The processing of e-waste

A business case for De Beurs and Twente Milieu

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Dr. Ir. S.J.A. Löwik

Group 8

J.A. Gonzalez Camacho (s1870866)

Y.R. Nyamsangya (s1751441)

A.I. Tamez Garza (s1263668)

T.J Seydel (s1626043)

S. van Weersel (s1485989)

Preface

Before reading this report, it is important to know how and why the report is realized. This report has been written to fulfill the demand of Second-hand Organization De Beurs (Oldenzaal) and garbage-collection company Twente Milieu (Hengelo). These companies wanted to develop a business case to collect, sort, recycle and re-use electronic products (e-waste). The central problem is stated as: how can De Beurs and Twente Milieu organize the processes most efficient and effective? This problem is defined in three problem areas:

1. Which steps of the supply chain of collecting, sorting, disassembling, repairing and selling can De Beurs best do in-house, and which can best be outsourced?
2. Given a supply of products and available production area what would be the most efficient lay-out and logistics at the Beurs?
3. What is the 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?

After the introduction to the problem, groups were formed and assigned to a problem statement. In this report, problem area 2 will be taken care of, and the report is written to advise Twente Milieu and De Beurs. The approach of the problem area is based on the Managerial Problem Solving Method (Heerkens & Winden, 2012). This method consists of 7 phases: Problem identification, Solution planning, Problem analysis, Solution generation, Solution choice, Solution implementation and the Solution evaluation.

In chapter 1 the problem identification can be found. In this chapter, an introduction to the problem will be given, among other things the reality and the norm will be mentioned.

We want to thank our teacher Dr. Ir. S.J.A. Löwik and the representatives of De Beurs and Twente Mileu for the information and the guidance.

Enjoy your reading.

J.A. Gonzalez Camacho
Y.R. Nyamsangya,
T. J. Seydel,
I.A Tamez Garza,
S. van Weersel,

Management Summary (English)

De Beurs and Twente Milieu want to collaborate to increase the added value gained from recycling e-waste. The following three problem areas were defined: which steps from the recycling process should be done in-house and which steps should be outsourced; what would be the most efficient layout and logistics at De Beurs; should the recycling process be based on employees or on the amount of yield per component type. This research focused on the second area: what would be the most efficient layout and logistics at De Beurs. We approached this problem by using the Managerial Problem Solving Method by Heerkens & Winden.

At the beginning, we analyzed the current flow of the processing of e-waste at Twente Milieu and De Beurs. Besides this we gained more information about the problem identified by De Beurs and Twente Milieu. De problem could be summarized as followed: in the current situation, the collected e-waste is outsourced to Omrin which hinders the employability in Twente and the maximizing of added value gained from e-waste. This problem is caused by several factors; therefore, the core problem has to be identified. The core problem identified is 'there is no production layout for the processing of e-waste'.

To solve this problem, we followed the methodology of Slack et al. (2004) as a procedural solution approach to choose the right process type and layout type leading to an appropriate detailed layout for the production process. Therefore, we have taken the following 5 steps.

Firstly, we determined the degree of volume and variety of the processed e-waste. Based on literature we decided to include the following types of e-waste in the production process: large household's appliances, small households appliances and It and telecommunications equipment

Besides this, we identified the stakeholders of the processing of e-waste and took into account their requirements and constraints of the production process. These can be summarized as followed: Keep the work at Twente while maximize the added value of e-waste. Besides this we considered the European and Dutch legislations concerning the processing of e-waste. To meet the requirements and constraints, we decided to include repairing, sorting and dismantling type 0 and 1 in the production process.

Next, we made a flowchart of the production process which will take place at the new location of Twente Milieu and De Beurs, which is represented in figure A. This production process is based on the requirements and constraints of the representatives and besides this it includes a literature review about the processing of e-waste. We concluded that the new production process would be a batch or jobbing process. According to Slack et al. (2004), a functional layout is the most appropriate layout for these specific production processes.

At the end, we developed a detailed lay-out for the production process. The layout is represented in figure B below. In addition, we develop some design rules to make sure that this layout can also be applied at other locations.

Management samenvatting (Nederlands)

De Beurs en Twente milieu willen samenwerken op het gebied van de verwerking van e-waste om de toegevoegde waarde hiervan te verhogen. De organisaties hebben de volgende drie probleemgebieden geformuleerd: welke stappen in het recyclen van e-waste zouden intern uitgevoerd moeten worden en welke zouden moeten worden uitbesteed; wat zijn de meest efficiënte lay-out en logistiek voor het verwerken van e-waste bij De Beurs; moet het recycling proces gebaseerd zijn op de werknemers of op de hoeveelheid winst per bestandsdeel van de e-waste. Dit onderzoek is gefocust op het tweede probleemgebied: wat zijn de meest efficiënte lay-out en logistiek voor het verwerken van e-waste bij De Beurs. Wij hebben dit probleem benaderd door middel van de 'Managerial Problem Solving Method' van Heerkens & Winden.

De eerste stap in het project was het analyseren van het huidige verwerkingsproces van e-waste bij Twente Milieu en De Beurs. Daarnaast hebben wij aanvullende informatie verzameld over het probleemgebied. Het probleem kan als volgt worden samengevat: op dit moment wordt de verzamelde e-waste getransporteerd naar Omrin om hier verwerkt te worden, hierdoor wordt op dit moment niet het werk in Twente gehouden en wordt de toegevoegde waarde van e-waste voor De Beurs en Twente Milieu niet gemaximaliseerd. Dit probleem wordt veroorzaakt door meerdere factoren, daarom moet er één kernprobleem worden geformuleerd. In dit project is het volgende kernprobleem geïdentificeerd: er is geen productie lay-out beschikbaar voor het verwerken van e-waste. Om dit probleem op te lossen hebben wij de methodologie van Slack et al. (2004) gebruikt. Hiervoor hebben wij de volgende vijf stappen gevolgd.

Ten eerste hebben wij de volume en de variëteit van de verzamelde e-waste vastgesteld. Gebaseerd op literatuur is er besloten om de volgende types e-waste in het productieproces te betrekken: grote huishoudapparaten, kleine huishoud apparaten en IT en telecommunicatie apparatuur.
Vervolgens hebben wij de stakeholders en hun vereisten van het verwerken van e-waste geïdentificeerd. Op aanvulling hierop hebben wij ook de beperkingen van het productieproces bepaald. De vereisten en beperkingen kunnen als volgt worden samengevat: houd het werk in Twente en maximaliseer de toegevoegde waarde van e-waste, hierbij moet rekening gehouden met de veiligheid en vaardigheden van de vrijwilligers. Om aan deze vereisten en beperkingen te voldoen hebben wij besloten om de volgende stappen te betrekken in het productieproces van e-waste: repareren, sorteren en demonteren in de vorm van type 0 en 1.

In de volgende stap hebben we een flowchart gemaakt van het productieproces dat plaats moet gaan vinden op de locatie van Twente Milieu, deze flowchart is weergegeven in figuur A. Het productieproces is gebaseerd op de vereisten en beperkingen geformuleerd in de vorige paragraaf. Daarnaast hebben wij een systematisch literatuuronderzoek uitgevoerd naar de stappen die genomen moeten worden tijdens het verwerken van e-waste. Op basis van het ontworpen productieproces lijkt een 'batch' of 'jobbing' process het beste te passen in deze situatie. Volgens Slack et al. (2004) is een functionele lay-out het meest efficiënt voor dit specifieke productieproces.

Tot slot hebben wij een gedetailleerde lay-out van het productieproces gemaakt, welke weergegeven is in figuur B. Als aanvulling hierop hebben we ontwerp regels geformuleerd zodat deze lay-out ook toegepast kan worden op andere locaties.

