recycling Federatie (MRF, 2016) and we assumed that the scrap can be sold for the same price to Omrin as before (€80,- per ton). According to Bas Assink from Twente Milieu (Assink & Wilderink, 2016), the metal cover can be sold to the Metaal Recycling Federatie (MRF). They use a variable price per ton, which was €132,47 in December 2016 (MRF, 2016). For the PCB and the engine we called several companies in the Netherlands to retrieve more information on the price per kilogram, shown in appendix 5. Ilgin & Gupta (2011) suggested that all motors and PCB’s can be sold and reused in the market. This might be the case if Twente Milieu and De Beurs expand their repair business or find buyers for spare parts. However, electromotors are also bought per kilogram for their metals. From our small field research we identified a maximum price of 60 cents per kilogram. We chose to use this price because we think that it is hard to find a buyer for spare parts who needs 40 engines of washing machines per week. The PCB’s price highly depends on the specifics, and the buyers we contacted were not able to name a price per kg for PCB’s from washing machines. That is why we used the average price as suggested by Ilgen & Gupta (2011) although we think that for PCB's it is also hard to find someone who will reuse 40 PCB's of washing machines per week. The chosen prices can be found in table 4.1

For our business case we assume that all motors are shredded. We see opportunities in reusing working motors and encourage Twente Milieu and De Beurs to look for possibilities with repair shops and stores who sell parts. This could only increase the work and money earned in this process, since an individual working engine is more valuable than getting it shredded per kilo.

Taken into account all the different prices for the parts that we found to be most valuable we figured that a washing machine is worth €40,35.

Washing machine parts	**Weight**	**Average weight** (Ilgin & Gupta, 2011)	**Market price** (Ilgin & Gupta, 2011)	**Market price (Field research)**	**Used price**
Metal cover	8-16 lbs	5,44 kg	---------------------	€ 0,67	€ 0,67
PCB	0,5-1,5 lbs	0,45 kg	€ 32,23	-------------------	€ 32,23
Engine	5-15 lbs	4,55 kg	€ 80,77	€ 2,45	€ 2,45
Scrap	100-140 lbs	54,43 kg	---------------------	€ 4,99	€ 4,99
Total	**113,5-172,5 lbs**	**64,87 kg**			**€ 40,35**

TABLE 4.1 Weight/prices valuable components **(ILGIN & GUPTA, 2011) (MRF, 2016)**

4.3 Collectable washing machines

Twente Milieu supports and performs activities in seven municipalities in Twente; Almelo, Borne, Enschede, Losser, Oldenzaal, Hengelo and Hof van Twente. Altogether in 2016, there are 192,467 households in these municipalities (Centraal Bureau voor de Statistiek, 2017) and in 95% of these households, there is one washing machine (Wecycle, sd). As can be seen in table 4.6 this means that in the seven municipalities there are 182.844 washing machines. Based on information from a group consumers we assumed that the technical lifetime cycle of washing machines is 10 years (Beste Wasmachine Kopen, 2015). If we assume that the end of the lifetimes of all those washing machines is evenly distributed over the next ten years then this means that in one year 18.284 washing machines are at the end of their life cycle.

According to the CBS in 2040 the number of citizens in the region will grow to 189.715 (Centraal Bureau voor de Statistiek, 2016). This is a growth of 4%, which means that in 2040 18.972 washing machines will end their life cycle (table 4.2). A growth of 4% over 25 years is rather small, so we can say that the number of washing machines in the region is relatively stable.

In potential, Twente Milieu and De Beurs together could collect between 18284 and 18972 washing machines per year between 2016 and 2040 in the seven municipalities. But it is impossible for them to collect all these washing machines. Due to other second-hand stores, white good dealers or dealer in spare parts the lifetime of these washing machines might be extended, local electronic shops might have deals with other companies to collect their e-waste and citizens at the border of the communities also can bring their e-waste to collecting points in other regions. It is not possible for us to determine how many washing machines it concerns, but for the business case, we assumed that half of the potential washing machines in the region will be collected by Twente Milieu or De Beurs. We asked Bas Assink from Twente Milieu if he had an idea if this was correct, he did not have exact numbers either but he supported our assumption. This means 9124 washing machines per year and based on 228 working days (Gemiddeld Gezien, sd); 40 washing machines per working day.

