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E-waste project

At "Twente Milieu" & "De Beurs"
Final report

"An optimal central location to sort, disassemble and repair E-waste"

UNIVERSITEIT TWENTE.

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Preface

This report is the final project assignment of our research project that we have conducted for the companies Twente Milieu and De Beurs. We executed this research project for the Academic Skills course, which is part of the premaster program Production & Logistics Management.

The core problem that we recognized is that, currently, there is no central location to sort, disassemble and repair E-waste. The goal of our research is to find an optimal central location where this can be done, to get more value out of the E-waste and more employment in the Twente region can be accomplished. In order to do this, we specified to following main research question: *"What is the optimal location for a new plant that sorts, disassembles and repairs E-waste in the Twente area?".*

In the first part of the report the problem identification, solution planning and the research design are described. In part II, the results of our research are explained. Last, the conclusions and implications of the research are stated.

Finally, we would like to thank Twente Milieu and De Beurs for giving us the opportunity to work on a real-life case and giving us assistance and feedback during this quarter. We would also like to thank our instructor, Sandor Löwik, who has given useful lectures and weekly assistance during this semester.

January 2015

Management summary

This report contains the description of the research project that we have conducted for De Beurs and Twente Milieu. The main topic of the project is E-waste. Each of the two companies would like to get more value out of E-waste and therefore create more employment in the area. In the current state, there is no central location to sort, disassemble and repair E-waste within the Twente area. In order to solve this core problem, the following research question needs to be answered: *"What is the optimal location for a new plant that sorts, disassembles and repair E-waste in the Twente area?".*

We used a 7-step problem solving approach. After defining the core problem, we did systematic literature review to find appropriate methods and criteria to determine the optimal location. Thereafter we applied these methods and we created a model for determining the optimal solution.

We determined first the optimal location coordinates, using the centricity of all involved municipalities. A contribution of the amount of E-waste (% of total KG's) is added to this as relative weights. Thereafter we searched for industrial areas with a radius of 5 kilometers around the optimal coordinates, which resulted in the following sites:

- Bedrijventerrein Oosterveld;
- Twentekanaal Noord;
- Twentekanaal Zuid;
- Westermaat Zuid-West;
- Westermaat Noord-Oost.

From our systematic literature review, the following six criteria with their indicators are concluded to be most important in determining the optimal location.

Criteria	**Indicator**
Transportation costs	Total cost/km/kilo E-waste per location
Land costs	Average cost/m² for industrial area
Proximity to center of gravity	Difference in meters between location and center of gravity
Proximity to buyer of scrap	Difference in meters between location and the buyer (Omrin)
Industrial taxation of municipality	Average cost of the industrial taxation in the municipality
Existence of modes of transportation	Number of bus stops per m²

Table 1 – Criteria and their indicators

There are also three criteria defined, that lay out of our research scope. Although these criteria may be very interesting and useful. The three criteria are: Availability of labor force, lead times & responsiveness/total lead time and last the taxes structure & incentives.

The Analytical Hierarchy Process (AHP) – method is used to score the locations and criteria together. This is a method for organizing and analyzing complex decisions, where multiple criteria and other aspects (locations) play a role. By using pairwise comparison, every option got a weight. The result of this is that the most optimal location would be near the industrial area 'Westermaat Zuid-West', in this area Twente milieu is already located and therefore benefits may be achieved.

In the excel model that we finally created, in order to get to this solution, it is possible for De Beurs and Twente Milieu to adjust the weights which are given to each criterion. Also, we formulated an instruction, so that the model can be easily extended with other/more important criteria. Our conclusion is that a new facility to sort, disassemble and repairing E-waste should be located on Westermaat Zuid-West. Also, the AHP-method and our model can be used as a decision tool for many more purposes in the, hopefully, great future that Twente Milieu and De Beurs have ahead of them!

Management samenvatting

Dit rapport bevat een beschrijving van het onderzoeksproject dat wij hebben uitgevoerd voor De Beurs en Twente Milieu. Het hoofdonderwerp van het project is E-waste. Elk van de twee bedrijven wil graag meer waarde verkrijgen uit E-waste en daardoor meer werkgelegenheid te verkrijgen in de Twente regio. In de huidige situatie is er geen centrale locatie om E-waste te sorteren, te disassembleren en te repareren in de Twente regio. Om dit hoofdprobleem op te lossen dient te volgende onderzoeksvraag beantwoord te worden: *"Wat is de optimale locatie voor een nieuwe bedrijfspand waar E-waste gesorteerd, gedisassembleerd en gerepareerd kan worden in de Twente regio?".*

We hebben een 7 stappen probleemoplossings aanpak gebruikt. Na de definiëring van het hoofdprobleem hebben we een systematisch literatuur onderzoek gedaan om passende methoden en criteria te vinden, om de optimale locatie te kunnen bepalen. Hierna hebben we deze methoden toegepast en hebben we uiteindelijk een model gecreëerd om de optimale locatie te kunnen bepalen.

We hebben eerst de optimale locatie coördinaten bepaald, door gebruik te maken van de centraliteit van alle betrokken gemeenten. Een bijdrage van de hoeveelheid E-waste (% of totale KG's) is toegevoegd als relatief gewicht. Hierna hebben we gezocht naar industrie gebieden met een radius van 5 kilometer rond de optimale coördinaten, wat resulteert in de volgende locaties:
Bedrijventerrein Oosterveld;

- Twentekanaal Noord;
- Twentekanaal Zuid;
- Westermaat Zuid-West;
- Westermaat Noord-Oost.

Uit ons systematische literatuur onderzoek, de volgende zes criteria met hun indicatoren zijn geconcludeerd als meest belangrijk voor het bepalen van de optimale locatie:

Criteria	**Indicator**
Transportkosten	Total cost/km/kilo E-waste per location
Grondkosten	Average cost/m² for industrial area
Afstand tot de centrale coördinaten	Verschil in meters tussen locatie en optimale coördinaten
Afstand tot de opkoper van afval	Verschil in meters tussen locatie en de opkoper (Omrin)
Industriële belastingen van de gemeente	Gemiddelde kosten van de industriële gemeentelijke belastingen
Het bestaan van vervoersmogelijkheden	Aantal bus stops per m²

Table 2 – Criteria en de indicatoren

Er zijn daarnaast nog drie criteria bepaald, welke niet in ons onderzoeksgebied liggen. Al hoewel deze criteria zijn mogelijk erg interessant en toepasbaar. De drie criteria zijn: Beschikbaarheid van arbeidskrachten, doorlooptijden & responsiviteit/totale doorlooptijd en de laatste is belastingstructuur en stimulansen.

De Analytical Hierarchy Process (AHP) – methode is gebruik om de locaties en criteria samen te scoren. Dit is een methode voor het organiseren en analyseren van complexe beslissingen, waar meerdere criteria en andere aspecten (locaties) een rol spelen. Door gebruik te maken van paarsgewijze vergelijkingen, krijgt elke optie een gewicht. Het resultaat hiervan is dat de meest optimale locatie in de buurt van industriegebied 'Westermaat Zuid-West' gelegen is, in dit gebied is Twente Milieu al gevestigd en daardoor zouden er voordelen behaald kunnen worden.

In het Excel model dat we uiteindelijk gecreëerd hebben, om tot dit resultaat te komen, is het mogelijk voor De Beurs en Twente Milieu om de wegingen aan te passen die aan elke criteria is gegeven. Daarnaast hebben we een handleiding opgesteld, zodat het model makkelijk uitgebreid kan

worden met andere/meer criteria. Onze conclusie is dat een nieuw bedrijfspand voor het sorteren, disassembleren en repareren van E-waste gevestigd dient te worden nabij Westermaat Zuid-West. Ook is de AHP-methode en ons model uitermate geschikt als beslissingsmodel voor veel meer doeleinden in de, hopelijk, geweldige toekomst die de bedrijven tegemoet zien!

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PART I

1. Problem identification

In this chapter, we will start with an introduction to the problem. After that, we will explain the problem by using a problem cluster. Then we will derive our core problem from our problem cluster.

1.1. Problem introduction

De Beurs is a recycling company and thrift shop. A key task of De Beurs is to employ unemployed or hard-to-employ people and to manage waste streams in the Twente region. Residents of the municipalities can deliver used products to various locations of De Beurs which are located in Oldenzaal (headquarters), Denekamp, Tubbergen and Losser. At the location in Oldenzaal the functioning products are sold in a thrift shop. Products which do not function will be either repaired and sold in the thrift shop or sent to a company called "Omrin" located in Friesland. De Beurs employs around 250 people which consist mainly of social workers and volunteers. De Beurs also functions as a springboard for unemployed people to get a full-time job. The government has an interest in this because they want to lower the unemployment rate. Every unemployed person in a municipality costs money and if a foundation can contribute to a solution for this problem, they are very interested.