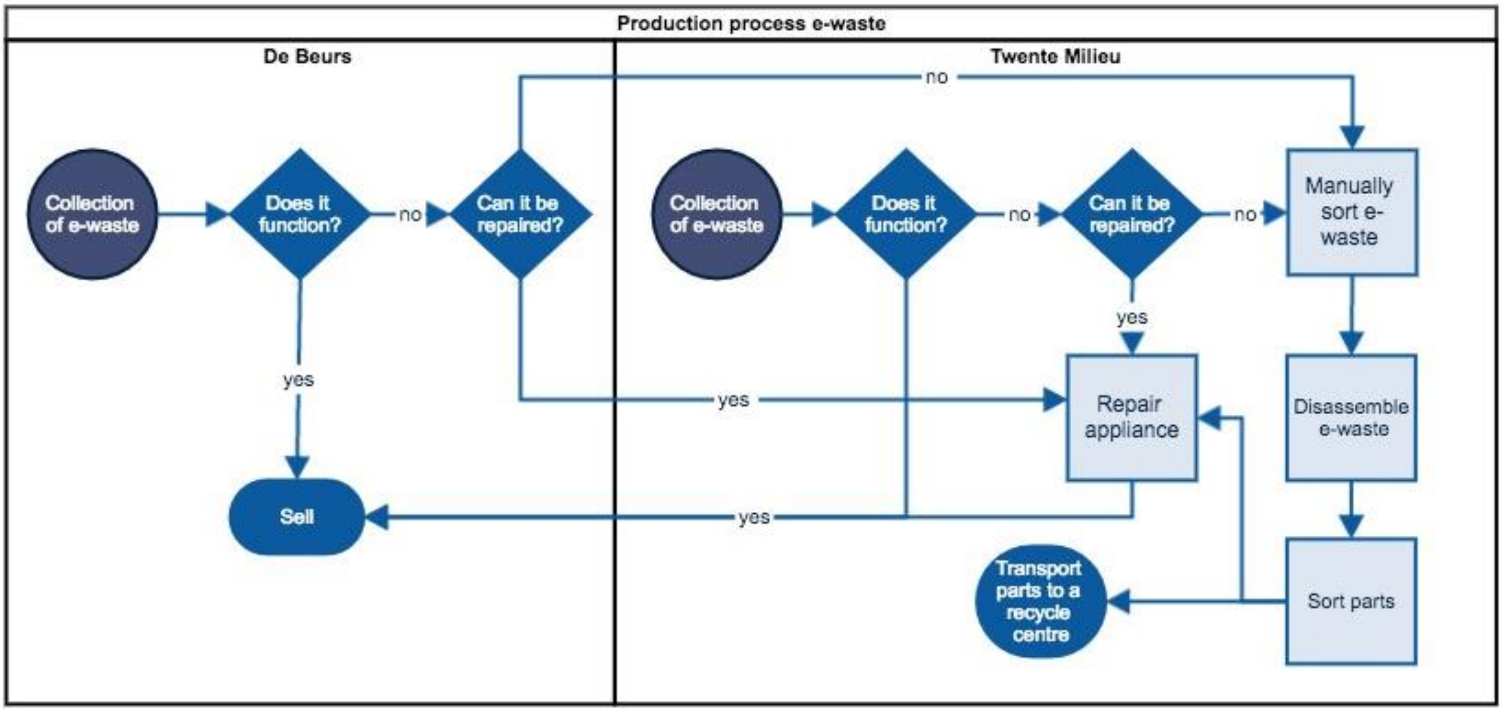

Figure A. Production process summary

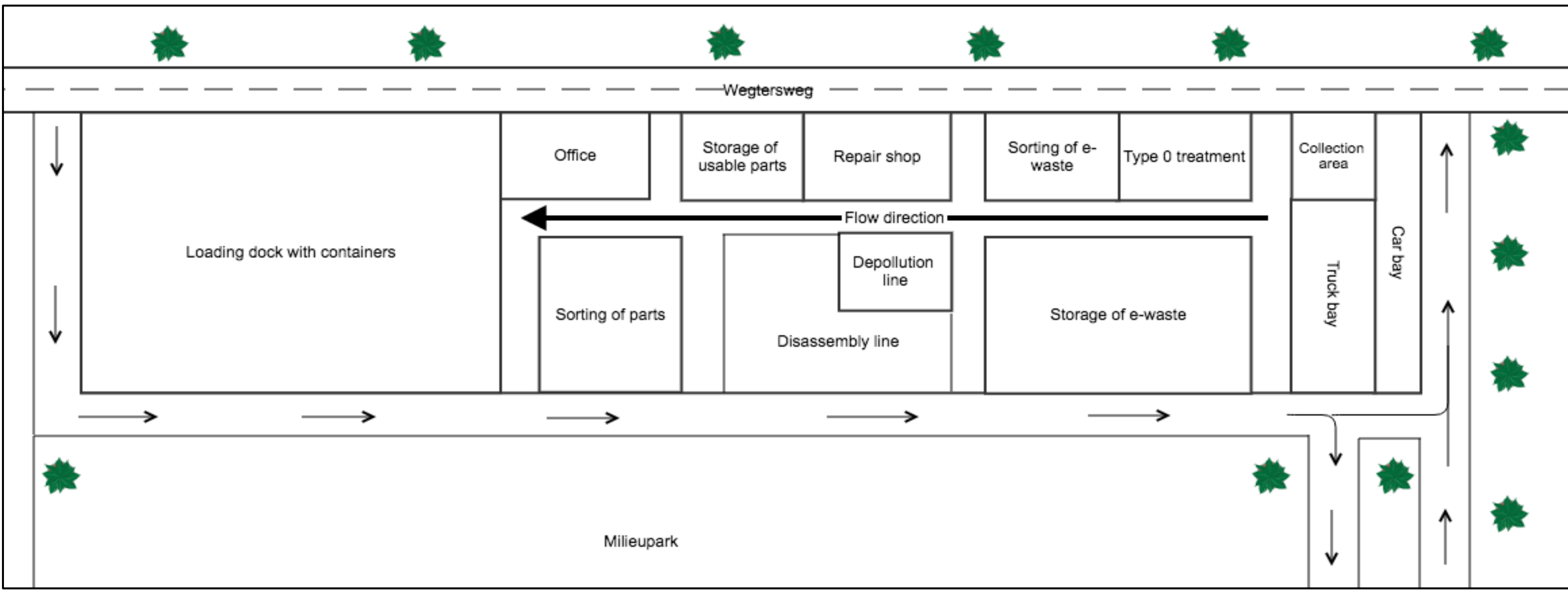

Figure B. Detailed layout summary

List of definitions

Concept	Definition
e-Waste	With e-waste the following types of waste are meant: batteries, ICT equipment, whitegood, browngood, electronic tools, fans, other electronics and cars
Lay-out	A layout is how the transforming resources of production process are positioned relative to each other and how its various tasks are allocated to these transforming resources.
Transformed resources	The input which is transformed to output by transforming resources
Transforming resources	Resources which transforms the input of the production process into output
Variety	The range of different products and services produced by a process
Volume	The level or rate of output from a process
Volunteers	Volunteers and people who have difficulties to participate in regular working processes

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1. Problem description

In this chapter, we will introduce the involved organizations and the problems they are facing. After this short introduction, the core problem will be chosen. This problem will be solved by using the Managerial Problem Solving Method (Heerkens & Winden, 2012).

1.1 Introduction

In the last century, the quality of life in the Netherlands has increased significantly. One of the causes of this phenomenon is the increase in wealth. People were able to spend more money and a lot of new products were introduced to the consumer market. (Riessen, Rovers, & Wilschut, 2008)

With this increase in wealth, a big problem arose: People started to generate more and more waste (Rijksoverheid, 2016). Waste was dumped without regulation and burned in remote places. This had a great impact on the environment. Therefore, several initiatives were developed to decrease the effect of waste disposal on the environment. One of these initiatives was to sort the waste and use more environmental friendly methods of waste disposal per type of waste. Currently, consumer waste is being divided into several subgroups, one of which is electronic waste (e-waste). Electronic waste consists, as the name already implies, of electronic products. According to Nederlandse Verwijdering Metaelektro Producten (NVMP) the following groups of e-waste exists: batteries, ICT equipment, whitegood, browngood, electronic tools, fans, other electronics and cars (Vereniging NVMP, 2012). In this report, we will take this definition of e-waste. E-waste is a special type of waste since it excels in its value due to the many metals and ground materials used in these products. This high value and the possible environmental consequences of processing these products encouraged the government to develop a program to recycle these products.

De Beurs and Twente Milieu are two examples of organizations that are involved in the processing of e-waste. Both organizations have a different focus; de Beurs is a recycling foundation, while Twente Milieu is company that is processing waste. De Beurs is a foundation, which has four different locations in Twente. The head office is in Oldenzaal; three smaller shops are located in Tubbergen, Denekamp and Losser. People can bring several types of recyclable waste to De Beurs for free. De Beurs will determine if the waste is recyclable or resalable. If this is not the case, the customers are redirected to Twente Milieu; there they can hand in their waste upon payment. Twente Milieu will process these kinds of waste. Besides this it is important to know that De Beurs is primarily working with volunteers; this includes volunteers and people who have difficulties to participate in regular working processes. De Beurs wants to offer these people work and guide them to the regular working market.

A flowchart of the processing of e-waste at De Beurs is represented in appendix A. People will bring their e-waste to De Beurs. Volunteers will check if the products still work, if this is the case the products will be cleaned, priced and sold in one of the shops. If the products do not function, one of the volunteers will check if it can be repaired easily. If this is the case then the product will be brought to the workplace to be repaired, afterwards it will be sold. If the product cannot be easily repaired, the product will be brought to the container. However, if the inflow of e-waste is too large, the volunteers will not check if the product is reparable easily: the product will be brought to the container. In contrast to De Beurs, Twente Milieu is not checking whether the electronic products are working or not. The consumers themselves sort all electronics +into big and small appliances. The flowchart of processing e-waste at Twente Milieu is given in appendix A. The containers of De Beurs and Twente Milieu are picked up weekly by Omrin and transported to Friesland for further recycling. Omrin pays organizations €90 per ton of e-waste.

The interests of de Beurs and Twente Milieu are comparable. The goal of the companies is to recycle waste in an environmental friendly way and keep work in the region Twente. Currently, these goals are not achieved. Firstly, the environmental goal is not achieved because most of the collected e-waste is not repaired and reused. Many of the electronic products in the container could be repaired and sold. Secondly, the employment goal is not achieved: The e-waste is transported to Omrin in Friesland and is not further processed in Twente. Opportunities are available for Twente Milieu and De Beurs to improve their recycling with respect to the environment and employment.

1.2 Problem cluster

The identified problems by the commissioning organizations are decreasing employability in Twente and losing value of e-waste. These two problems are caused by the fact that currently the processing of e-waste is outsourced to Omrin. Both companies do not sort, recycle or repair most of the e-waste in-house. This problem is caused by three different factors: a limited capacity of space at De Beurs, available space (2000 m^2) at Twente Milieu which is not used and a lack of knowledge about processing e-waste.

According to the managerial problem solving approach by Hans Heerkens (2012), one core problem should be solved. This core problem should meet the following requirements: it should not be caused by other problems, it should be solvable and it should be the most important problem in the problem cluster.

Three problems are identified which are not caused by other problems. The space capacity problem at De Beurs cannot be solved, since the maximum utilization of available space is already reached. We have to choose between the knowledge problems existing at the organizations or the lack of a production lay-out. We will focus this report on finding solutions for the lack of a production layout, since this problem involves the first step for processing e-waste at Twente Milieu. The lack of knowledge on e-waste disassembly should be addressed in a later stage. This problem cluster is shown in figure 1.

This results in the following norm and reality:

Reality: A production layout for the processing of e-waste does not exist for the available space at Twente Milieu.

Norm: A production layout for the processing of e-waste does exist for the available space at Twente Milieu.

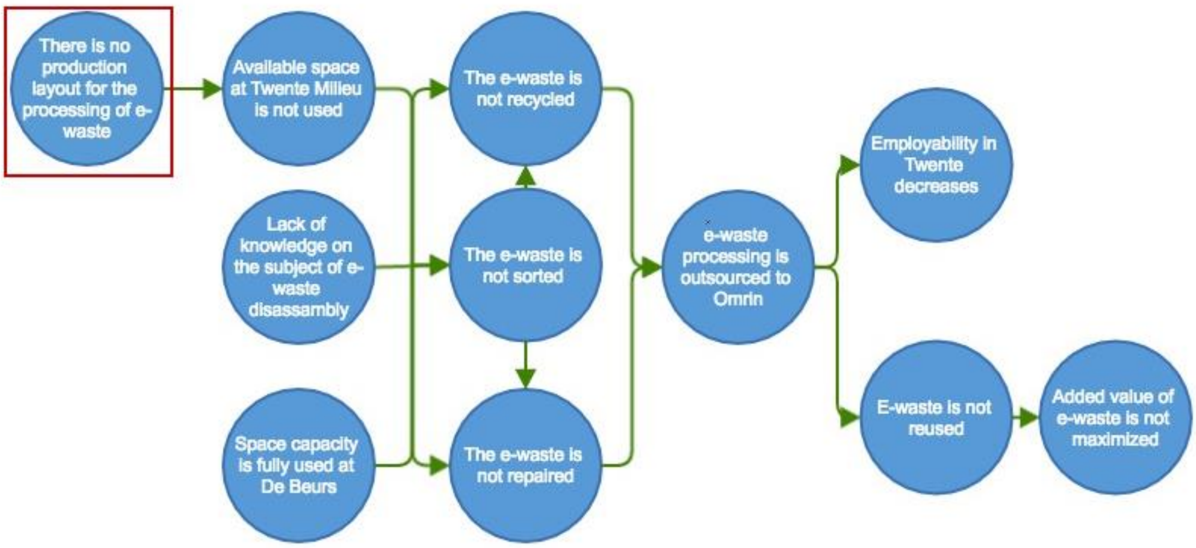

Figure 1. Problem cluster

1.3 Research question

The core problem mentioned in paragraph 1.2 leads to the following research question:
How should the layout of the 2000 m2 location at Twente Milieu look like to process e-waste by Twente Milieu and De Beurs?