Municipalities	Number of households in 2016		Number of households in 2040	
	Total	95% of total	Total	95% of total
Almelo	31,695	30,110	35,300	33,535
Borne	9,302	8,837	10,300	9,785
Enschede	77,027	73,176	78,200	74,290
Losser	9,200	8,740	9,100	8,645
Oldenzaal	13,826	13,135	14,900	14,155
Hengelo	36,874	35,030	37,200	35,340
Hof van Twente	14,543	13,816	14,700	13,965
Total	192,467	182,844	199,700	189,715

Table 4.2 Number of Washing Machines

4.4 Disassembling staff

In order to calculate how many FTE's are needed, we first have to know how long it takes to disassemble one washing machine. In our disassembly process, we want to remove the metal cover, the circuit board, and the motor. According to Baylakoglu & Yüksel (Baylakoglu & Yüksel, 2007), who tested over 60,000 household appliances, the time it takes to get the motor out of a washing machine is 150 seconds. We can conclude that this is including the metal cover being removed because without removing this metal cover, it is impossible to reach the motor.

Due to the lack of literature on disassembling a circuit board, we have to estimate how much extra time it takes to remove a circuit board from a washing machine. Since it already takes 150 seconds to remove the metal cover and the motor, we can assume that removing a circuit board is between 0 and 150 seconds. It seems easier to remove a circuit board than a motor, especially when factoring that the metal cover has already been removed. That is why we estimate that the removing of the circuit board will take an additional 60 seconds. Before the disassembling can start the washing machine has to be taken to the workstation and after the washing machine has been disassembled, the remainder must be thrown away and the employee needs to clean his working space to be ready for the next washing machine, we estimated an additional 450 seconds for all those actions. This brings the total disassembling time for one washing machine to 660 seconds.

Activity	Time (seconds)
Transport washing machine to working station	120
Removing metal cover and motor	150
Removing circuit board	60
Putting the disassembled parts in bins	120
Putting scrap in container	120
Cleaning up	90
Total	**660**

Table 4.3 Disassembly time washing machine

Recapitulatory, we can say that the disassembling of a washing machine will take eleven minutes.

These observations of Baylakoglu & Yüksel (2007) and the estimations by us are inherent to the fact that employees will need to learn these processes before they can disassemble a washing machine in eleven minutes. Especially since Twente Milieu and De Beurs are working with social workers, who might switch jobs or leave the social work program. For this business case, we will use the eleven-minute disassembly estimation to calculate possible outcomes. Based on these outcomes we can create the limitations and provide a coherent solution for Twente Milieu and De Beurs.

According to section 4.2, there can be brought in 9124 washing machines per year. If all these washing machines are indeed collected, it will take 9124 * 11 minutes = 1676 hours per year. We estimated that a working day consists of 8 hours and that there are 228 working days per year (Gemiddeld Gezien, sd) this means that a full-time equivalent (FTE) consists of 1824 hours. The number of FTE's needed in this business case is 1676/1824 = 0,92 FTE.

4.5 Disassembling environment

Bonal et al (Bonal, et al., 1998) wrote in 1998 that a company should identify its bottlenecks in order to organize a continuous flow of production. To efficiently design a disassembly process for Twente Milieu and De Beurs we want to ensure that the disassembly process is continuous. Sims and Wan (Sims & Wan, 2015) wrote that there are two possible options when designing a production process. Either by using an assembly line or by designing individual workstations.

It is important to keep the number of washing machines in mind, Twente Milieu and De Beurs need a vast amount of washing machines to maintain a disassembly line with multiple employees.

The theory furthermore suggests that the bottlenecks determine how and if a disassembly line is possible. For a continuous process, we want the process and workload evenly distributed to prevent washing machines getting stuck in the process, or having too many employees working on 1 machine. Because De Beurs works with social workers, it is not always possible that they have every time the same employers and that they have every time the same number of employers. That is why a disassembly line is not the most efficient process.

We have chosen for individual workstations which means that one employee is responsible for the disassembling of the whole washing machine. This is called a short fat arrangement. The advantages of the short arrangement instead of a disassembly line are a higher mix flexibility, higher volume flexibility, less monotonous work and higher robustness which is very important for Twente Milieu and De Beurs. Robustness means here that if one workstation breaks down, the other parallel stages are unaffected (Slack, Brandon-Jones, & Johnston, 2013). So with the use of social workers, as stated above, it is more efficient to choose a process which is more robust. To use a short fat arrangement, the washing machines can always be disassembled by some of the employees.