The director of De Beurs sees an opportunity to create more work in the Twente region. In the current situation about 1% of the E-waste is repaired and sold in the thrift shop while 99% of the E-waste is sent to Omrin. This means a lot of employment opportunity is going to Friesland. The idea for the new situation is that the E-waste will be partly disassembled at an undefined location in the Twente region. This must be at a new location because there is no space to expand at any of the current locations. The E-waste will still be sent to Omrin afterwards. This will cause an increase in value of the E-waste and an increase in jobs in the Twente region. In order to get bigger volumes of E-waste a collaboration can be established with Twente Milieu NV. Twente Milieu is also a company with a key task to manage waste streams in the Twente region.

In order to realize the idea, a location for the production area for the production location is needed. The problem that is addressed in this research will be the allocation of the new production area.

1.2. Problem cluster

In this paragraph, the problem cluster that we defined is presented. This problem cluster is a result of our analysis of the current situation, which resulted in the following overview:

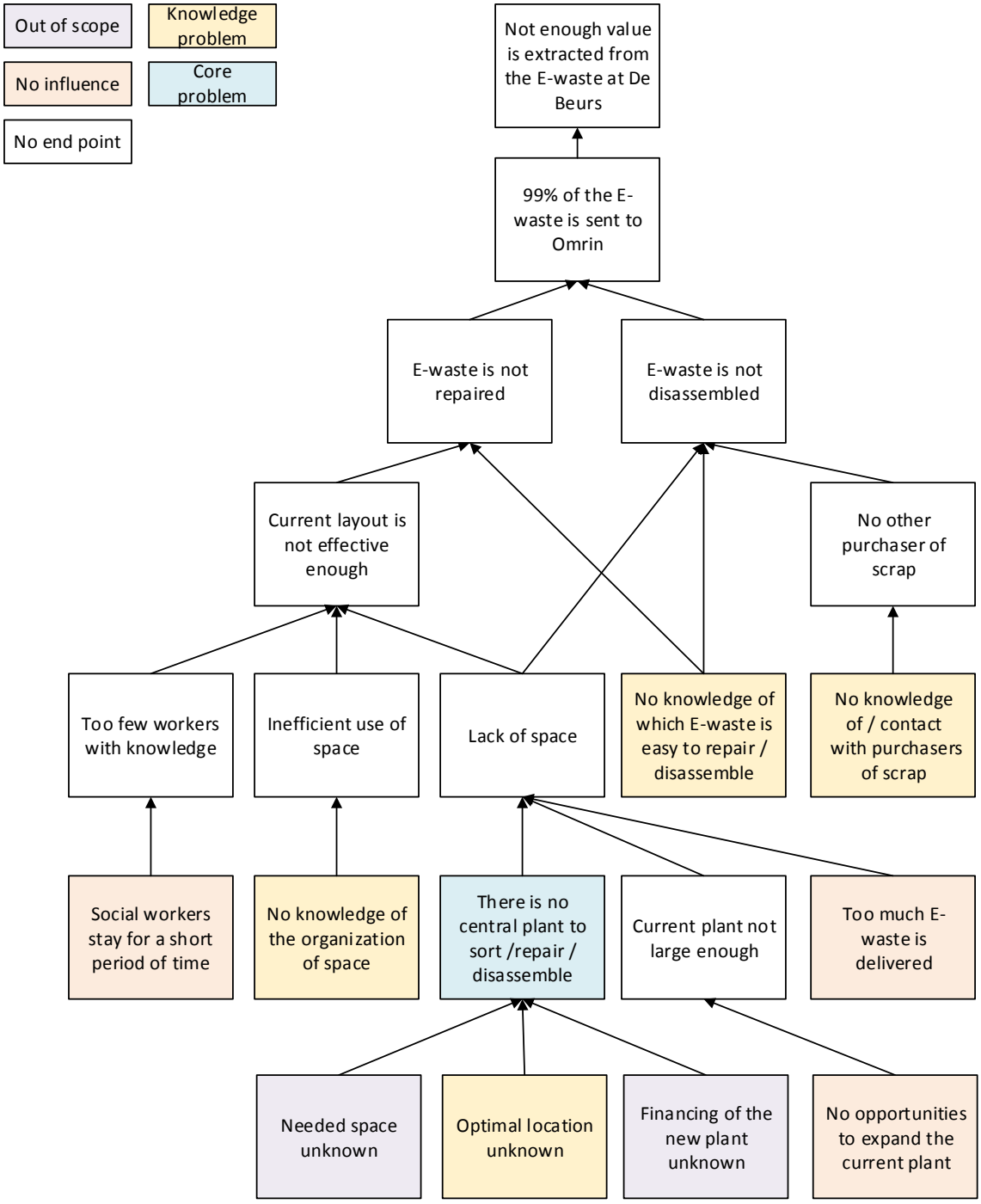

Figure 1: Problem cluster

Explanation of problem cluster
In our problem cluster you can see the different subsets we've given for problems with causal relationships to other problems. We've started at the top and worked our way down based on combining information available to us and the use of some reasoning/ logic/ assumptions.

Since we had a lot of problems at the end of the line, we had to select our core problem. First of all, we could create a subset of problems on which we don't have any influence. According to the micro-lectures of Professor Heerkens you can directly consider these problems as non-core. After that we've selected which problems would be categorized as knowledge problems (A problem for which research is needed to obtain the knowledge), since the core problem should be an action problem (A problem solved by executing). At that point all the problems which were at the end of the line were categorized and we had not yet found the core problem, so we had to take a step back.

Therefore, we selected "There is no central location to sort / disassemble/ repair "as our core problem. The purple subset is used to inform that some knowledge problems fall out of our scope in this research and that we will go in depth on the aspect of the location of the new location.

1.3. Core problem

In our opinion the real problem that the companies are facing (to get more value out of E-waste and create more employment) is the fact that they don't have a location where these activities could take place. The core problem stems directly from a gap in norm and reality. This is because that there is a norm (goal) to which the company wants to commit itself and a current state at which it is now. Our core problem is an aspect of bridging the gap between norm and reality.

The current state is that "There is no central location to sort/ disassemble/ repair" while the preferred state is that "There is a central location to sort/ disassemble/ repair".

This seems rather black and white, but since it's very hard to have a something between a location and no location we find this logical.

So, for a core problem you have to ask yourself: Why hasn't it simply been done? Why haven't they just bought a location and moved to the norm? This is where the knowledge problems which in turn are (sub)research questions can be used as a motivation. A new location can be bought, but if the answers to the underlying knowledge problems are unknown, it's unlikely to solve the problem. (E.g. a new location can be bought as cheap as possible without regards to the location and the location may end up in Spain).

We've also chosen this core problem over other possibilities such as "current location not large enough" and "inefficient use of space" because based on the information we got from De Beurs, sooner rather than later they'd have to expand if they want to recycle more E-waste. They can only successfully recycle less than 1% of all E-waste and since the goal is 5%, an optimization of a factor 5 should be necessary. We've seen the space in which they work and this seems highly unlikely for us. Also, we saw no options to expand the current location.

Challenges which play a role in selecting a location in this case are for example the fact that creating more employment is very important for the clients. Therefore the location has to be good reachable for employees. On the other side, we have to keep in mind that the costs for the new location don't get to high and that the un going transport costs exceed the acceptable limit. All these factors, and others, need to be considered.

2. Solution planning

In this chapter, we will describe the broad outlines for arriving at a solution. We will do this by first describing the stages of the project. Then we will formulate research questions and the scope of this research. Furthermore, we will describe the stakeholders who can possibly influence the solution. Lastly, we will determine the deliverables of the project.

2.1. Project steps

The project consists of multiple steps (Figure 2) to solve the core problem which has to be identified in the problem identification step. Since the core problem is that there is no central location for repairing and disassembling E-waste our goal is to find a location that fits best for all incoming E-waste in the Twente region.

In step 2 (Figure 2), we will find methods to assess locations by criteria and find single facility location techniques by doing research. When assessing locations by criteria it is important to take every factor into account that is of any influence in deciding the optimal location. This is done in step 3 (Figure 2). After we found location techniques in step 4 (Figure 2), we will apply the techniques to find multiple feasible locations. When the possible locations are found, the criteria determined earlier need to obtain a weight per factor (Step 5 in figure 2). After assigning weights to each criterion each location can be assessed based on the criteria to get a final score. The model to calculate the location scores, which is made in step 6 (Figure 2), will be adjustable in case some criteria are no longer important, new criteria are found or when the weights are not representable anymore. In step 7 (Figure 2), the location that has the highest overall score will be advised to de Beurs and Twente Milieu.