We use the following definition of layout by Slack (2004): A layout is how the transforming resources of production process are positioned relative to each other and how its various tasks are allocated to these transforming resources. Transforming resources are resources which transforms the input into output. With transformed resources, we mean the input which is transformed to output by transforming resources.

1.4 Deliverable

We will design a detailed production layout for De Beurs and Twente Milieu. The detailed layout is meant to advise De Beurs and Twente Milieu how to utilize the available production area most efficient. By designing a detailed production layout, we will consider that the companies work with volunteers. This will lead to several restrictions where the layout should be adhered to. Besides this we will deliver design rules to the organizations, this will make sure that the production process can also be applied at different locations of Twente Milieu and De Beurs.

2. Problem approach

In this chapter, we will describe a problem approach for the chosen core problem. The problem approach contains a systematic method. After a description of the problem approach methodology, the reliability and validity of the chosen methodology will be discussed.

2.1 Problem approach methodology

To deliver a layout design to Twente Milieu and De Beurs, we have to take different steps. We will use the method described by Slack et al (2004). This method is represented in figure 1.

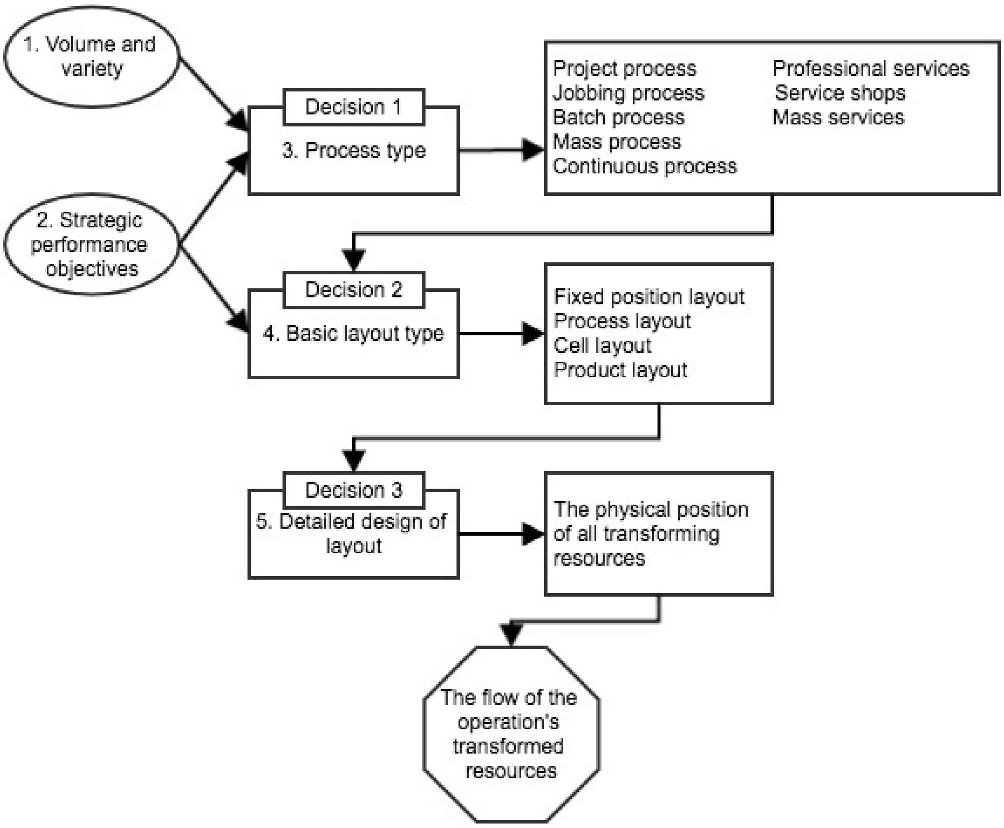

Figure 2. Problem approach (Slack, Chambers, & Johnston, 2004)

In most of the steps mentioned in the methodology of Slack et al. (2004) knowledge problems exists, these problems must be solved before we can accomplish these steps. To solve these knowledge problems, we have defined the following sub-questions in each of the steps:

1. Define volume and variety of the production process
    - What is meant with volume and variety?
    - How to measure volume and variety?
    - What types of e-waste should be included in the production process?
2. Define the strategic performance objectives of the production process
    - What are the requirements of the production process?
    - What are the constraints concerning the production process?
3. Select process type
    - What processes can be included in the production process?
    - What treatments of e-waste exists?
    - What process types exists?

4. Select the basic layout type
    - What is layout?
    - What basic layout types exists?
5. Design the detailed layout of the production process

2.2 Validity & Reliability

Reliability and validity are terms usually used in quantitative research. This report does not include quantitative research so we should translate these terms into terms that fit our research. Therefore, we will define the terms validity and reliability in this report as:

- The reliability is the scale in which the research method used is reliable in this specific situation.
- Validity is the degree in which the problem approach can be applied in this situation and in which degree the data correspondents with the real world

Reliability

The reliability of a source can be measured with the h-index. The h-index considers the number of publications of an author and its impact. From this score, we can derive how reliable the source is. The h-index scores of the authors of our problem approach are the following: Nigel slack 10, Robert Johnston 24, Alistair Brandon-Jones 7. All three authors are experts in the fields of operations management and production research. Therefore, it can be assumed that the problem approach, which is described in slack et al (2012), has a high reliability.

Validity

The problem approach in Slack et al. (2004) can be used to design manufacturing production processes. Manufacturing processes are processes in which input is transformed into output (transformed resources) by transforming resources. Twente Milieu and De Beurs want to repair and disassemble e-waste. These processes can be approached as manufacturing processes, because the input (e-waste) is transformed into output. In this case the output is second-hand electronics and disassembled e-waste.

In one of the steps of the problem approach we will determine the volume and variety to determine the appropriate production layout. The numbers representing the volumes of e-waste processed currently are measured by Twente Milieu and have a high reliability. The number of kilograms' e-waste processed is measured every month by Twente Milieu. The numbers obtained from representatives of De Beurs are less reliable because these numbers are estimates and are not derived from exact measurements. The information obtained concerning the variation of the processes and their inputs of De Beurs and Twente Milieu cannot be considered as reliable because the representatives from De Beurs and Twente Milieu do not know how much e-waste is collected of the e-waste categories. The organizations only provided data about which e-waste categories are collected.

3. Theory

In this chapter, each of the sub questions mentioned in the problem approach of chapter 2 will be answered; each paragraph is devoted to one of the five steps mentioned in the problem approach. Based on this theory, each of the steps of the method of Slack will be accomplished in chapter 4 Results.

3.1 Volume and Variety

To determine the degree of volume and variety of the collected e-waste, we have to find out what is meant with volume and variety and how these variables can be measured. These questions will be answered in this paragraph. Besides this, we have to determine which types of e-waste should be included in the production process. After this we can determine the degree of volume and variety in chapter 4.

3.1.1 Variables and operationalization

What is meant with volume and variety?

To determine what kind of layout type fits best for this production process we must determine the volume and the variety of the collected e-waste by Twente Milieu and De Beurs. In Slack and et al. the following definitions of volume and variety are described: volume is the level or rate of output from a process; variety is the range of different products and services produced by a process. Both variables are a key characteristic that determines process behavior. (Slack, Chambers, & Johnston, 2004). In this report, we will use the following definitions to determine the volume and variety of the production process:

- Volume: The amount of e-waste processed by Twente Milieu and De Beurs
- Variety: The variety of e-waste processed by Twente Milieu and De Beurs

How to measure volume and variety?

The variables volume and variety need to be operationalized to make sure these are measurable. The volume of the amount of e-waste processed by Twente Milieu and De Beurs can be measured in kilograms of e-waste brought in for processing each year. The variety can be measured by counting the number of different categories of e-waste processed each week. This leads to the following operationalization of the variables:

- Volume: The number of kilograms of e-waste collected yearly by De Beurs and Twente Milieu
- Variety: The number of different categories of e-waste processed by De Beurs and Twente Milieu

3.1.3 Types of e-waste

What types of e-waste should be included in the production process?

To determine the variety of the production process, we have to select the different types of e-waste which will be processed by Twente Milieu and De Beurs. According to the directive 2012/19/EU of The European Parliament and of The Council (2012) the following types of e-waste exists:

- Large households' appliances
- Small households' appliances
- IT and telecommunications equipment
- Consumer equipment and photovoltaic panels
- Lighting equipment
- Electrical and electronic tools
- Toys, leisure and sports equipment
- Medical devices
- Monitoring and control instruments
- Automatic dispensers

In appendix B the content of each of this category is listed.
Although e-waste might contain toxic materials such as cadmium, lead and mercury, it also contains scarce materials such as gold, copper and steel. Therefore, dismantling various types of e-waste is still profitable (Seager, Hieronymi, McIntrye, Guilcher, & Janse van Rensburg, 2012). Each of these categories consists of different components, which do have different positive and negative value. We will only include the e-waste types who do give a positive added value and do not have problematic fractions which may need incentive mechanisms. Using the paper of Seager et al (2012), we decided to include the following three types of e-waste: large households' appliances, small households' appliances and It and telecommunications equipment.

3.2 Strategic performance objectives

Before we can formulate the strategic performance objective of the new location at Twente Milieu, we must know the requirements and the constraints of the production process which is taking place at this location. In this paragraph the two sub-questions concerning the requirements and constraints will be answered.

3.2.1 Stakeholder analysis

What are the requirements of the production process?
To design a production layout for the processing of e-waste, the requirements for this production process need to be defined clearly. Stakeholders of this production layout do probably have different interest and therefore different requirements for the production layout. Logical trade-offs should be made if these interests contradict with each other. Therefore, we will do a stakeholder analysis to map the requirements of the different stakeholders, we will use the following definition of stakeholder: a stakeholder is any group or individual who can affect or is affected by the achievement of the organization's objectives (Freeman & Reed, 1983).