In conclusion, we recommend Twente Milieu and De Beurs to use individual workstations for the process we designed. The actions taken are simple and we expect that the social employees are able to perform the disassembly with some support from experienced technicians. The difference in disassembly times per step, and the fact that we only have a limited amount of supply available support this decision.

4.6 Investments and variable costs

The exact calculations and references for the following sub-question can be found in the Excel Sheet "Calculation_Disassembling_Process" because they were too complex to show here in view of readability.

In chapter 4.1 we have described the variables and their relationship to the sub-questions. For the kind of investments, we will look at the materials needed for the disassembling of the washing machines and at the space which is necessary to disassemble washing machines.

4.6.1 Investment materials

The materials needed to disassemble a washing machine are a worktable, a screwdriver set, a hammer and a socket wrench set for each workstation and a small forklift and three bins to store the valuable parts as general equipment. Table 4.4 shows the prices and the total price of all the needed materials.

Materials 1 workstation	**Price (€)**	**General materials**	**Price (€)**
Screwdriver set (Gamma, sd)	14.95	Bins	100
Socket wrench set (Gereedschapcentrum, sd)	148.99	Forklift	4500
Hammer (Gamma, sd)	14,49		
Work table (Werkplaatsexpert, sd)	327.00		
Total	**505,43**		**4600**

Table 4.4 Costs needed materials

To calculate the total investment for the materials the following formula can be used:

Total investment materials = Costs materials for 1 workstation * number of workstations + costs general equipment

In section 4.4 we calculated that for this business case 0,92 FTE is needed which is rounded up to 1 workstation. This makes the total investment for materials for this business case €5105,43.

4.6.2 Investment space

In order to know what investment is needed in terms of space and buildings, we need to estimate how much space is needed to store the inventory of incoming goods and outcoming goods, to load and unload the goods and to perform the disassembling activities. Then we will multiply the total ground needed by an average land price and multiply the ground for the building with the disassembling activities with an average price for the building. It is not in the scope of our business case to investigate where the activities should/could be located, therefore we use the average price to obtain land and the average price to build in order to calculate the investment.

First, we calculated the space needed for 1 workstation, we based this on the dimensions of the worktable and space an employee needs (Arboportaal, sd) which gives a total of 7 m^2. Then we estimated the general space that is needed in a building; a small office, a toilet, a small kitchen and a small canteen, we estimated this is around 25 m^2. Outside we need containers to store incoming goods, scrap and disassembled parts and space for loading and unloading, we estimated this as 332 m^2.

Altogether this means that, for this case, we need 364 m^2 of land and a building of 57 m3 (based on one level building. We found the average price for land to be €390,- per m^2 (Landprijzen, sd) and the average price for building to be €350 per m^3 (ITX bouwconsult, sd). This means that the total investment for the land and building is €161.791,60.

The total investments of the material and the investment of the land and building together are €166.897,03.

4.6.3 Variable costs

In this business case, the variable costs consist of the salary costs for the employee and of the transportation costs. We assumed the average salary for an employee in a governmental organization to be €42,27 per hour (Centraal Bureau voor de Statistiek, 2014).

This multiplied by 0,92 FTE for 8 hours a day gives daily salary costs of €310,73. Other variable costs that we accounted for are transportation costs, these are the fuel costs and salary costs for bringing the washing machines from all the collecting point in the region to Twente Milieu in Hengelo. We decided to not count the salary costs for transport costs and not for salary costs because we also did not take these hours in consideration for the FTE calculation. The transportation takes 45 hours per year and this is too little to get a new employee for that is skilled to drive the containers to Hengelo. The daily costs for transportation are €11,54. This brings the total variable costs per day to €322,28.