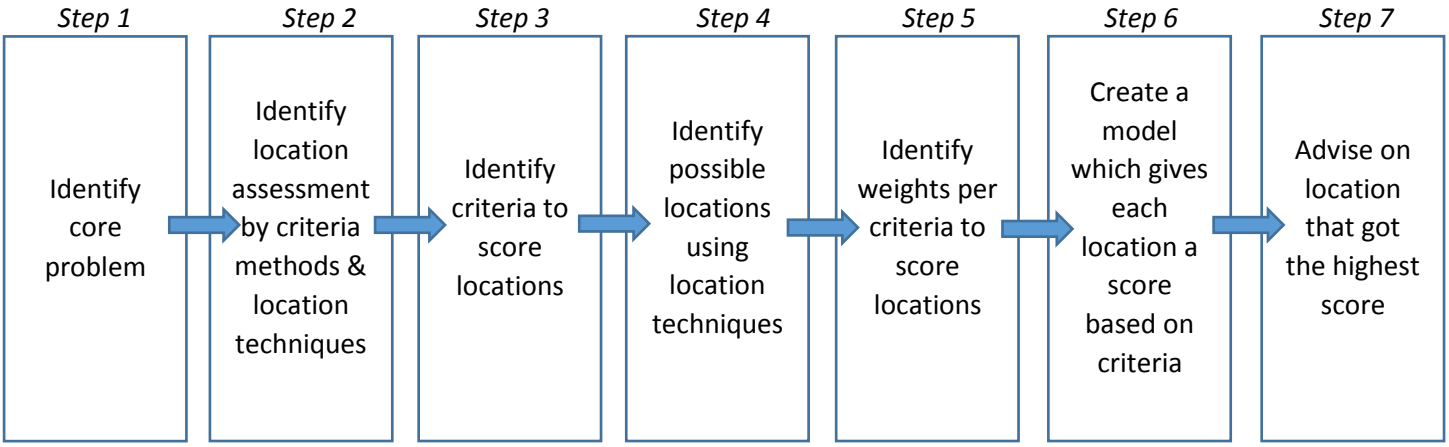

Figure 2: Problem solving approach

2.2. Research questions

In order to solve the core problem, the following main question needs to be answered:

"What is the optimal location for a new plant that sorts, disassembles and repairs E-waste in the Twente area?"

In which optimal is the location where the new location is as central as possible considering the relevance of each E-waste supplier.
This main question can be solved if each project stage is completed. To complete these stages, each stage in which information should be 'identified' raises a new question. These questions, called sub questions, are the knowledge problems that need to be answered by research.

Sub questions:

- (1) Which methods for location assessment by criteria are available? (Step 2, Figure 2)
- (2) Which methods for finding feasible locations are available? (Step 2, Figure 2)
- (3) Which criteria exist to score the feasible locations? (Step 3, Figure 2)
- (4) How should each factor of the criteria be scored? (Step 5, Figure 2)

2.3. Constructs and definitions

In this paragraph, the main constructs and their definitions within our project are described.
E-waste – "All dismissed devices with a plug or (rechargeable) battery and all dismissed striplights, low energy lightbulbs and LED-lamps" (Wecycle, 2016).

Twente Region – The region consisting of the seven municipalities which make up Twente Milieu (Almelo, Oldenzaal, Enschede, Hof van Twente, Hengelo, Losser)

Optimal Location – An existing industrial area within the Twente Region that scores best on the assessment criteria.

Location (Geography) – "a tract of land designated for a purpose" (Merriam-Webster, 2017). For our project this purpose is acting as a central site where suppliers can supply E-waste and repaired & recycled devices can be transported to the shops of de Beurs.

Optimal – "Being the best or of the greatest value, sometimes under certain parameters or restrictions." (Business Dictionary, 2017). Greatest value in our case is being as central as possible within the Twente Region considering the relevance (Relevance is measured by percentage of total waste collection) of each E-waste supplier.

Criteria – "A standard, rule, or test on which a judgment or decision can be based." (The Free Dictionary, 2017). For this project, the standards are found by literature review on how to evaluate locations.

2.4. Scope of research

In our research, we focused on one central location (single-factor location), which means that we not considered options for multiple locations. For the systematic literature review we focused on sub question 1: "Which methods for location assessment by criteria are available?" and sub question 3: "Which criteria exist to score the feasible locations?". We choose this sub-questions because these questions are crucial in our project and weren't obvious enough after some basic literature research, therefore we analyzed these parts using (scientific) papers (maximal 10 papers because of project time restrictions). After we determined the central point using a specific technique, the area in which we searched for industrial areas is limited to a 5-kilometer radius. In this way we captured the whole area of Hengelo, which is well located regarding highways and the different locations of the companies. We only consider industrial areas as those are the only places suitable for this operation (Think of the traffic required). The number of feasible locations for assessment will be determined by the total number of industrial areas in Hengelo subtracting the ones that do not fit within the picture because of purpose plans of those areas.

In step 5 (figure 2: Problem Solving Approach), identify weight per criteria to score locations, we only used to exact transportation quantities for each facility of Twente Milieu. This is done, because transportation numbers of E-waste concerning De Beurs was very limited and these numbers were an estimate.

2.5. Stakeholders

The stakeholders of our project are given below. For each party, their interests and relationship to our study are shortly explained. During the project we had regular meetings with our instructor from the University of Twente. Also a few contact moments with the client, De Beurs and Twente Milieu. In the end of the project, a presentation will be given at the company site of De Beurs. The final report will be available for De Beurs, Twente Milieu and University Twente.

- *Omrin*

The company 'Omrin' collects and processes garbage. This party receives in the current situation tons of E-waste from the collecting organizations (who are our clients). If our clients choose to create a central location to process E-waste, this means that less to none of the E-waste will be send to Omrin in the future. As a result of this, they will gain less revenue and the employment in their region may decrease. This report does not directly affect Omrin, as de Beurs and Twente Milieu firstly have to make the decision to build a new plant and obtain new employees.

- *De Beurs*

De Beurs is the client of our project. This second-hand organization collects and receives E-waste. Some of the E-waste is sold in their thrift shop and the rest of all the E-waste is shipped to Omrin. De Beurs employs people (social workers) who have difficulties to participate in regular working processes, therefore their biggest interest is to keep the work in Twente and create more employment. Another goal is to get more value of out the E-waste, which also means that the whole operation must be organized as cost efficient as possible. They don't want to be at the end of the whole chain. Our study will help them to organize their process of collecting, sorting and disassembling E-waste on a central location. In this way more employment will be generated and more value can attained out of the E-waste. This report affects de Beurs in a way that they can be sure if a fancied location is the best one.

- *Twente Milieu*

Twente Milieu is also client of our project. This company collects also E-waste, but all E-waste is instantly sent to Omrin. They want to put a stimulus on recycling E-waste and get more value out of the E-waste. On the new possible central location, that our study will yield, Twente Milieu can also recycle, repair or disassemble their E-waste. This report affects Twente Milieu the same way as it

effects de Beurs, it ensures that the chosen location for the new plant is the optimal location.

- *The Municipalities*

The municipalities are stakeholders because unemployed inhabitants gain a chance to work at the central collecting point to repair, recycle or disassemble. People who start to work for De Beurs can use this experience as a springboard for a full-time job somewhere else. This means that the government doesn't have to pay payments to this people anymore and the unemployment rate will decrease. The second point is that a central location will make sure that each municipality can reach this location good. The Municipalities are not directly affected by this report as this will only happen when a new plant will be build. Then the municipalities improves their employment rates and can save money when a social worker obtains a full time job.

- *Employees of all involved companies*

The employees who work at for example Omrin might lose their job if less E-waste is sent to Omrin. As a result, employees of other companies in the chain might lose their jobs. Certain parts of the supply chain might not be done at the current location anymore for other companies involved which means that they either need to do a different task or go to a different location for work. This report does not directly have effect on the employees of the involved companies as no decisions are made yet. When a new location is build, employees of e.g. de Beurs might be asked to perform their work at the new plant.

- *Residents*

Residents are the main source of the E-waste, but also the main customer of the thrift shop. This means that they have a stake since a new situation might limit/increase supply of certain items. Also, some residents will get the opportunity to work at the new location. The residents are not directly affected by this reported as this report only advises de Beurs and Twente Milieu.

- *University Twente*

We conduct this project for the premaster program. The University Twente has also an interest in this study, because they want students to develop a set of defined skills that meet the required level. Finally, they want to maintain their relationship with the clients. The University is not directly affected by this report as the advice has no link to the activities of de Beurs and Twente Milieu.

2.6. Deliverables

At the end of the project we will present our findings to De Beurs and Twente Milieu. We will deliver:

- A model (in Excel) in which multiple locations can be assessed by using criteria and their assigned weights. This model will be adjustable by the companies when criteria, locations or weights need to be changed.
- An advice report giving one optimal location found and answering all sub questions.

3. Research design

In this chapter, we will explain how our research is designed and which methods are used to execute our project.

3.1. Research methods and data collection methods

In the first step of our project (figure 2: Problem Solving Approach), problem identification, we've executed exploratory research. We read information about the companies (Twente Milieu and De Beurs), the assignments and we visited each of the companies. After this, we could define the correct problem cluster and core problem description. We started step 2 with an extensive desk research to investigate which methods for location assessment by criteria are available (sub question 1). We used a systematic literature review to do this. This is a literature review that collects and critically analyzes multiple research studies or papers. The main question of our systematic literature review contains to parts and is as follows:

"Which methods for location assessment by criteria are available, and which criteria exist to score the feasible locations?".