The identification of the stakeholders will be performed using the definitions and methods of Mitchell et al. (1997). Stakeholders can influence or be influenced directly or indirectly by the production process. Directly influencing/influenced stakeholders are stakeholders that have big influence or interests in the production process. Indirectly influencing/influenced stakeholders have smaller influence or interests in the production process. During the first step of the stakeholder analysis, the following stakeholder of the process were identified: Twente Milieu, De Beurs, Government & Municipalities, Employees, Households, Customers and Omrin. The positions of these stakeholders are mapped in figure 3. Explanation of the positions of the different stakeholder can be found in Appendix C.

These stakeholders do have different requirements of the objectives of the production process. The new production process needs to be designed in such a way that it will meet most of these requirements. Therefore, we must keep in mind that the requirements of the directly influenced/influencing stakeholders are more important than the requirements of the indirectly influenced/influencing stakeholders. In table 1 the requirements of the stakeholders are listed, beginning with the most important stakeholders following by the less important stakeholders. In our performance objectives, we will consider the stakeholder requirements.

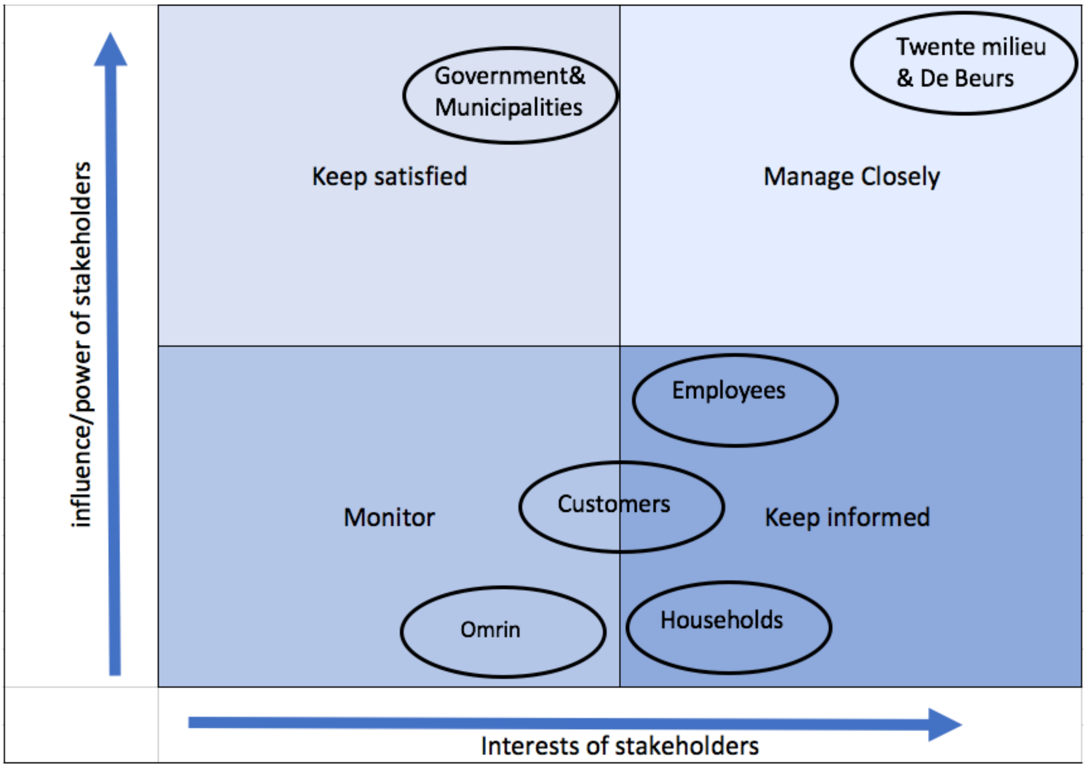

Figure 3. Stakeholder analysis

Table 1. Stakeholder requirements

Stakeholder	Requirements
Twente Milieu	- Breakeven (or make profit) - Keep the work in Twente - Sort and disassemble most of the e-waste
De Beurs	- Breakeven (or make profit) - Keep the work in Twente - Work with volunteers - Resell and repair most of the e-waste
Government and municipalities	- Keep the work in Twente - Process e-waste at an environmental friendly way
Employees	- Safe working condition - The opportunity to develop themselves
Households	- Bring in their e-waste close to their homes - Keep the work in Twente
Customers	- Cheap and good working second hand electronics
Omrin	- Gain profit from e-waste

3.2.2. Constraints

What are the constraints concerning the production process?

Before we can start designing the production process, we must know the constraints concerning this production process. Unfortunately, due some constraints not all production processes are possible in this specific situation. We identified two kinds of constraints: constraints formulated by the involved organizations and constraints identified by laws. In this paragraph these constraints will be listed.

The constraints identified by consulting the representatives of both Twente Milieu and De Beurs can be defined as follows:

1. Work should not be too complicated.
   The work that will be done through the production process must be kept simple because of the overall skill set of the work force. The work force in Twente Milieu and De Beurs that will be part of the production process is composed, in its majority, by social workers and volunteers. This means that big variations between skill sets of employees can occur. By keeping the work simple we can assure that most of the work force will be able to perform the tasks assigned.
2. Space limitations.
   The current space used for e-waste disposal and collection cannot be modified or changed. Therefore, the process will be moved to the free space in Twente Milieu, Hengelo. This space consists of open air area of around 100m by 20m a total of 2000m^2.

Other constraints were identified by consulting European and Dutch directives related to the disposal of e-waste. According to the European Parliament and the Council of the European Union (2012) and Weeeforum (2013) these constraints are defined as follows:

3. Hazardous components and substances.
   A minimum hazardous components and substances have to be removed from any collected e-waste. A list to this components and substances can be found in the European Directive 2012/19/EU. Some of this hazardous components and substances will require a special recycling treatment. Some if these components are: equipment with gases that are ozone depleting, cathode ray tubes, gas discharge lamps between others.
4. Re-use of equipment with hazardous materials.
   The preparation for re-use of equipment with hazardous material should be done according to the European Directive 2012/19/EU.
5. Disposal/ treatment of e-waste.
   Landfill and incineration of e-waste is prohibited.
6. Storage.
   The storage facility most have impermeable surfaces and waterproof surfaces.
   According to the WEELABEX standards the maximum stored e-waste cannot exceed the amount of e-waste that can be process within 6 months.
7. Standards.
   Any recycling operator in the Netherlands must comply with the WEELABEX standards. Apart from the WEELABEX standards they also must comply with the European standards WEE.
8. Workers.
   All workers at the treatment facility should be familiar with the environmental, health, and safety policy of the facility. Employees and contractors involved in the operations most be instructed and trained to perform the tasks assigned to them. For the training requirements refer to the WEELABEX standards 4.4.1-4.4.3.
9. Certification. Every e-waste recycling operator should be certified by the WEELABEX standards.
   After consulting a report of the European Environmental Agency (Crowe, et al., 2003) related to e-waste another set of constraints were found:
10. Collection infrastructure.
    The e-waste should be separated and collected according to the subsequent waste disposal treatment.
11. Dismantling and separation.

E-waste should be dismantled and separated to avoid large amounts of the e-waste to end up landfilled or incinerated.

3.3 Process types

In this chapter, we will describe the theory to choose the appropriate process type for the production process. Before we can select this process type, we must know which steps can be included in the production process, which types of treatments to include and what process types exist.

3.3.1 Steps in the production process

What processes can be included in the production process?

As mentioned in the literature, the production process of e-waste recycling consists of sorting, disassembling, repairing and further processing of the retrieved materials (Cui & Roven, 2011). The most important steps for this report, as mentioned by the representatives of Twente Milieu and De Beurs, are sorting, disassembling and repairing of e-waste. In this report a distinction is being made between the sorting and disassembling process, and the repairing process. The scope of the systematic literature review is limited to the process of sorting and disassembling e-waste. A process description of the systematic literature review can be found in appendix D.

Various existing disassembly line processes can be found in the literature. These processes can be divided in three different models (Opalić, Panić, & Vucković, 2004):

-Model 1: Single worker parallel operation without sorting.

Each worker independently receives a batch, then disassembles the unit and transports the full collection bins to the collection area. The batches are not sorted.

-Model 2: Single worker parallel operation with sorting.

The batches are sorted in a central location. The sorted batches are distributed to the different workstations. Here, a single worker disassembles the appliances. The full bins with parts are then transported to the collection area.

-Model 3: Single worker serie operation with sorting.

The batches are sorted in a central location. The sorted batches are distributed to the different workstations. Here, a single worker disassembles the appliances. The workstations are located adjacent to a conveyor belt (in serie). The disassembled parts are placed on a conveyor belt so they can be sorted at a central collection area.

Each model has its own disadvantages. The disadvantages of each disassembly line model can be found in the following table.

Table 2. Disadvantages of disassembly line types

Disassembly line	Disadvantages
Model 1	• Workers use the majority of the time to transport the products and parts rather than disassembling products. This may require larger storage places between batches. • Workers are lifting and placing all products that have to be disassembled.
Model 2	• Workers use much time to transport the parts to the central collection area. • Workers are lifting and placing all products that have to be disassembled
Model 3	• The conveyor belt carries mixed parts. These parts have to be sorted at a central location at the end of the conveyor belt.

	• The worker who sorts the parts at the end of the conveyor may get overloaded due to the high variety and high load of parts.

As mentioned above, not all disassembly processes include prior sorting of the e-waste. When sorting of the e-waste is present in the production process, two options are available: Manual sorting or mechanical sorting. Manually sorting of e-waste is reported to be the most efficient since e-waste is generally a heterogeneous stream (Opalić, Kljajin, & Vučković, 2010). Though, manual sorting can cause some health risks when the workers are not properly protected. New innovations in sorting technologies could minimize these risks. (Taghavi, Barletta, & Berlin, 2015). An overview of the advantages and disadvantages of manual and mechanical sorting can be found in table 3.

Table 3. Advantages and disadvantages of manual and mechanical sorting

	Advantages	Disadvantages
Manual sorting	• High flexibility of the production process	• Low throughput of products • Health risks are present if employees are not properly protected
Mechanical sorting	• High throughput of products • Reduces health risks for employees	• Employees have to be trained to operate the complex machine • Reduces employability • Requires a big initial investment • Low flexibility of the production process

3.3.2 Treatment types

What treatments of e-waste exists?