4.7 Summary

A brief summary of the results of the sub-questions is given below:

Sub question 1

- Valuable parts: Metal cover, PCB & engine
- Revenue per washing machine: €40,35

Sub question 2

- 9124 washing machines per year
- 40 washing machines per day

Sub question 3

- Time for disassembling one washing machine: 11 minutes
- FTE needed to process 9124 washing machines: 0,92 FTE

Sub question 4

- In this case; individual workstations are preferred over an assembly line

Sub question 5

- Total investment: €166.897,03
- Variable costs per day: €322,28

5 Conclusion and recommendations

From Twente Milieu and De Beurs, we got the assignment to investigate if more activities in the supply chain of the processing of e-waste could be done in house. For this case, we looked at the possibilities for performing more in-house activities on the disassembling of washing machines. Through a literature study, we found that the most valuable parts to recover from a washing machine are the metal cover, the PCB, and the engine. With this knowledge, we created a flowchart which Twente Milieu and De Beurs can use to perform in-house activities on disassembling washing machines.

The objectives for these in-house activities where more employability in the region and more value out of e-waste. To see if these objectives could be met with the flow chart that was made, we made extensive calculations based on estimations, internet sources, field research, literature and information from Twente Milieu and De Beurs. These calculations show that if half of the washing machines in the region are brought to Twente Milieu or De Beurs, 40 washing machines per day, one employee can be hired to perform in-house activities on the disassembling of washing machines.

The revenue that can be gained per washing machine when following the flowchart is €40,35 per day. This is almost 8 times higher than the current estimated price of €5,20 that is given by Omrin per washing machine.

This disassembling process will generate €1617,89 revenue per day, based on a revenue of €40,35 per washing machine and a disassembling time of 11 minutes. The variable costs are calculated to be €322,28 per day. This makes the profit per day equal to €1295,61. With an initial investment of €166.897,03 this gives a payback time of 129 working days.

To conclude, Twente Milieu and De Beurs can redesign the individual employee process of the disassembling of a washing machine according to the flowchart that we made in order to perform more in-house activities. According to the business case that we set-up this will generate a small increase in employment, a huge increase in the value of the collected washing machines and is profitable in half a year.

Due to the relative low payback time, we would recommend Twente Milieu and De Beurs to make the suggested investment and start with the disassembly of washing machines. The process as we suggested in this research can be strengthened by data collection from Twente Milieu and De Beurs on the number of washing machines collected in Twente every day, and by using the exact prices the marketing is paying for the components. Finding the right buyers for the components is important before starting the process. We recommend Twente Milieu and De Beurs to schedule the investment in such a way that space is kept available for growth, in either recycling or repairing.

By using the process we have suggested, Twente Milieu and De Beurs will open opportunities for more recycling. When the process is established and stable, it will be interesting to look to develop the washing machines repairing facilities of De Beurs and expand the disassembly process at Twente Milieu. It might be possible to completely disassemble a washing machine, without leaving scrap for Omrin. To obtain even more work, this step will increase future possibilities to increase the recycling of more electronic waste. That is why we recommend Twente Milieu and De Beurs to further explore and research recycling options outside of the scope of this research.

6 Discussion

In this research, we showed the possibilities for Twente Milieu and De Beurs to do more of the recycling process of e-waste in-house.

The results of our research are influenced by the limitations of our research. These are shown in paragraph 6.1. The internal validity of our assumptions and the results can be checked by the field study. An integral part of our research is based on Ilgen & Gupta (2011), whose impact factor shows reliable results. These prices seemed valid at first since they highly correlated with the average prices we found online for buying spare washing machine parts. However, for such a large disassembly line we argued that it might not be possible to resell all or any of the working motors. For our research we have decided to go with the findings of our field study, which provided a price range for shredding the motors, thus recycling their metals even further.

In our first analysis, we expected enough available washing machines to create a disassembly line. When we started, we vastly underestimated the throughput time of a washing machine. Assuming that an employee would need a lot more time to disassemble a machine. This did not hold in our business case and we, therefore, designed a process around a static workstation.

We expect that more value could be obtained from the e-waste and have shown that to be true. The investment and recommendations are specifically tailored to Twente Milieu and De Beurs, but most of the general reasoning should hold for other regions and companies. In these scenarios, it is important to identify the number of washing machines available for disassembly.

We believe that this research could be used for other e-waste. The Excel sheet provides a lot of flexibility to Twente Milieu and De Beurs to change the variables and to test different scenarios. Follow-up studies could be done to test our hypothesis on different kinds of e-waste or to incorporate more repairing of washing machines. Repairing would also provide more value for the disassembled motors who still work and that is why further research could also usefully explore market research on second hand washing machine motors or repaired washing machines.