A full description of our systematic literature review can be found in appendix 3. Also, we used basic literature research like textbooks and Google Scholar in order to get an answer on sub question 2, which methods for finding feasible locations are available. During step 3 we used first, textbooks to get an overview of the criteria which exist to score the feasible locations (sub question 3), thereafter we used the same systematic literature review as stated above to compare this with existing studies. In step 4 we used Google Maps to get a total picture of all the municipalities and the distances. Thereafter we used the internet to look for interesting sites near the optimal locations (when there was already a company established, we had to search for alternatives in the area). Determining the weights for the selected criteria in order to score locations (sub question 4) was the fifth step. This is done by searching in the literature how this can be done. For step 6 'create a model which gives each location a score based on criteria', we used the manuals of Excel and VBA, our prior knowledge and google to come up with a model that fits. Finally, we reviewed the guidelines in the PDF 'Manual Q2', to write (hopefully) a clear report which contains our advice.

3.2. Research limitations

In our research, we had to deal with general limitations. We couldn't contact Twente Milieu and De Beurs directly, the research had to be completed on 26th January 2017 and we did not have any funds to spend/invest in our research. Below, the most important limitations regarding our research itself are given:

- We evaluated a limited number of eight articles in our literature review because of time restrictions, therefore it may be possible that some relevant criteria (for determining the optimal location) are not included. Although we selected the most relevant papers and theory;
- For using the AHP method to analyze a multi-criteria decision problem, a maximum of 10 different criteria to score the different options is recommended. The larger the number of criteria is, the more comparisons are made in the model, the weights will be less accurate and because of more overlap the consistency will be lower;
- In the excel model for the optimal location, weights of the different criteria can be easily be adjusted. When somebody would like to add other/more criteria or locations to the model, the AHP-method has to be executed again to come up with a new solution;
- Due to some unknown factors and variables some assumptions are made regarding the importance of criteria, as also will be described in the following paragraph.

3.3. Validity and reliability of research

In this paragraph, first the validity of our research project is explained. Second the reliability is treated.

External Validity

The criteria that we used in our research are the result of a systematic literature review, in which relevant papers that are used in other multiple-criteria decision making methods. We kept in mind the goals and targets of Twente Milieu and De Beurs. Thereafter we selected the criteria, in which we used three inclusion/exclusion reasons. First, applicability, to make sure that only relevant criteria influence the decision. Second, overlap, so cluster criteria that are mainly the same to 1 criteria. The third is if the criteria are measurable, this will make sure that the process can be executed in an objective way. We think that we have a good spread of criteria which are important and reflect upon reality in such a way that we can say that it's good. However, this could be improved by discussing these criteria with professionals / companies and to add the criteria which were important, but out of scope for us.

By using the above described procedure, only the criteria that are important for determining the optimal location for Twente Milieu and De Beurs are measured. In chapter 7, a reliability and validity check is described for each of the selected criteria.

Internal validity

In the process of assigning the importance's regarding all the criteria and different locations, we used a measurement scale of 1 to 9 (equal importance to extreme importance). This measurement scale is part of the AHP method that we performed. We assigned importance in such a way that we thought is right for this situation, keeping in mind the goals of the companies. When the assigned scores are a little different, the final solution will probably not chance because the final solution has a big win margin. The main criteria on which the best option wins is Transportation Costs with a weight of 36,9%. This has to drop to 15,2% (rest of the weight divided equally over other criteria) in order to have another best location. When someone of Twente Milieu or De Beurs will assign the importance, there is a chance that other numbers (1 to 9) will be assigned. The reason for this is that they have more professional knowledge about their business and the sector that they are operating in. This may result in other priorities. The final solution (optimal solution), could change as a result of this, but then a lot of significant changes have to be made. In order to ensure internal validity, we've operationalized the selected criteria in such a way that De Beurs and Twente Milieu will understand the definition and have the same understanding of a criteria as we do.

Reliability

In the process of assigning the importance's regarding all the criteria and different locations, we used a measurement scale of 1 to 9 (equal importance to extreme importance). This measurement scale is part of the AHP method that we performed. Since the criteria are pairwise compared in this model, a lot of scores have to be given. In our case, we've done the process one time, so reliability isn't very high, but is easy to improve by doing it a few times or by more people. The reliability within the AHP is good, since you can check the consistency. All these scores were OK. We've taken our time for the AHP test and have given argumentations why a criterion is more important than another criterion.

PART II

In the second part of this report, first the results of our literature research are shortly described. Thereafter, the results of using the picked methods is described in chapter 5. In chapter 6 the criteria will be operationalized. In chapter 7 the optimal location is found using the AHP method. Finally, the conclusions and the implications of the solution will be discussed.

4. Literature results to answer knowledge problems

In the following paragraphs, the first three knowledge problems (sub questions) are answered:

- (1) Which methods for location assessment by criteria are available? (Step 2, Figure 2)
- (2) Which methods for finding feasible locations are available? (Step 2, Figure 2)
- (3) Which criteria exist to score the feasible locations? (Step 3, Figure 2)

4.1. Multi-criteria method

The Analytical Hierarchy Process (AHP) method is found to be a very suitable multi-criteria decision method in determining the optimal location. This Is a structured technique for organizing and analyzing complex decisions. The AHP-method helps to find the solution that best suits the goal and understanding of the core problem. It is a specific method that used a pair-wise comparison matrix in which. It can be used with objective, subjective and critical factors. AHP is one of the most reliable methodologies according to the scientific literature consulted.

The procedure for using the AHP can be summarized as follows:

1. Model the problem as hierarchy containing the decision goal, the alternative for reaching it, and the criteria for evaluating the alternatives;
2. Establish priorities among the elements of the hierarchy by making a series of judgments based on pairwise comparisons of the elements;
3. Synthesize these judgments to yield a set of overall priorities for the hierarchy. This would combine for example the locations, price and timing of different properties A, B, C, and D into overall priorities for each property;
4. Check the consistency of the judgements;
5. Come to a final decision based on the results of this process.

4.2. Location problem solver method

For sub-question 2 “Which methods for finding feasible locations are available?”, the method below is found. Since we are searching for one optimal location for one facility, we can use the Weber problem method (van der Heijden & van der Wegen, 2015) to solve the problem. Instead of having N customers to supply, we deal with N depots that have to deliver to the optimal location. Customers (i) are represented with coordinates, in our case the customers consist of the delivering parties (Facilities of Twente Milieu & de Beurs) and the parties that have to be supplied (Kringloop de Beurs). All parties are shown as dots on the map below, black represents the facilities of Twente Milieu and red represents the facilities of de Beurs.

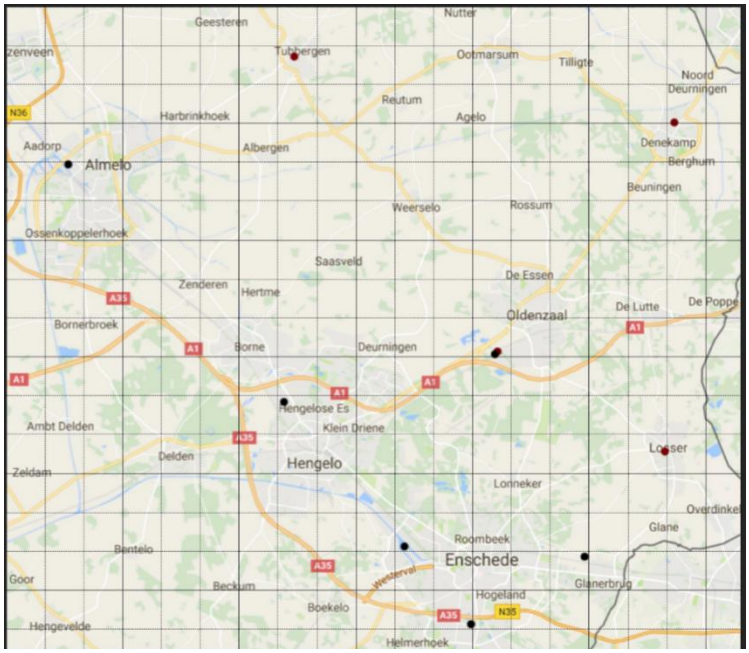

Figure 3 – Map with locations of De Beurs and Twente Milieu

the Center-of-Gravity (COG) method (van der Heijden & van der Wegen, 2015) can be applied to calculate weighted coordinates. The Center-of-Gravity calculation:

$$y_1 = \frac{\sum_{i=1}^{N} w_i * x_{i1}}{\sum_{i=1}^{N} w_i} \tag{1-1}$$

$$y_2 = \frac{\sum_{i=1}^{N} w_i * x_{i2}}{\sum_{i=1}^{N} w_i} \tag{1-2}$$

y_1 and y_2 respectively represent the x- and y-coordinate of the location found after the first iteration. With this method, the weight of E-waste (in kg) that each facility receives is taken into account as w_i, representing the weight of facility i.