Due to the presence of hazardous and toxic materials in some e-waste different types of treatments were developed for the disposal of electronic and electrical waste by WEEELABEX (Weeeforum, 2013). To make a design of the production layout, we have to determine which types of treatments will be conducted by De Beurs and Twente Milieu. These different treatments types can be defined as follows:

1. Type 0: Manual cannibalization of appliances (no depollution)
2. Type 1: Manual dismantling, including all or some depollution.
3. Type 2: Mechanical treatment (pre-treatment and intermediate treatment), including some or all depollution (where indicated).
4. Type 3: Advanced mechanical treatment, including some or all depollution (where indicated).
5. Type 4: End-processing (pure fractions), or incineration / energy from waste facilities.

Type 0 treatment is the simplest disposal treatment and type 4 being the end of the line treatment in which complete disposal of the e-waste is achieved. Type 0 and type 1 treatment are manual treatments and the other types of treatment require mechanical treatment.

An operator which performs a type 0 treatment is the one who only manually removes the ferrous metal, motors and cables. No depollution is performed by this type of operators. Meaning that this type of treatment does not involve any hazardous substances or materials allowing the operator to keep the work relatively simple. Also, an operator which performs type 0 treatment it is not eligible for WEELABEX certification. In the case of the type 1 the operator performs a complete dismantling of the e-waste. For a type 1 treatment the WEELABEX certification is recommended, but still not mandatory. For type 2, 3 and 4, mechanical treatments of e-waste are needed and some hazardous and toxic materials will be released. For type 2, 3 and 4 a WEELABEX certification is mandatory. Due to the complexity of these treatments types, we will not describe these types in detail.

3.3.3 Kind of process types

Which process types exist?

According to, the method of Slack et al. (2004), it is important to identify the process type of the production process, this will help in designing the appropriate production layout. Therefore, we will describe these different kinds of process types identified by Slack et al.

Each of these process types differ from variety, volume, process flow (intermittent to continuous) and diversity of process tasks. In figure 4 the positions of these process types with respect to variety and volume is represented. The characteristics of these different types of processes will be described in this paragraph.

Project processes have low volume and high variety, and deal with discrete, usually highly customized products. Often the timescale between the completion of an item is relatively long. Each job has a well-defined start and finish. Each project has resources devoted exclusively to it.

Jobbing processes also deals with high variety and low volumes. However, in jobbing processes each product shares the operation's resources with some other processes. Jobbing processes usually produces physically smaller products and, although sometimes require considerable skills. Many jobs will be 'one-offs' that are never repeated.

Batch processes may look a bit like jobbing processes, but do not have the same degree of variety. Each time a batch process produces; it produces more than one item at a time. The batch type of process can be found over a wide range of volume and variety level because there can be a big difference in the size of one batch.

Mass processes are those which produce items in high volume and relatively low variety. The activities of mass processes are usually repetitive and largely predictable. An example of a mass process is the production of DVD's.

Continuous processes have an even higher volume and lower variety than mass processes. They also operate for longer periods of time usually. Sometimes they are literally continuous in that their products are inseparable; they are being produced in an endless flow. They often have relatively inflexible and capital-intensive technologies with a highly predictable flow.

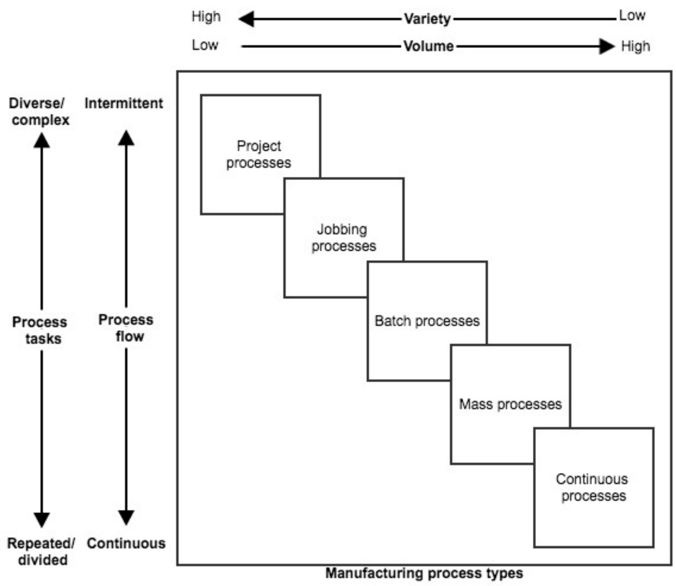

Figure 4. Theoretical framework (Slack, Chambers, & Johnston, 2004)

3.4 Basic layout types

Besides the five process types mentioned in paragraph 3.3.2, Slack et al (2004) identified different types of layouts. Each type of layout is, just as the different process types, based on the degree of volume and variety of the production process. According to slack et al. (2004) four different types of layout exist, ordered from low volume and high variety to high volume and low variety: fixed-position layout, functional lay-out, cell-layout and product layout. The production layout describes the relative position of transforming and transformed resources to each other. In this paragraph, each of these layout types will be described.

In the **fixed position layout,** the transformed resources do not move between the transforming resources. Instead of materials, information or customers flowing through the operation, the receipt of the processing is stationary and the equipment, machinery, plant and people move as necessary.

In the **functional layout,** similar transforming resources and processes are located together because it is convenient to group them together. When transformed resources flow through the operation, they will take a route from activity to activity according to their needs.

In the **cell layout** transformed resources entering the operation are pre-selected to move to one part of the operation (cell) where all needed transforming resources are available and located. After being processed in one cell the transformed resources may go on to another cell when necessary.

The **product layout** is designed so that the transforming resources are located so that it is most convenient for the transformed resources. Each product, each piece of information or customer follows a prearranged route in which the sequence of activities that are required matches the sequence in which the process have been located. The transformed resources flow along a line of processes.

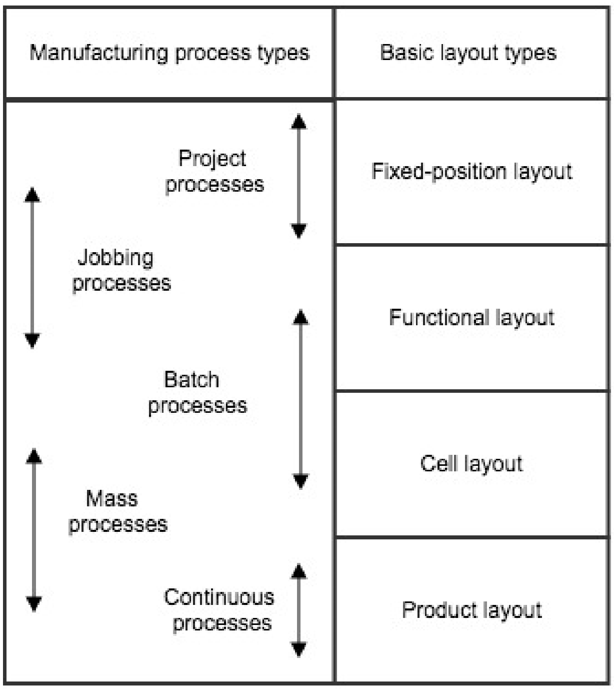

Figure 5. Relationship between process types and basic layout types (Slack, Chambers, & Johnston, 2004)

4. Results

In this chapter, the results of each of the steps of the problem approach will be presented. Each paragraph is devoted to one of the steps of the problem approach. These results are based on the theory described in chapter 3.

4.1 Volume and Variety

In this paragraph the volume and the degree of variety of the collected e-waste will be determined. We use the variables mentioned in paragraph 3.1 to determine to volume and variety. This data is provided by the representatives of Twente Milieu and De Beurs. In table 2 the number of kilograms of collected e-waste by Twente Milieu and De Beurs in 2015 is shown. Based on this date we can state that the volume of processed e-waste is moderate.

As mentioned in the theory, we will include the following three categories in the processing of e-waste: large households' appliances, small households appliances and It and telecommunications equipment. Since we include only a couple categories of e-waste, we could state that the variety of the production process is low. However, De Beurs and Twente Milieu are working with volunteers. These people have different skills; therefore the production process must be adapted to the level of skills of the volunteer. This will increase the variety of the production process, therefore the variety of the production process will, such as the volume, be determined as moderate.

Volume

Table 4. Amount of e-waste collected by twente Milieu and De Beurs in 2015

Location	Amount e-waste collected 2015 (kg)
Twente Milieu	
- Almelo	236.760
- Enschede Oost	50.720
- Enschede West	129.240
- Enschede Zuid	233.380
- Hengelo	427.520
- Oldenzaal	204.700
Total Twente milieu	**1.282.320**
De Beurs	
- Oldenzaal	250.000
- Denekamp	100.000
- Tubbergen	0
- Losser	0
Total De Beurs	**350.000**
Total	**1.632.320**

4.2 Strategic performance objectives

Based on the requirements and constraint formulated by De Beurs and Twente Milieu, we have defined the following strategic performance objective:

The production layout should enable De Beurs and Twente Milieu to obtain as much value as possible from the e-waste by disassembling, repairing or reselling of the collected e-waste. In case the e-waste is not repairable, it should be disassembled. The usable parts should be sorted and stored in inventory, so these can *be used for other repairs. Non-usable parts and the e-waste that consists of no usable parts at all should be transported to Omrin where it will be recycled. De Beurs and Twente Milieu should negotiate with Omrin about the products they will bring in.*

With this goal, we make sure that most of the e-waste is resold, repaired, sorted or disassembled. This location will create jobs in Twente for volunteers and probabilities for payed labours. The lay-out should be designed in such a way it is safe for the workers. In this project, we will not focus on the fact that Twente Milieu and De Beurs want to go for a financial breakeven, we do not have enough data to compile a cost-effectiveness study.

4.3 Process type

In this paragraph, we will describe which steps will be included in the production process, which treatment types will be conducted by Twente Milieu and De Beurs and what kind of process types fits best for this production process.

4.3.1 Production process

Since employability is one of the most important requirements of De Beurs and Twente Milieu, we chose to incorporate manual sorting in our production process., this will ensure a higher employability than mechanical sorting. Also, as found during the systematic literature review, manual sorting is the most efficient method in such a heterogeneous stream as e-waste. During the manual sorting, the workers may be exposed to some health risks. Therefore, we should pay extra attention to the protection of the volunteers of De Beurs while designing the production process layout. For our process, we would recommend to incorporate a model 3 disassembly line, this will minimize the amount of lifting for the workers. The description of this model can be found in paragraph 3.3.1.