6.1 Research limitations

In this research, there are quite a few things we assumed or determined because there was no way to substantiate this scientifically. These things are:

- We calculated the FTE and throughput time based on a 'regular' employee, because it is hard, perhaps even impossible, to determine how much time it takes for a social worker to do a certain task compared to a 'regular' employee.
- We assumed the scrap could be transported to Omrin while receiving the same price as now. Because we take valuable components out of the washing machine, Omrin probably will not pay the same amount of money as before. Because we were not allowed to contact Omrin, we could not determine how much Omrin will pay for the scrap after taking out the PCB, metal cover and motor.
- We determined the transportation costs of washing machines from the collecting point to the terrain of Twente Milieu in Hengelo, but not the transportation costs of the components to the buyer. This because we cannot predict which companies will buy the components.
- We did not consider the price of the containers in which the valuable components are stored because we couldn't find prices of these containers, and we assumed that Twente Milieu possess these kinds of containers.
- We assumed that there is no loss of time during the process and we achieve 100% efficiency. This is nearly impossible, especially considering the social workers, but we couldn't determine what the efficiency of the disassembling process will be.

- We assumed the transport of the containers from the collecting points to the terrain in Hengelo will be done with the trucks Twente Milieu already possesses. The truck driver, we assume, is already working for Twente Milieu, and it is possible for him to work an extra 45 hours per year.

6.2 Reflection

In the beginning of this project, we had difficulties in choosing the appropriate problem-solving method. We started with the MPSM, but gradually we came to the conclusion that this method did not fit with our ideas to come to a solution. We thought we had to use this one because we were working on an action problem. After we determined to choose another approach, we looked in the literature for some different methods.

Another thing that went wrong in the beginning was that it took a very long time before we knew what we would deliver at the end of this project. We should have put more time in discovering the right deliverables. This was also a reason that we did not have a good problem-solving method.

In the end we decided on delivering a flowchart and an excel sheet with our calculations so that Twente Milieu and De Beurs can adapt when the figures are changing.

Then we were going to explain every step we needed to come to these deliverables. And on the basis of this approach, we came to the best solution and we found the problem-solving method we had been using.

An improvement for the next time could be to not keep trying to fit an idea in a specific problem-solving approach. It is important to explain every step you have made, and that is something we did wrong in the beginning. And it is very important to know what you want to deliver, otherwise, it is not possible to choose an appropriate problem-solving method.

Bibliography

Ahmad, A. (2013, October 26). *Is the trend of short product life cycle of electronic products a real cause of increasing e-waste?* Retrieved December 20, 2016, from https://www.researchgate.net: https://www.researchgate.net/post/Is_the_trend_of_short_product_life_cycle_of_electronic_products_a_real_cause_of_increasing_e-waste

Arboportaal. (n.d.). *Werkplaatsnormen*. Retrieved from arboportaal.nl: https://www.arboportaal.nl/onderwerpen/werkplaatsnormen

Assink, B., & Wilderink, P. (2016, November 15). Presentation Twente Milieu and De Beurs. (G. 2, Interviewer)

Baylakoglu, I., & Yüksel, T. (2007). Recycling of Electrical and Electronic Equipment, Benchmarking of Disassembly Methods and Cost Analysis. *Proceedings of the 2007 IEEE International Symposium on Electronics and the Environment*, 222-226.

Beste Wasmachine Kopen. (2015). *De Levensduur en Garantie van een Wasmachine*. Retrieved from Bestewasmachinekopen.nl: http://bestewasmachinekopen.nl/wasadvies/levensduur-wasmachine-garantie/#

Bonal, J., Sadai, A., Ortega, C., Aparicio, S., Fernandez, M., Oliva, R., . . . Ojeda, D. (1998). Management of multiple pass constraints. *IEEE/SEMI Advanced Semiconductor Manufacturing Conference and Workshop*.

Bourne, L., & Weaver, P. (2010). *Construction Stakeholder Management.* Blackwell Publishing Ltd.