4.3. Criteria to score feasible locations

In Appendix 1 we gathered some broad indicators used in location decision making. In order to find the right criteria for our specific location problem, we started with these indicators and assessed whether they are applicable and differentiated enough between alternatives for this situation.

Out of all the indicators which are listed in the theoretical overview in Appendix 1, the indicators: Transportation costs and Land costs are applicable and potentially different enough between locations.

We want to score the alternative locations on more than 2 criteria in order to get a better comparison, so we've made a total sum of all criteria mentioned in the articles we've already used to answer our method sub-question and again assessed whether they are applicable and differentiated enough between alternatives and whether they overlap with other criteria. Applicable can also mean that to measure these criteria is simply out of scope for our research. These tables can be found in our Appendix 2. The following criteria will be included in the research:

- Transportation costs;
- Land costs;
- Proximity to center of gravity;
- Proximity to buyer of scrap;
- Industrial taxation of municipality;
- Existence of modes of transportation.

The following criteria were identified as (partially) usable but did not fall within our scope. Two of the four (Combined into point 2) overlap. The remaining three criteria can be used to score locations if they are considered relevant enough to affect the location. To add these criteria, please follow the steps mentioned in the manual for using the AHP.

- 1) Availability of labor force

The availability of labor force falls outside of our scope because do not have the means to get a hold of this information within the time available for this project. This criterion could be measured as available labor force per squared kilometer of a city/municipality/district.

- 2) Lead times and responsiveness/ Total lead time

The lead times fall outside our scope because we have no insight on the duration of the total process. If this criterion is to be added, the total lead time can be identified as the total time needed from the start of collection up until the moment a device is ready to be sold at de Beurs. This process includes: the collection of E-waste at any collection point, the travelling time from the collection point to the new central location, the time needed to sort/disassemble/repair the E-waste and the time needed to transport the good back to any of the shops of de Beurs. Disassembled devices not to be sold again are not considered as they are not send back to de Beurs.

- 3) Tax structure & incentives

This point falls not within our scope because it is not measurable for us. We identified this criterion as the subsidy that will be received if deciding to choose a location within a certain municipality, city or industrial area. In order to add this criterion, for every location the subsidy should be measured with in the same way.

5. Location problem solving

In this chapter, first the method for determining the central location is used. Thereafter, the selecting of possible industrial areas is described.

5.1. Performing the method

With the COG method, a good approximation of the central location is determined.
The weight contribution (% in KG) is obtained from the E-waste data received from Twente Milieu containing the locations, their monthly collected weight and monthly number of loads needed to transport the E-waste.

The locations of the Twente Milieu facilities are turned into coordinates in figure 3. These coordinates are based on the location within figure 3.

Twente Milieu locations	Coordinates	Weight contribution (in % of KG)
Almelo	(1.6 , 13)	19
Hengelo	(7.1 , 6.9)	33
Enschede West	(10.3 , 3.1)	4
Enschede Oost	(12 , 1.1)	10
Enschede Zuid	(14.9 , 2.9)	18
Oldenzaal	(12.6 , 8.1)	16

Table 3 – Coordinates Twente Milieu Location

The calculations of the coordinates for the central location:

$$x - coordinate = \frac{1.6 * 19 + 7.1 * 33 + 10.3 * 4 + 12 * 10 + 14.9 * 18 + 12.6 * 16}{(18 + 33 + 4 + 10 + 18 + 16)} \approx 9$$

$$y - coordinate = \frac{13 * 19 + 6.9 * 33 + 3.1 * 4 + 1.1 * 10 + 2.9 * 18 + 8.1 * 16}{(18 + 33 + 4 + 10 + 18 + 16)} \approx 6.7$$

The location with coordinates (9 , 6.7) is not feasible as an actual location for the new facility because the location is not suitable for industry.

After executing the COG-method for the most central location within the Twente Region, five feasible and thus existing sites are selected within a radius of 5 kilometers of the COG determined location.
- We chose to select sites within a certain radius because the COG location is not feasible.
- We chose a radius of 5 kilometers because with this radius we cover all industrial areas in the municipality of Hengelo.
- We chose five locations because only five of the seven industrial areas within Hengelo are feasible for this industry.

Because we chose to have sites within a radius of the COG selected location, the proximity of the location to the COG selected location is included as a criterion to score locations.

5.2. Finding options for industrial area's

In figure 4, the feasible locations are shown as blue dots. The red dots represent the location given by performing the COG method.

After we determined the central location coordinates, using the Centre of Gravity method, it became clear that the optimal central location will be near Hengelo as described in the previous paragraph. From an overview in which the industrial area's in the municipality are given, there were seven different options. These options are selected from the source "*Plattegrond + grondprijzen 2017 brochure bedrijventerreinen WEB.PDF*", granted by the economic and ground departmant of the municipality of Hengelo. The eight feasible locations consist of:

- t' Oosterveld;
- Westermaat Zuid-West;
- Westermaat Zoord-Oost;
- Twentekanaal Noord;
- Twentekanaal Zuid;
- Gezondheidspark;
- Campus;
- Lintelerweg.

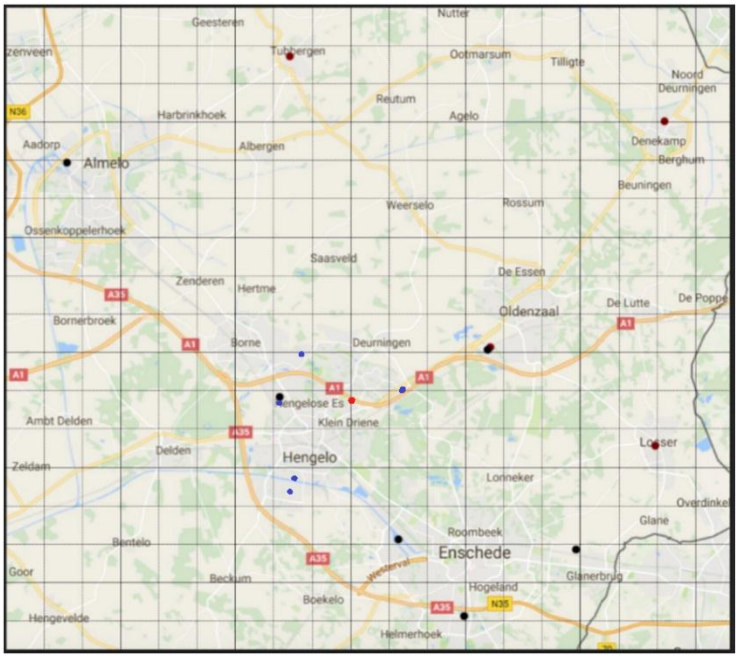

Figure 4 – Map with the feasible locations (Blue) and the COG location (red)

Finally, we scraped the last three options. First of all 'Gezondheidspark', because this area is meant for care, care-related activity and living. There is also need for supporting functions like sport and fitness, which is not applicable for E-waste. The 'Campus' area is also not available for this business purpose because this area is meant for knowledge-intensive of initiating industries, wholesale supply and business services. At last, 'Lintelerweg', is scrapped because there is very limited place available in this area.

The five potential area's that are selected and analyzed in our research are all within a 5 kilometer radius of the Centre of Gravity method and are all suitable for Twente Milieu and De Beurs and the activities that they would like to perform on this new site.

6. Operationalization of the criteria

We have operationalized these criteria according a method by (Baarda, de Goede, & Kalmijn, Basisboek Enqueteren, 2015). After this, a conceptual model is described.

1. Definition of optimal location

"An existing industrial area within the Twente Region that scores best on the assessment criteria. In which optimal is the location where the new location is as central as possible taking into account the relevance of each E-waste supplier (Relevance is measured by percentage of total waste collection)."

2. Dimensions

According to (Slack, Brandon-Jones, & Johnston, 2013) there are two dimensions to the criteria for an optimal location, namely demand-side and supply-side. These dimensions are less relevant, as we already have determined what the criteria are.

3. Indicators per criteria

Criteria	Indicator(s)
Transportation costs	The amount of yearly E-waste kilos times the difference in kilometres (shortest distance that a truck has to cover on the roads) between the feasible locations and the current locations.
Land costs	Taking an average cost per square meter of a nearby municipality to assess the land costs per alternative location.
Proximity to centre of gravity	Taking the difference in kilometres between the alternative location and the centre of gravity to assess the centralization factor of the location. (Euclidean distances)
Proximity to buyer of scrap	Taking the difference in kilometres (shortest distance that a truck has to cover on the roads) between the alternative location and the location of the buyer to access the centralization factor of the location.
Industrial taxation of municipality	Taking an average cost of the industrial taxation in the municipality in order to cover the cost of taxation.
Existence of modes of transportation	Bus stops / hectare to find out the density of public transportation in the municipality.