Besides this, we should determine which type of e-waste treatments should take place in this disassembly line. We have to take in account two different constraints: the work should be kept simple for the volunteers and the number of hazardous components and substances removed from the e-waste should be minimized. To satisfy these two constraints, we decided to focus the disassembly line on treatment type 0 and 1. The production process should focus just on dismantling the e-waste. The description of these treatments types can be found in paragraph 3.3.2.

Another import requirement of De Beurs and Twente Milieu is the environmental impact. As mentioned before, De Beurs already repairs some of its incoming e-waste, though due to space limitations this process is not optimized. We therefore wanted increase the amount of e-waste that is repaired by assigning a bigger area for repairs in the new production process. This bigger area will be located at the new facility.

The proposed decisions above have some impact on the current production processes of De Beurs and Twente Milieu. The two organizations will have to increase their collaboration and some of the processes will be moved to another location. An overview of the new production process with all the incorporated adjustments mentioned above can be found in figure 6. In the figure, it is clear that the majority of the production process will be executed at the new location.

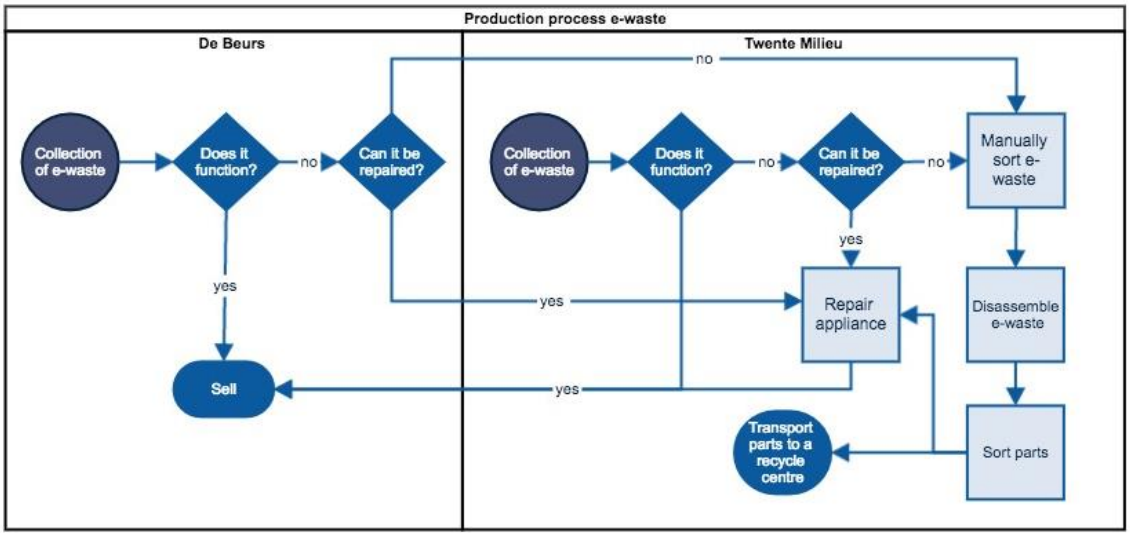

Figure 6. Production process e-waste

4.3.2 Selection of the process type

The selection of the process types is based on the theoretical framework provided by slack et al. (2004). This theoretical framework can be found in figure 4. Two key variables to determine the process type are the volume and variety of the product that is being processed. As determined in paragraph 4.1, the volume and variety of the processed products are moderate. According to these findings we believe that the process described by us in the report is either a Jobbing process or a Batch process. Diversity/ complexity is also a variable to determine the process type. Because De Beurs and Twente Milieu deploys a high variability of employees, the complexity of the production process increases. This makes it harder to determine the degree of complexity of process tasks and the choice between a Jobbing process and a Batch process. Therefore, we believe that the production process can be considered as a Jobbing process as well as a Batch process.

4.4 Layout type

For each of the different layout types described in paragraph 3.4 a different detailed design fits best. This depends on the volume and variety of the production process. In this paragraph, we will chose a layout type which fits best for this production process.

As mentioned in the previous paragraph, the production process can be approach as a Jobbing process as well as a Batch process. This is determined based on the moderate volume and variety of the e-waste processed at De Beurs and Twente Milieu. According to figure 5 a functional layout will be most appropriate in this situation. In the functional layout, similar transforming resources and processes are located together. Transformed resources flow through the operation, they will take a route trough the transforming resources according to their needs.

4.5 Detailed layout

Design rules should be constructed in order to design a functional layout. These design rules form the foundation of the layout and need to be incorporated to fulfil all the decisions made based on the theory. Two very important objectives of a good layout design is minimizing the length of flow through an operation and making the flow clear (Slack, Chambers, & Johnston, 2004).

We developed the following general design rules:

- The flow should of the process should be in the following order: 1 collecting – 2 sorting – 3 disassembling/repairing – 4 sorting of parts – 5 transportation.

This design rule is based on the theory of the process. In the literature, the steps of a recycling process were clearly defined and in which order they should be performed. Applying the theory to our process gave the order of steps above.

- The repair area and the storage for repair should be close together.

Placing these areas together will minimize the amount of transporting time and the length of the flow.

- The loading dock should have separate containers for the different types of waste.

After dismantling the resulting waste should be sorted and separated according to the subsequent waste disposal treatment.

- Type 0 treatment should be the first step in the disassembly layout.

There is no sorting needed in advance to execute this treatment and the treatment should be applied to every piece of e-waste, therefore it is logical to perform the type 0 treatment as a first step in the disassembly process.

-The sorting area of e-waste and the storage area of e-waste should be close together.

Placing the sorting and storing area close together will minimize the transportation time and the length of the flow.

-The width of an aisle between two work areas should be a minimum of 250cm; just wider than two times the dimensions of a euro pellet, which is 80cm x 120cm.

- In case a collection point will be present at the new location: Car and truck bay should be next to each other.

By placing both bays together all the input of e-waste will come from the same direction, which will minimize the length of flow of products.

- In case hazardous e-waste like refrigerators and TV's will be processed: Both a disassembly and depollution area should be present.

As found in the literature, processing small and big appliances has the highest added value without complicating the production process. Though, as stated in literature, hazardous material should be removed from any collected e-waste. Therefore, a depollution area should also be present in the layout.

We chose to apply the design rules to the available space at location of Twente Milieu in Hengelo. This layout can be found in figure 7.

The first step in the process is the collection of e-waste. This part consists of two inputs: the input from De Beurs, which is delivered by a truck in the truck bay and consumers that bring the e-waste to Twente Milieu. During the collection of e-waste from the visitors of Twente Milieu, a function check will be performed. The products that still function will be transported to a container in the loading docks. The products that can be repaired are transported to the repair shop.

After the collection, the e-waste is manually sorted into the different e-waste types. E-waste types that will not be disassembled will be collected in a container in the loading dock so these can be directly transported to Omrin.

In the storage area of e-waste, the different usable e-waste types will be stored separately until there is enough of one type of e-waste to disassemble a whole batch. Cooling systems and TV's will need to be depolluted and disassembled in the depollution area, so the health risks for the employees are minimized. All other non-toxic appliances will go through the disassembly area. As mentioned before, we recommend implementing a model 3 disassembly line. More information on the different disassembly models can be found in paragraph 3.3.1.

After the disassembly, all the different parts are sorted. Parts that can be used during the repair process are transported to the storage of area of the repair shop. All other parts are transported to their designated container in the loading dock.

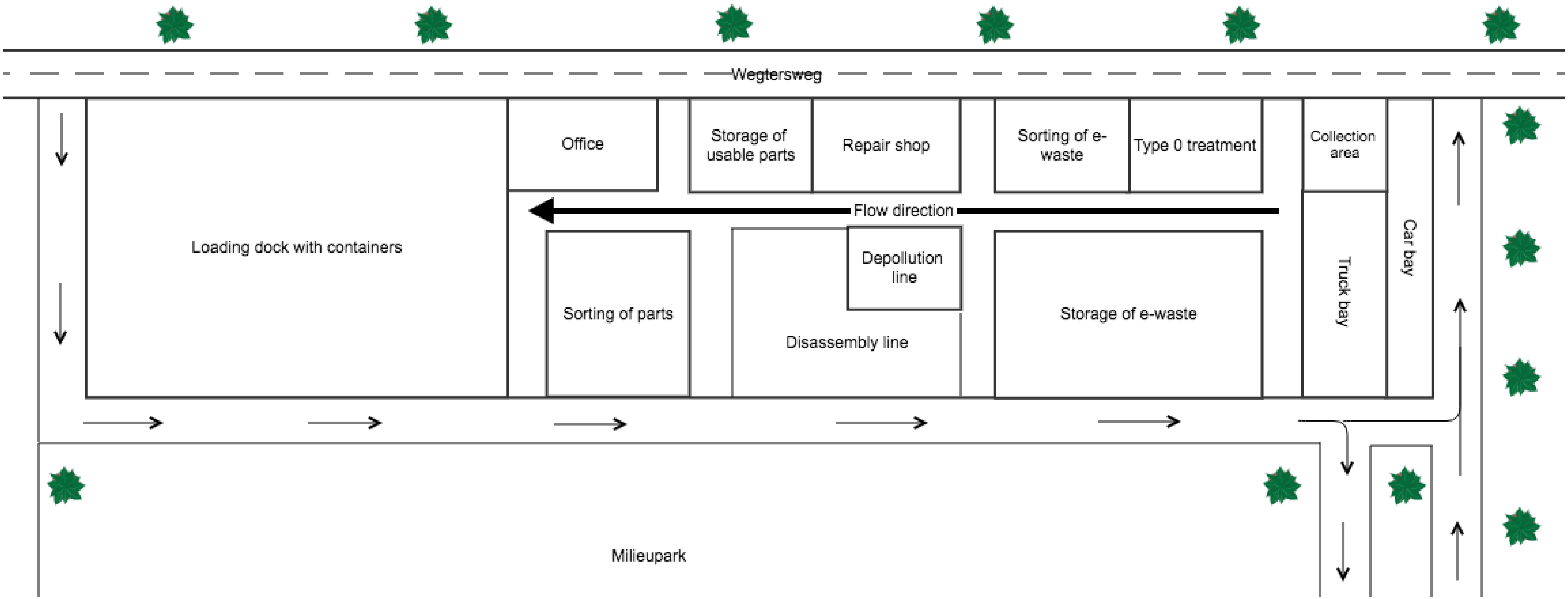

Figure 7. Detailed layout location Twente Milieu Hengelo

5. Implementation

The sixth phase of the managerial problem solving method consists of the solution implementation. In this paragraph, we will describe what incorporates this phase. The actual implementing and evaluating should be performed in a later stage (seventh phase of the MPSM), with as responsible persons the directors of De Beurs and Twente Milieu.