Centraal Bureau voor de Statistiek. (2014, December 1). *Arbeidskosten; structuur arbeidskosten, arbeidsduur, bedrijfstak, 2012*. Retrieved from cbs.nl: http://statline.cbs.nl/StatWeb/publication/?DM=SLNL&PA=82853NED

Centraal Bureau voor de Statistiek. (2016, September 12). *Regionale Prognose 2017 - 2040*. Retrieved from CBS.nl: http://statline.cbs.nl/Statweb/publication/?DM=SLNL&PA=71486ned&D1=0-19&D2=0&D3=69,135,203,282,291,358,431&D4=0,5,14-16&VW=C

Centraal Bureau voor de Statistiek. (2017, January 1). *Huishoudens; samenstelling, groootte, regio*. Retrieved from Statline.cbs.nl: http://statline.cbs.nl/Statweb/publication/?DM=SLNL&PA=71486ned&D1=0-19&D2=0&D3=69,135,203,282,291,358,431&D4=0,5,14-16&VW=C

Elsevier. (n.d.). *Impact Factor*. Retrieved from Journals.elsevier.com: https://www.journals.elsevier.com/futures/

Fuller, T. (2016, December 22). *Futures*. Retrieved from Journals.elsevier.com: https://www.journals.elsevier.com/futures/

Gamma. (n.d.). *Black+Decker bit- en dopsleutelset A7039 45-delig*. Retrieved January 10, 2017, from https://www.gamma.nl: https://www.gamma.nl/assortiment/black-decker-bit-en-dopsleutelset-a7039-45-delig/p/B114188?q=fh_location%3d%2f%2fcatalog01%2fnl_NL%2f%24s%3dschroevendraaier%2fcategories%3C%7bcatalog01_catgereedschap%7d%2fcategories%3C%7bcatalog01_catgereedschap_catgeree

Gamma. (n.d.). *Stanley klauwhamer 325 mm*. Retrieved 10 January, 2017, from https://www.gamma.nl: https://www.gamma.nl/assortiment/stanley-klauwhamer-325-mm/p/B589808?q=fh_location%3d%2f%2fcatalog01%2fnl_NL%2f%24s%3dhamer%2ffh_item_type%3E%7bproduct%7d%26fh_start_index%3d0%26fh_view_size%3d20%26fh_lister_pos%3d8%26fh_refview%3dsearch%26date_time%3d201

Gemiddeld Gezien. (n.d.). *Gemiddeld aantal werkdagen*. Retrieved from gemiddeldgezien.nl: http://gemiddeldgezien.nl/gemiddelde-aantal-werkdagen

Gereedschapcentrum. (n.d.). *Bahco S560 56 delige doppenset*. Retrieved January 10, 2017, from https://www.gereedschapcentrum.nl: https://www.gereedschapcentrum.nl/merken/bahco/handgereedschap/doppenset/bahco-s560-56-delige-doppenset.html

Habib Al Razi, K. M. (2016). Resourceful recycling process of waste desktop computers: A review study. *Resources, Conversion and Recycling*, 30-47.

Heerkens, H. (2010). *A Methodological Checklist For The High-Tech Marketing Project.* Enschede: TSM Business School. Retrieved November 28, 2016

Heerkens, H. (2012). *Geen Probleem.* Nieuwegein: Van Winden Communicatie. Retrieved November 28, 2016

Ilgin, M. A., & Gupta, S. M. (2011). Recovery of sensor embedded washing machines using a multi-kanban controlled disassembly line. *Robotics and Computer-Integrated Manufacturing*, 318-334.

Imperial College London. (2007). *Power/Interest Matrix.* London.

International Gouvernments. (2005, 10 8). *Verdrag van Bazel inzake de beheersing van de grensoverschrijdende overbrenging van gevaarlijke afvalstoffen en de verwijdering ervan*. Retrieved from wetten.overheid.nl: http://wetten.overheid.nl/BWBV0002081/2005-10-08

ITX bouwconsult. (n.d.). *Wat zijn bouwkosten per m2 of per m3 van een nieuwbouw woning?* Retrieved from Itx-bouwconsult.nl: http://www.itx-bouwconsult.nl/diensten-particulier/gemiddelde-bouwkosten-per-m2

Kaya, M. (2016). Recovery of metals and nonmetals from electronic waste by physical and chemical recycling processes. *Waste Management* , 64-90.