Table 4: Criteria from literature and their indicators

4. Reliability and validity check of the criteria

- Transportation costs – E-waste kilos * Difference in kilometres between feasible locations and current locations (distance that a truck has to cover on the roads)
  We think that the total E-waste kilos times the difference in kilometres between feasible locations and current locations is a reliable indicator to determine the transportations costs. The costs per km per kilo E-waste is unknown therefore we have to make the assumptions that the cost per km per E-waste kilo doesn't differ between different locations. We think this is a reasonable assumption because they are all from the same company using the same trucks, drivers, and gasoline.

- Land costs - Average cost/m² nearest municipality
  To measure land costs, we will use the average cost per square metre. This is a commonly used method to calculate land costs. Also, municipalities use this indicator to charge buyers of land. This is valid if Twente Milieu / De Beurs don't already own a spare part of land, in that case the

cost/m2 needs to be adjusted to adapt to the sunk costs (if they can't sell it for the price they bought it for and the surface is big enough).

- Proximity to centre of gravity - Difference in meters between location and centre of gravity
  To measure the proximity to the centre of gravity we use the Euclidean distances between the centre of gravity to the feasible locations.

- Proximity to buyer of scrap - Difference in kilometres between location and the buyer
  The measure the proximity to buyer of scrap we will use the shortest distance that a truck has to drive between Omrin and the feasible locations. We think that this is a reliable and valid indicator as this is the distance that the truck has to drive in practice. We take the shortest distance instead of the fastest way because the fastest way can differ at different times.

- Industrial taxation of municipality - Average cost of the industrial taxation in the municipality
  To measure the taxation of municipality we will take the average cost of industrial taxation in the municipality of the industrial site.

- Existence of modes of transportation - Bus stops per hectare
  As an indicator for the existence of modes of transportation we use the bus stops per hectare. This is valid for the application we use this criterion as in our report (to ensure that employees can easily come to their work). Because we only look at the general area and not a specific site, this indicator is good. Otherwise another indicator was required (e.g. Distance from site to nearest bus stop).

Conceptual model

The conceptual model (figure 6) is derived from the operationalization of optimal location. In order to find an optimal location, we have first examined feasible locations. The feasible locations will then be scored by means of the measurable criteria.

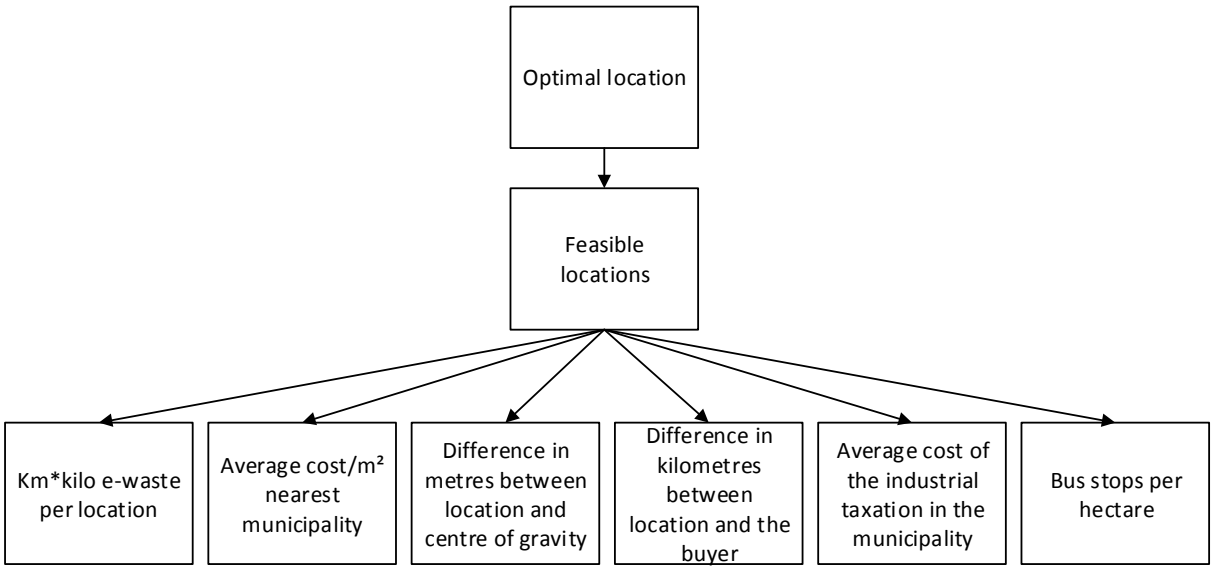

Figure 5: conceptual model

7. Finding the optimal location using AHP

In this chapter, the answer for the last sub question is derived: “How should each factor of the criteria be scored?”. We used the AHP method in this process. As described in paragraph 4.1, this method uses pairwise comparison to determine all the weights for the criteria and score each location per criteria. After this the weights are multiplied with the score to find the total score per location.

It is possible to do the needed calculations by hand, but we have decided the use an online calculator. The site we used for the calculations is: http://bpmsg.com/academic/ahp_calc.php. In this way, the process of weighing and scoring could speed up significantly. We have checked all tables on consistency with the consistency ratio, all scores were given consistently. The complete process, with argumentation, can be found in Appendix 3.

In the table below, the ranking of the criteria with the assigned priorities are given:

Category	Priority	Rank
1 Transportation Costs	36.9%	1
2 Land Costs	13.3%	4
3 Proximity to CoG	10.7%	5
4 Proximity to Buyer	4.5%	6
5 Taxation	21.0%	2
6 Modes of Transportation	13.6%	3

Table 4 – Criteria and their priority

The weights that we assigned with the AHP method to each criterion are based on argumentation which can be found in Appendix 3. Keep in mind that even though it is consistent, there is subjectivity involved in assigning these weights. So, the weights are consistently subjective. After multiplying each weight with the score (for results, see Appendix 3), we have the following table:

Criteria	Bedrijventerrein Oosterveld	Twentekanaal Noord	Twentekanaal Zuid	Westermaat Zuid-West	Westermaat Noord-Oost
Transportation Costs	0,080073	0,047601	0,015867	0,177858	0,047601
Land Costs	0,012502	0,038038	0,069027	0,006251	0,007182
Proximity to CoG	0,047615	0,010058	0,007276	0,015729	0,026322
Proximity to Buyer	0,00279	0,00279	0,004635	0,02079	0,013995
Taxation	0,042	0,042	0,042	0,042	0,042
Modes of Transportation	0,003944	0,036856	0,018632	0,018904	0,057664
Total:	0,188924	0,177343	0,157437	0,281532	0,194764

Table 5 – AHP Score per location

This means that based on the current AHP method, Westermaat Zuid-West would be the best alternative for this location problem. Weights can be changed in the attached Excel document in order to see best alternatives in other situations. Also, criteria can be added or removed in this document to make this customizable for Twente Milieu and De Beurs.

Conclusions

In the solution planning we determined four sub question and that need to be answered to answer the main question. In this chapter we will give answers to the questions. After this we will assess the implications of our solution.

Sub questions

1. Which methods for location assessment by criteria are available?

After doing a systematic literature review we found that the analytic hierarchy process (AHP) is the best technique for organizing and analyzing complex decisions. This method is used to make the location decision.

2. Which methods for finding feasible locations are available?

We wanted to determine feasible location based on centralization between the current locations. We found that the Centre of Gravity method is an appropriate method to determine the most centralized position between the current locations of Twente Milieu NV. This is based on the Euclidean distances and the amount of E-waste kilos per year of each current location. We found five feasible locations which are industrial sites in a radius of five kilometers around the Centre of Gravity.

3. Which criteria exist to score the feasible locations?

After doing systematic literature review we found 76 different criteria to score the feasible locations. We narrowed these criteria down to six criteria based on exclusion criteria. The following criteria and their indicators were eventually used to score the feasible locations.

- Transportation costs – E-waste kilos * Difference in kilometres between feasible locations and current locations (distance that a truck has to cover on the roads);
- Land costs - Average cost/m² nearest municipality;
- Proximity to centre of gravity - Difference in meters between location and centre of gravity;
- Proximity to buyer of scrap - Difference in kilometres between location and the buyer;
- Industrial taxation of municipality - Average cost of the industrial taxation in the municipality;
- Existence of modes of transportation - Bus stops per hectare.

4. How should each factor of the criteria be scored?

The AHP method is also applicable to this sub question. This method uses pairwise comparison to determine all the weights for the criteria to score each feasible location. This way the decision will be made in a systematic way.

Main question

"What is the optimal location for a new plant that sorts,disassembles and repair E-waste in the Twente area?"

Based on our weights to each criteria (which we found by using the AHP method) we found that the industrial site of "Westermaat Zuid-West" is the most optimal location for a new plant that repairs, sorts and dissembles E-waste.

Because the decision is always based on subjective aspects (despite the systematic approach), we have created a model in Excel. In this model the end user can decide the optimal location based on his/her opinion.