Before the proposed layout can be implemented at Twente Milieu and De Beurs, the boards of directors should be convinced by this layout and the boards will have to find agreement about their collaboration. The proposed layout requires a significant investment: a building must be built, equipment must be purchased, volunteers need training, transportation networks should be set up. This will cost both organizations a significant amount of effort, time and money. Therefore, we recommend both organizations to collaborate and gain more information about the consequences for both organizations.

Firstly, the organizations should perform a cost benefit analysis to determine if this proposed layout is beneficiary for both organizations. If the proposed production process and layout appears to be beneficiary, the organizations should consider whether they have the capacity to carry out the proposed lay-out. If both organizations can reach the required level of capacity, the organizations can develop an implementation plan and implement the proposed layout.

Due to some research limitations, this proposed layout is not ready to be implemented yet. It is a basis for both organization to further investigate the possibilities about the processing of e-waste in-house. Due to these uncertainties, constructing an implementation plan for the proposed layout is premature.

6. Research limitations

The focus of this qualitative research was to develop a detailed layout for the disassembly of e-waste. We had to make some assumptions during this research, which leads to some research limitations. These limitations will be described in this chapter.

Firstly, we did not take in consideration the amounts of each category of e-waste coming in at the new location at Twente Milieu. Besides this, we did not collect any data about the work rate of the volunteers. Therefore, we do not know the time needed to process the collected e-waste, the amount volunteers needed and the appropriate size of the location for this situation. Twente Milieu and De Beurs have to conduct further research to determine these quantitative variables and decide whether the size of the current layout is appropriate or not. We have minimized the effect of this limitation by creating design rules which can be applied in each possible location.

Secondly, we did not conduct a cost-benefit analysis. Therefore, we do not know if the profit gained from the e-waste will be sufficient to cover the costs of the investments, materials and employers. We do not know if it is beneficiary to do the processing of e-waste in-house. As mentioned in the previous chapter, Twente Milieu and De Beurs should conduct a cost-benefit analysis before they decide whether to process the e-waste in-house or not.

In the end, we assumed that the volunteers are able to repair, sort and dismantle the e-waste. We do not have any insights in the skills of the volunteers and their ability to learn new skills. Twente Milieu and De Beurs should assess for each volunteer which tasks they can perform based on their skills and ability to learn new skills. Thereafter, the organizations can decide if it is possible to do the repairing, sorting and dismantling in-house.

7. Conclusion

7.1 Conclusions

This research has focused on identifying the core problem of not having an efficient layout and giving a solution by designing a new line process flow and an efficient detailed layout. In this section, we mention the conclusions of this research.

We concluded that the core problem arises from the full capacity of space at De Beurs. Also, from the lack of knowledge on e-waste disassembling, which leads to outsourced this process. Hence, the employability in Twente decreases.

Considering the volume and variety of e-waste that De Beurs collects, a solution to this problem would be opening a new location to process the e-waste in-house. This, new location should have a form of a functional layout type to process discarded appliances through a batch or jobbing process.

Nowadays, disassembling e-waste still profitable, however some appliances or devices are more valuable than others. Therefore, we concluded that De Beurs should focus on large appliances, small appliances and It and telecommunications equipment.

Finally, the types of e-waste treatments, from treatments Type 0, Type 1, Type 2 and Type 3 De Beurs currently performance only type 0, meaning that there is an area of improvement for the organization.

7.2 Recommendations

From the findings in the report, we would list the following recommendations:

- In order to implement the layout, it is very important that the organizations should perform a cost benefit analysis first to determine if the proposed layout is beneficiary.
- To maximize the efficiency of the detailed layout it is important to carry out the tasks in the order explained in chapter 4.5.
- To ensure a higher employability it is important to use manual sorting instead of mechanical sorting, it is also more efficient because e-waste is a heterogeneous stream.
- Because of the use of volunteers and the number of hazardous components and substances removed from the e-waste it is best to focus the disassembly line on treatment type 0 and 1. However, volunteers need to be continuously trained in order to perform treatment type 1.
- From the 1st of July 2015, for treating e-waste in the Netherlands, it is mandatory to comply with the WEEELABEX standards. Hence, De Beurs should apply for the WEEELABEX certification type 1.

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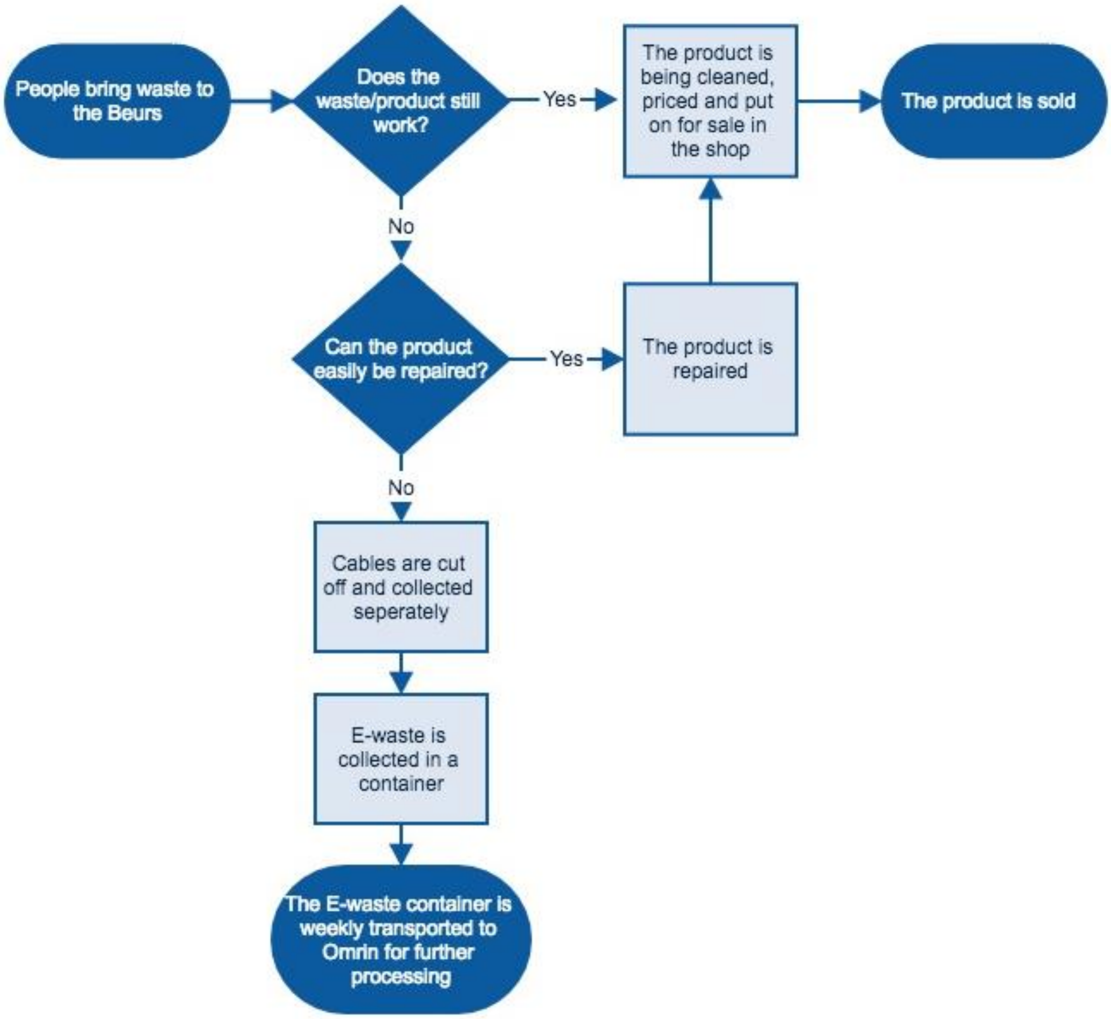
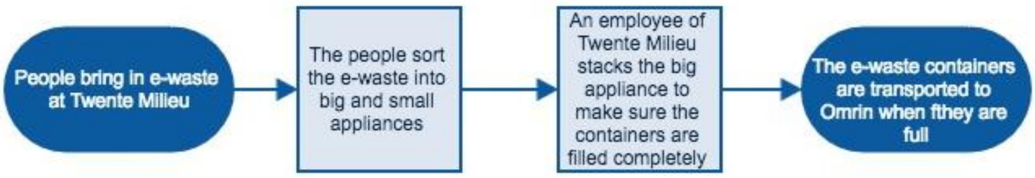
Appendix A: Current processes of Twente Milieu and De Beurs

De Beurs



Twente Milieu



Appendix B: Categories of e-waste

According to the Directive 2012/19/EU, the electronic waste is divided into the following categories:

Categories	Appliances and devices
Large Household appliances:	Large cooling appliances Refrigerators Freezers Other large appliances used for refrigeration, conservation and storage of food Washing machines Clothes dryers Dish washing machines Cookers Electric stoves Electric hot plates Microwaves Other large appliances used for cooking and other processing of food Electric heating appliances Electric radiators Other large appliances for heating rooms, beds, seating furniture Electric fans Air conditioner appliances Other fanning, exhaust ventilation and conditioning equipment
Small Household appliances:	Vacuum cleaners Carpet sweepers Other appliances for cleaning Appliances used for sewing, knitting, weaving and other processing for textiles Irons and other appliances for ironing, mangling and other care of clothing Toasters Fryers Grinders, coffee machines and equipment for opening or sealing containers or packages Electric knives Appliances for hair cutting, hair drying, tooth brushing, shaving, massage and other body care appliances Clocks, watches and equipment for the purpose of measuring, indicating or registering time Scales