Kazmerski, L. (2016, December 22). *Renewable & Sustainable Energy Reviews*. Retrieved from journals.elsevier.com: https://www.journals.elsevier.com/renewable-and-sustainable-energy-reviews

Landprijzen. (n.d.). *Prijs Bouwgrond*. Retrieved from Landprijzen.nl: http://landprijzen.nl/bouwgrond-2/

Lavernia, E. (2016, December 7). *Materials Science and Engineering: A*. Retrieved from journals.elsevier.com: https://www.journals.elsevier.com/materials-science-and-engineering-a/

Löwik, S. (2016, December). Presentation on literature review. (G. 2, Interviewer)

MRF. (2016, December). *Metaal Recycling*. Retrieved from HKSmetals.eu: https://www.hksmetals.eu/nl/over-ons/metaal-recycling

Sims, T., & Wan, H. (2015). Constraint identification techniques for lean manufacturing systems. *Robotics and computer-integrated manufacturing*.

Slack, N., Brandon-Jones, A., & Johnston, R. (2013). *Operations Management.* Edinburgh Cate: Pearson Education Limited. Retrieved January 11, 2017

Slack, N., Brandon-Jones, A., & Johnston, R. (2013). *Operations Management (7th Edition.* Harlow: Pearson Education Ltd.

Wecycle. (n.d.). *Recycling groot witgoedapparaten*. Retrieved from wecycle.nl: https://www.wecycle.nl/consumenten/educatie/

Werkplaatsexpert. (n.d.). *Werkbank 52-3710-12*. Retrieved January 10, 2017, from http://werkplaatsexpert.nl: http://werkplaatsexpert.nl/werkbanken/standaard-werkbanken/werkbanken-met-laden/werkbank-52-3710-12.html

Werkplaatsnormen. (n.d.). Retrieved January 13, 2017, from https://www.arboportaal.nl: https://www.arboportaal.nl/onderwerpen/werkplaatsnormen

Appendices

Appendix 1 Steps research approach

Step	Action	Deliverable	Planning	Deadline
Define the problem	• Finding norm and reality • Mapping of current situation • Make a problem cluster • Define scope	Core problem	Company visit (24 November) Project work together (28 November) Project work together (30 November)	1 Dec
Decide research requirements	• Stakeholders analysis • Formulate research questions • Define key constructs	Literature review	Company visit (24 November) Project work together (30 November)	1 Dec
Redesign disassembling process	• Make a flowchart	Flowchart	Project work together (28,30 November)	9 Jan
Define variables	• Making key constructs measurable	Measurable key variables	Project work together (28,30 November) Project work together (7,14,20,21 December)	9 Jan
Solution generation	• Make calculations to answer the research question	Answer to research question and Excel sheet which the firms can adapt	Project work together (11,18,19,23,24,25 January)	26 Jan
Solution and recommendations	• Choose best solution	Conclusion and recommendation	Project work together (11,18,19,23,24,25 January)	26 Jan

Appendix 2 Literature review value of e-waste

Exclusion		
Number	Criteria	Reason
1.	Articles written for 1989	On March 22nd of 1989 the Bazel Convention took place. During this convention international environmental laws were signed. These laws were one of the first to recognize the concept of e-waste in such a scale (International Gouvernments, 2005). Therefore, only articles published after 1988 are relevant.
2.	Articles that refer to e-waste in not-western world	In third world countries and upcoming countries, the problems and opportunities with e-waste are way different from that in western countries.
3.	E-waste not mentioned in the title	The construct is specific on the value of e-waste, not any other kind of value.
4.	Articles about legislation on e-waste	This is a relevant research topic on e-waste but falls out of the scope of this case
5.	Articles about the societal value of e-waste	This is a relevant research topic on e-waste but falls out of the scope of this case
Inclusion		
1.	Articles with focus on economic value of e-waste	Because this fits the scope of the case

Table 1 Exclusion/inclusion criteria

All articles are searched on Scopus.com

Search strings	**Scope**	**Date of search**	**Date range**	**Number of entities**
"E-waste" and "economic"	Resp. "Titel" & "Titel, keywords and abstracts"	20-12-2016	1989 – present	+60
"E-waste" and "value"	Resp. "Titel" & "Titel, keywords and abstracts"	20-12-2016	1989 – present	+112
Total				**172**
Removed duplicates				-5
Removed based on exclusion criteria 2				-142
Removed based on exclusion criteria 4				-8
Excluded after reading abstract and exclusion criteria 5				-7
Excluded after reading abstract				-7
Total selected for review				**3**