Implications of the solutions
After tackling the optimal location problem, further research is needed for the other problems such as the lay-out for the new facility, the amount of needed space, and financing of the new plant (see 1.2. problem cluster) to be able to actually build the new plant.

The AHP can be used for every multi criteria decision. This means that the tool can be used in many complex decisions which the companies will have to make during the next period in which they are setting up the new facility.

The employability that is brought to the Twente area can be at the expense of employability in Friesland.

Reflection

We would like to use this paragraph to highlight shortcomings of our research, after fully conducting our research, creating the conclusions and delivering the deliverables. Although consistency and systematic have proven to be our flagship ideas in this research, we have to be critical and look to our process and see that we haven't always lived up to our own advice. E.g. : Choosing the alternative locations, selection of the Centre of Gravity as a method, selection of criteria, Ensuring reliability in the AHP by doing it multiple times, Selecting and processing Tax as a criteria while this is no current differentiation and not operationalising other criteria which had nu current impact but might be worthwhile in the future.

We do think that we did a good job at staying systematic and right at the literature review, as well as the validity and reliability of the research. We think we've also done a good job selecting the AHP method and operationalise this method. Without any planning, beforehand or repeating the AHP process(honestly), the location which is the best location turned out to be a location for which they still have a piece of spare land. This of course directly results in an invalid estimation of the "land costs" of this location, so that is our bad, because we didn't know that they had this land. However, this even improves the margin with other optional locations.

The assignment (2), isn't fully implicating a research in the direction that we've chosen our core problem for. Partly this is because there were multiple core problems, but mostly because this assignment isn't very well defined as a stand-alone project. In our view, there was too little information and too many assumptions in order to fulfil this assignment in the way that probably was intended by the company (layout). This ultimately results in that the location solution is more of a confirmation of an idea they already had than a completely new insight. Nevertheless, we feel that the complete deliverable as a tool completely makes up for this. As stated in our Presentation at Twente Milieu, the amount of times we heard "importance" "decision" "important" in the few hours that we were there were astonishing. In hindsight we might even state that the core problem of most of the problems was a lack of systematic decision making (which could be solved now, if they implemented and used our manual + tool).

Overall, we are very content with the deliverable as a whole, but must state that the conclusion of the research may be less valuable for the company than the method, manual and tool we provide in general for decision making.

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Appendix 1: Systematic literature review

In this appendix, the systematic literature review that we conducted for this project is described. In the review, we focused on sub questions two and three and we combined them into one main research question: "Which methods for location assessment by criteria are available, and which criteria exist to score the feasible locations". Below, first the method that we used is be explained. Thereafter the theoretical concepts, the conceptual matrix and a flow chart of the review are given.

Method used:

We conducted our systematic literature review, following the method which is described in the paper "*Chapter 2 Dissertation Lowik-Paradoxes of absorptive capacity.pdf*", which is a digital copy of a chapter from the book "*Micro-foundations of absorptive capacity. A study on knowledge processes for innovation in SMEs.*" (Lowik, S. 2013). We also used the slides on literature review that were posted on blackboard by our instructor.

After reading this theory, we defined the following steps that are stated below. By executing this steps we conducted our review in a systematic way, each step is briefly explained:

1. Create an overview of the topic by using textbooks;
2. Define concepts (determine keywords, synonyms, create a conceptual model);
3. Formulate inclusion/exclusion criteria and explain them;
4. Determine the search strings;
5. Execute the actual search in Google Scholar and Scopus;
6. Report the results in a conceptual matrix and conclude.

First, we created an overview by using the textbook 'Operations Management' (Johnston, Brandon-Jones & Slack, 2013) to discover on the influences on location decision making for an operation.

Thereafter we defined our keywords and the possible synonyms that are related to this topic. By doing this the relationship between all these keywords became visible and the concepts could be formulated. After this, also the search strings could be determined, which are the main topics to search for during the search.

During the third step, we formulated criteria to which papers must hold in order to be selected for our review. By doing this we made sure that we only review relevant papers that have good quality. Stage four, was determination of the search strings that we would use to find our articles.

In the fifth step, we used the search engines to find all the relevant papers and we created a document in which all the papers are stated. By using the search strings and inclusion/exclusion criteria we could filter all found papers, only the most relevant and interesting papers were left over.

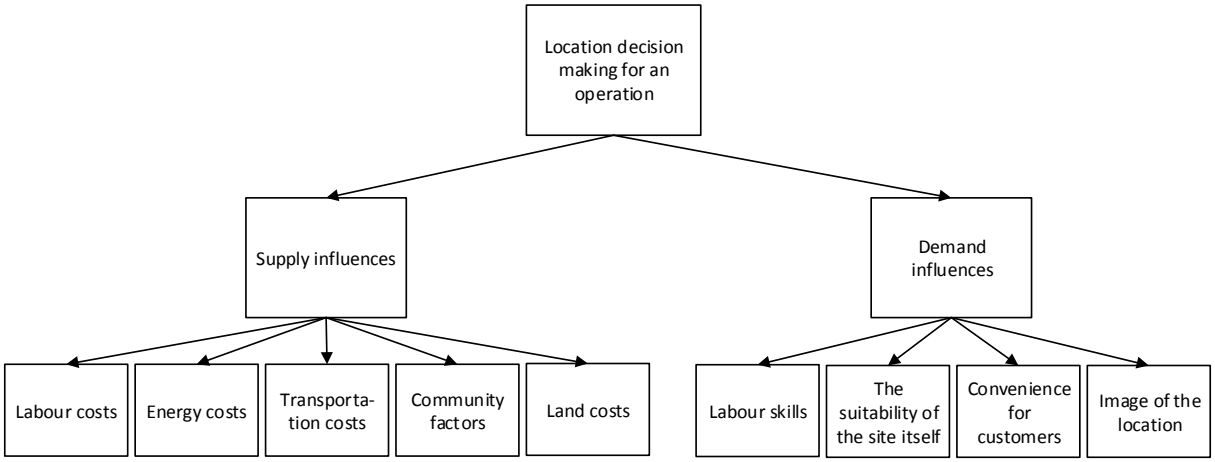
Finally, we fully read the most relevant papers and analysed them. We created a concept matrix in which the most important results of the literature review are given and described, so in the end we could write a conclusion.

Theoretical concepts

In this paragraph, first an overview of the theory is graphically presented. Thereafter the key words with their synonyms are given.

Overview theory

An overview of the topic of selecting a location for any operation is presented below, as already explained in chapter 3.2, these are the dimensions with their broad indicators.



(Slack, Brandon-Jones, & Johnston, 2013)

Figure 6: overview theory

Key words and synonyms

The key words with their synonyms are stated in the table below. All these words became clear when we were brainstorming about researching criteria to score potential locations.

Key words	Synonyms
Location	Facility, Single Facility, Warehouse, Shop, Site
Criteria	Multi-criteria, Evaluation, Factors
Location selection	Facility selection, single facility selection, Site selection

Table 6: keywords and synonyms

Inclusion and exclusion criteria

In this paragraph, the criteria that we used in our literature research are explained.

Number	Criteria	Inclusion Reason
1	Warehouse related selection	Relatable to needed operation in terms of infrastructure (supply)
2	Store related selection	Some relatable factors like accessibility (demand)
3	MCDM-related methods	Multi-criteria have to be assessed to advise a good location

Table 7: inclusion matrix

Number	Criteria	Exclusion Reason
1	Impact factor <1	Not relevant enough
2	Date before 2000	Make sure that the techniques/methods are useful in nowadays businesses.
3	Linguistic range (Dutch & English)	Can't be understood
4	International related operations with more than 1 facilities	There is no need to ship/transport overseas.

Table 8: exclusion matrix

Search strings

In the table below, the search strings that we used for our systematic literature review are given. We used Scopus to collect the data and found the articles.

Search string	**Scope**	**Date of search**	**Date range**	**Document type**	**Language**
"Location criteria" AND "Warehouse"	Title, Keywords & Abstract	2-1-2017	2000-2017	Article	English
"Site Selection" AND "Warehouse"	Title, Abstract	2-1-2017	2000-2017	Article	English
"Location selection" AND "Criteria" AND "Facility" OR "Site" OR "Warehouse"	Title, Keywords & Abstract	2-1-2017	2000-2017	Article	English
"Production site" OR "Warehouse" AND "Multi-criteria"	Title, Keywords & Abstract	3-1-2017	2000-2017	article	English

Table 9: search strings

Conceptual matrix

On the next pages, the conceptual matrix is given. This conceptual matrix is an overview of our systematic literature review and the key findings regarding Multi-criteria location selection. At the end, a short conclusion is stated which gives the finally chosen method.

Journal	**Authors (year)**	**Methodology**	**Operationalization Multi-criteria location selection**	**Key Finding Regarding Multi-criteria location selection**
Expert Systems with Applications	Tuncay Ozcan, Numan Celebi, Sakir Esnaf (2011)	Comparison of decision theory and a case theory	Methods: -TOPSIS -AHP -ELECTRE -Grey Theory	In multicriteria decision making methodologies, for the rank among the alternatives and the determination of their preference, the necessity to determine the relative importance of criteria reveals.