IT and Telecommunications Equipment	Centralized data processing: Mainframes, minicomputers and printer units Personal computing: Personal computers (CPU, mouse, screen and keyboard included), laptop computers (CPU, mouse, screen and keyboard included) notebook computers and notepad computers Printers Copying equipment Electrical and electronic typewriters Pocket and desk calculators and other products and equipment for the collection, storage, processing, presentation or communication of information by electronic means User terminals and systems Facsimile machine (fax) Telex Telephones Pay telephones Cordless telephones Cellular telephones Answering systems and other products or equipment of transmitting sound, images or other information by telecommunications
Consumer equipment and Photovoltaic panels	Radio sets Television sets Video cameras Video recorders Hi-fi recorders Audio amplifiers Musical instruments and other products or equipment for the purpose of recording or reproducing sound or images, including signals or other technologies for the distribution of sound and image than by telecommunications Photovoltaic panels
Lighting Equipment	Luminaires for fluorescent lamps with the exception of luminaires in households Straight fluorescent lamps Compact fluorescent lamps High intensity discharge lamps, including pressure sodium lamps and metal halide lamps Low pressure sodium lamps Other lighting or equipment for the purpose of spreading or controlling light with the exception of

	filament bulbs
Electrical and Electronic tools (with the exception of large-scale stationary industry tools)	Drills Saws Sewing machines Equipment for turning, milling, sanding, grinding, sawing, cutting, shearing, drilling, making holes, punching, folding, bending or similar processing of wood, metal and other materials Tools for riveting, nailing or screwing or removing rivets, nails, screws or similar uses Tools for welding, soldering or similar use Equipment for spraying, spreading, dispersing or other treatment of liquid or gaseous substances by other means Tools for mowing or other gardening activities
Toys, leisure and sport equipment's	Electric trains or car racing sets Hand-held video game consoles Video games Computers for biking, diving, running, rowing, etc. Sports equipment with electric or electronic components Coin slot machines
Medical devices (with the exception of all implanted and infected products)	Radiotherapy equipment Cardiology equipment Dialysis equipment Pulmonary ventilators Nuclear medicine equipment Laboratory equipment for in vitro diagnosis Analyzers Freezers Fertilization tests Other appliances for detecting, preventing, monitoring, treating, alleviating illness, injury or disability
Monitoring and control instruments	Smoke detector Heating regulators Thermostats Measuring, weighing or adjusting appliances for household or as laboratory equipment Other monitoring and control instruments used in industrial installations (e.g. in control panels)
Automatic dispensers	Automatic dispensers for hot drinks Automatic dispensers for hot or cold bottles or cans Automatic dispensers for solid products Automatic dispensers

	for money All appliances which deliver automatically all kinds of products

Appendix C: Explanation of the stakeholder analysis

Twente Milieu & De Beurs

Twente Milieu and De Beurs will be the most influential of all the stakeholders because they are the owners of the project and the new production process will be implemented at the site of Twente Milieu Hengelo. Twente Milieu and De Beurs have influence on budget, workers assigned to the e-waste and the final decision of the optimal solution.

Government & Municipalities

The production process influences the municipality since it will most probably deliver new job opportunities in the municipality. The government mostly influences the product process by existing laws on waste disposal and recycling.

All employees Twente Milieu and De Beurs

The production process influences all the employees of Twente Milieu and De Beurs. Some of them will have to work at a different location or have to perform different tasks than what they currently have to do. The influence of the employees on the production process is moderate since the lack of specialized skills brings a constraint on the tasks that can be performed during the production process.

Households

The households are both suppliers of the production process. The e-waste collected of the households serves as input of the production process. The behaviour of the households, related to the disposal of e-waste, can affect the production process. Though their behaviour is assumed not to decrease, since the amount of e-waste per person is still increasing.

Omrin

Omrin is influenced by the production process but has little influence on it. The production process takes over some of the tasks that are currently performed by Omrin. Though Twente Milieu and De Beurs aren't the only providers of e-waste, therefore the interest of Omrin is moderate.

Customers

Customers have a reasonable interest in the production process because if more things are repaired, more items will be available for sale, increasing the supply. Though the influence on the production process is not that high. They buy some of the output of the production process, but this output will still be a small fraction of the total output.

Appendix D: Systematic Literature Review

We performed a systematic literature review using the following steps:

1. Define key terms and in- and exclusion criteria
2. Define synonyms of the key terms
3. Define search strings
4. Combine the search strings
5. Asses the title and abstract based on in- and exclusion criteria
6. Read the usable papers and judge on usability
7. Use the sources to draw conclusions

We defined the key terms by dissecting the following research question:

What is most appropriate production process for the disassembling of e-waste given our restrictions?

The key terms, synonyms, search strings and combinations can be found in table 3.

Table 3: Search strategy

#	Key terms	Synonyms	Search strings	Date of Search	SCOPUS Hits
1	Disassembling	Take apart, disassemble ,Separate, Sorting	TITLE-ABS-KEY(Disassembl* OR "Take apart" OR Separate OR Sort OR Sorting)	22-dec-16	696, 016
2	E-waste	Consumer electronics, Electronic waste, Electric waste	TITLE-ABS-KEY(E-waste OR Consumer electronics OR "Electroni* waste" OR "Waste electrical and electronic equipment" OR WEEE)	22-dec-16	20,618
3	Design	Modelling, Build	TITLE-ABS-KEY(Design OR Model* OR Build)	22-dec-16	13,314,677
4	Layout	Blueprint, Map, Floorplan	TITLE-ABS-KEY(Layout OR Blueprint OR map OR Floorplan)	22-dec-16	816,436
5	1&2&3&4		TITLE-ABS-KEY((Disassembl* OR "Take apart" OR Separate OR Sort OR Sorting OR Recycle OR Repair) AND (E-waste OR Consumer electronics OR "Electroni* waste" OR "Waste electrical and electronic equipment" OR WEEE) AND (Design OR Model* OR Build) AND (Layout OR Blueprint OR map OR Floorplan))	22-dec-16	12
6	1&2&4		TITLE-ABS-KEY((Disassembl* OR "Take apart" OR Separate OR Sort OR Sorting) AND (E-waste OR Consumer electronics OR "Electroni* waste" OR "Waste electrical and electronic equipment" OR WEEE) AND (Layout OR Blueprint OR map OR Floorplan))	22-dec-16	16

7	1&2		TITLE-ABS-KEY((E-waste OR Consumer electronics OR "Electroni* waste" OR "Waste electrical and electronic equipment" OR WEEE) AND (Layout OR Blueprint OR map OR Floorplan))	22-dec-16	377

The initial search resulted in 377 hits. All the sources were evaluated based on our in- and exclusion criteria after the initial search. These criteria can be found in table 4. The assessment based on the criteria eliminated 334 articles, leaving 43 articles to be further examined. The remaining 43 articles were then assessed on the correlation of the abstract to our scope. After this assessment 15 articles were left. The remaining articles were fully assessed on content; this eliminated 10 articles leaving 5 which were used for our research. The process of elimination of articles can be found in figure 7. Key findings of the used articles can be found in table 5.

Table 4: In and Exclusion criteria

Number	Exclusion criteria	Reason for exclusion
1	"e-waste" or a synonym is not mentioned in the abstract	The scope of the research is restricted to the processing of e-waste
2	"Disassembl*" or a synonym is not mentioned in the abstract	The Scope of the research is restricted to the disassembly of e-waste
	Inclusion criteria	**Reason for inclusion**
1	Articles reporting on the recycling of e-waste	Most of the time the first step of recycling consists of the disassembly of the products.
2	Publication language: English or Dutch	The researchers are fluent in these two languages. Articles in other languages cannot be analysed.

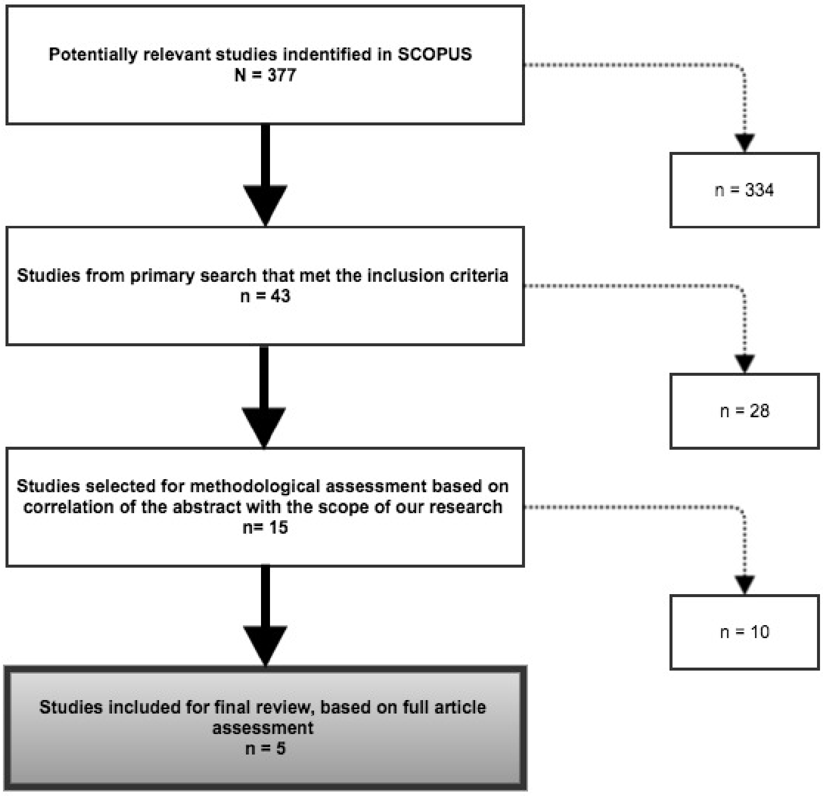


Figure 7: Selection of articles

Table 5: Concept matrix

Journal	Authors	H-Index	Year of publication	Methodology	Key findings regarding the disassembly of e-waste
IFIP Advances in Information and Communication Technology	Taghavi N., Barletta I., Berlin C.,	22	2015	Literature study, Non-structured and semi-structured interviews	Manual sorting of e-waste is an efficient method and can cause some health risks when the operators are not properly protected. New sorting technologies could lower the health risks, though it has some implication for the social sustainability: Some manual work will disappear and employees should be educated and trained in the use of these technologies.
Procedia CIRP	Barletta I., Johansson B., Reimers J., Stahre J., Berlin C.,	15	2015	Literature study, Non-structured and semi-structured interviews	In order to design a sustainable disassembly plant in the supply chain of e-waste, the prerequisites covered in the article should be addressed in advance.
Strojarstvo	Opalić, M., Kljajin, M., Vučković, K.	8	2010	Literature study	Manual disassembly is the most efficient method for a heterogeneous waste stream like that of e-waste. Layout changes in existing remanufacturing facilities can enhance the disassembly process by efficient material movement.
Polimeri	Opalić, M. , Vučković, K., Panić, N.	4	2004	Literature study	Three types of disassembly line layouts/processes can be found in existing remanufacturing facilities. Each layout has its own advantages and disadvantages.
Book: Waste A Handbook for Management - Chapter 20	Cui J., Roven H.J.,	-	2011	-	The automated disassembly for recycling of electronic equipment is not well advanced due to the fact that there are too many different types of products, the amount of products of the same type is too small, general

					disassembly unfriendly product design and variation in returned amount of products to be disassembled.