Table 2 Search strings

Appendix 3 Literature review knowledge of disassembling

Exclusion		
Number	Criteria	Reason
6.	All other subject areas	Other subject areas are irrelevant to the key construct
7.	Articles with a name of a chemical component in the title	These articles are not focused on disassembling or dismantling
Inclusion		
2.	Subject area is Environmental Science and/or Engineering	Since the key construct is about disassembling e-waste, the subject area is Environmental Science and/or Engineering
3.	Dismantling and/or disassembling must be in the abstract of the article	These terms are important with regard to the key construct. If these terms are not in the abstract, the articles are not relevant

Table 3 Exclusion/inclusion criteria

Search string	**Scope**	**Date of search**	**Date range**	**Number of entries**
Search protocol for Scopus				
E-waste AND dismantling methods AND disassembly AND dismantling process	Article title, Abstract, Keywords	20-12-2016	2000-present	32
Washing machines AND disassembly AND methods	Article title, Abstract, Keywords	21-12-2016	2000-present	25
Selecting based on inclusion and exclusion criteria				-43
Removed after reading abstract				-10
Selected for review				**4**

Table 4 Search strings

Appendix 4 Literature review continuous process

Number	Criteria	Reason for exclusion
1	Pre-1997	The theory of constraint came into life at 1984. However, this concept was not adapted for project management until 1997. Since this review is focussed on that, we will exclude everything from before that year.
2	The subject area of “Chemical Engineering”	Not included in this paper, because it has more focus on continuous processes compared to semi-continuous processes, which we are interested in.
3	The word “chemical” or “steel” in the abstract	-
4	The word “review” in the abstract	Articles about continuous review of processes are out of the scope of this paper.
5	The word “fuzzy” in the abstract	To exclude research on how to deal with “fuzzy information”, since we assume information on the process is clear.
6	The word “optimization” and “improvement”	Our focus is on continuous processes, not on continuous improvement/optimization processes
Number	**Criteria**	**Reason for inclusion**
1	Continuous production	We want to put the focus on production compared to process. Process has a lot more focus on team performance or other non-production processes.
2	Theory of constraint	What kind of constraints might we find before we can have a continuous disassembly?

Table 5 Reason for exclusion/inclusion

Search String	Scope	Date of search	Number of entries
Search protocol for Scopus			
“Continuous production” AND “Theory of Constraint”	Article title, abstract, keywords	21-12-2016	234
Total in Endnote			234
Exclusion criteria #1			- 32
Exclusion criteria #2			- 30
Exclusion criteria #3			- 34
Exclusion criteria #4			- 58
Exclusion criteria #5			- 22
Removed after reading abstract			- 14
Left to read			**5**
Removed after reading			2
Used for the research			**3**

Table 6 Exclusion/inclusion criteria

Appendix 5 Field research

After the literature research we have done small field research to determine the validity of our literature research.

We called the following companies who buy metals and process them further. We introduced ourselves as students who are doing a business case regarding the disassembly of washing machines. We asked them what prices they offer for a kilogram of washing machine motors and PCB's.

These are the results:

Company	**Day called**	**Price per kilogram motor**	**Price per kilogram PCB**
Interbaro	24-01-2017	60 cents	Do not deal in PCB's
Bakker metaal recycling	24-01-2017	50 cents	Depends per PCB
HKS metals	24-01-2017 Asked us to send an e-mail, still awaiting response		
Holland recycling	24-01-2017	50 cents	Depends per PCB
KH-metal	25-01-2017	40 cents	Depends per PCB
Metabel bv	24-01-2017	-	Depends per PCB

All the companies who deal in PCB's responded that the price per PCB is very different and that there are no averages for a washing machines. This is also supported by the research by Ilgin and Gupta (2011) who argued that the price range could be between 20 and 80 dollar. They all work the same, either the client sorts the PCB's together and sends the information to the dealer who determines a price, or the complete container is sent and the dealer sorts the PCB's and determines a price.