				AHP is a specific method, using a pair-wise comparison matrix.
Expert Systems with Applications	William Ho, Ali Emrouznejad (2008)	Exploration of optimization procedures in a network design	Methods: -AHP -Goal programming	In a MCDM technique it is important to consider both quantitative and qualitative factors. AHP is one of the most prevalent techniques that is used.
Applied Mathematical Modelling	Reza Zanjirani Farahani, Maryam SteadieSeifi, Nasrin Asgari (2009)	Review study on multi-criteria location selection using three methods	Methods: - ANP - AHP - ELECTRE - MAUT - TOPSIS - SMAA	MCDM can be used to solve multi-attribute location problems. Often the weights assigned to the criteria are inaccurate so fuzzy numbers can be used. AHP can be used with objective, subjective and critical factors.
Expert Systems with Applications	Tufan Demirel, Nihan Cetin Demirel, Cengiz Kahraman (2009)	Selecting Warehouse location using Choquet integral	Methods: - Choquet Integral	Creating sub-criteria for main criteria measured with fuzzy measures. Gives individual importance per criteria and sub-criteria that should be within tolerance levels.
International Journal of Advanced Manufacturing Technology	(Ertugrul & Karakasoglu, 2008)	Based on 5 criteria two methods are compared in the same situations (locations)	-Fuzzy AHP -Fuzzy TOPSIS	Methods are yielding the same outcome if decision-makers are consistent in determining the data. By using a consistent method to determine data, you will yield more objective and thus accurate results.
Information Sciences	(Kahraman, Ruan, & Dogan, Fuzzy group decision-making for facility location selection, 2003)	Literature review on fuzzy methods. Then a side-by-side comparison of 4 fuzzy multi-attribute group decision-making approaches	-Fuzzy Blin model -Fuzzy synthetic evaluation -Fuzzy AHP -Yager's weighted goals method	Data needed for each approach differs since the theoretic background differs. Importance of pin-pointing the weights in a systematic manner.
International Journal of Production Economics	Maro Vlachopoulou, George Silleos, Vassiliki Manthou (2001)	Integration of Geographic information systems (GIS) and Decision Support System (DSS).	GDSS	A location can be assessed using commercial software packages that uses a geographic decision

				support system (GDSS).
Computers and Electronics in Agriculture	J.L. Garcia, A. Alvarado, J. Blanco, E. Jiménez, A.A. Maldonado, G. Cortés(2014)	Development of the agribusiness location model based on Analytic Hierarchy Process.	AHP	After a revision of the methodologies, attributes, and frequent errors found during the process of selecting a placement location, it can be asserted that despite its wide variety, AHP is one of the most reliable methodologies according to the scientific literature consulted.

Table 10 – Conceptual matrix

Flow-chart article filtering for review

The flow-chart represents the way in which we selected our sources. After determining our keywords and their synonyms we were able to develop search strings. All articles found with the search strings (297 sources) are found in the first step of the selection. In the second step all sources were exported to Excel to dismiss five duplicates. For an article to be considerable for review, the impact factor has to be higher than 1. This is one of our inclusion criteria. Of the 98 remaining articles the title, abstract and keywords were analysed to conclude whether or not the article is going to be used in our literature review. For example, articles were excluded if they were not warehouse/store related which is relatable to our case.

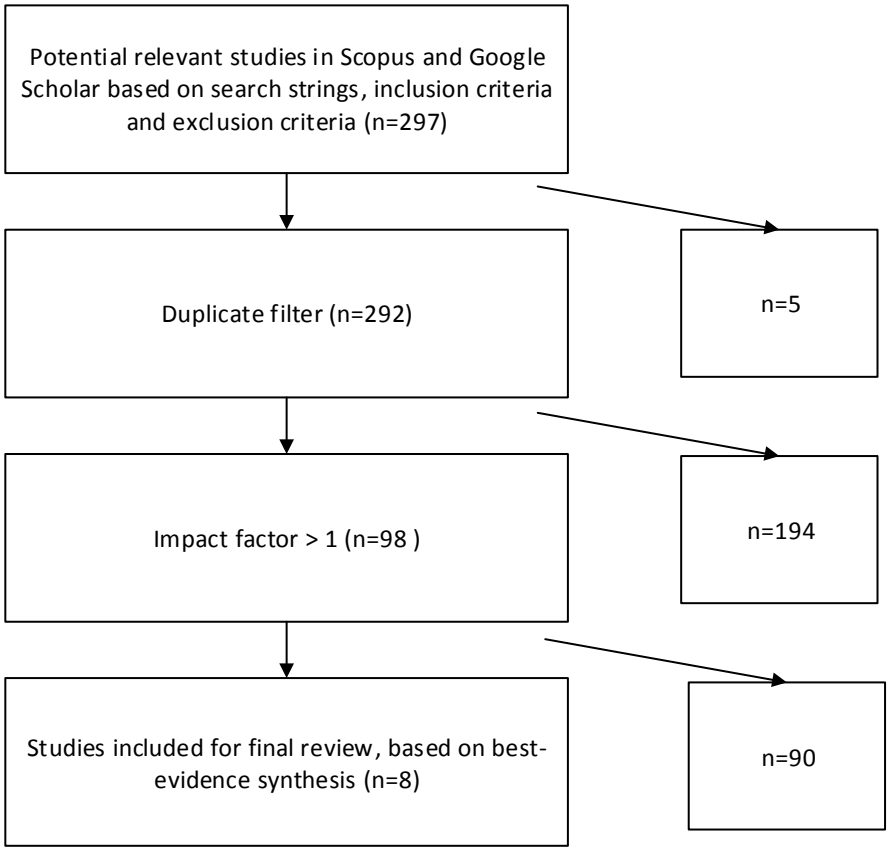


Figure 7: Flow-chart

Appendix 2: Criteria usability tables

In this table you can see all the criteria we've gathered and from which article we go them from. If criteria overlapped you can see which ones overlapped for our scenario. The project group column means that we've ourselves come up with this criteria. This was done because we wanted a criteria which measures centrallness.

Criteria / Source	(Tuncay Ozcan, 2011)	(William Ho, 2008)	(Farahani, SteadieSeifi, & Asgari, 2009)	(Demirel, Demirel, & Kahraman, 2009)	(Ertugrul & Karakasoglu, 2008)	(Kahraman, Ruan, & Dogan, Fuzzy group decision-making for facility location selection, 2003)	(Vlachopoulou, Silleos, & Manthou, 2001)	(Garcia, et al., 2014)	(Slack, N., Brandon-Jones, A.,& Johnston, R. (2013)	Project Group
Capacity			x							
Climate								x		
Community considerations					x				x	
Competition			x				x	x		
Competitive advantage						x				
Customer population							x			
Customs								x		

Distance to other public places	Average Distance to Shops		Public facility accessibility / Distance							
Economical			x							
Education and quality								x		
Environmental Risks			x							
Flexibility of capacity		x								
Free trade zones						x				
Handling costs				x						
Industrial regulation laws				x						
Infrastructure			Resource accessibility and utilization			Infastructure	Quality of transport links to site	Road access		
Labor Cost				x					x	
Land cost									x	
Local Government facilities								x		
Movement Flexibility	x									

Overall costs			Costs	Production costs			Warehouse management cost , Distribution Costs	Production costs	Energy costs	
Parking facilities							x			
Policies of government				x						
Political matters and regulations			x							
Population			x							
Possible store size							x			
Productivity								x		
Proposed in-store facilities							x			
Proximity to Centre of Gravity										x
Proximity to customers/buyer				x		x				

Proximity to Markets					x					
Proximity to suppliers / resources	x			x	x					
Purchase capacity								x		
Quality		x								
Quality of labour						x				
Quality of life					x			x		
Raw material								x		
Reliability of order fulfullment		x								
Risks								x		
Skilled labor				x					x	
Spending power of population							x			
Stock Holding Capacity	x									
Suitability			x						x	

Tax				Tax structure-incentives / Financial incentives				Taxation		
Telecommunication systems				x						
Terrain								x	x	
Total Lead time		Total Lead time		Lead times and responsiveness						
Transport of employees				Availability of labor force / Existence of modes of transport / Quality and reliability of modes of transportation						
Transportation Cost				x					x	
Union activity								x		

Unit price	x									
Value and benefits			x							
Value-added services		x								
Zoning and construction plan				x						
Convenience for customers									x	

Table 11 – All criteria

Appendix 3: Detailed AHP method worked out

In this part we're going to do show you the full AHP method we used for our report. For the criteria we will show you the reasoning / argumentation behind the score. After each section you can find the CR score, which stands for consistency. The total scores can be found in the Excell file, which is the weight of the criteria * score of the alternative.

First we are going to calculate the weights of the criteria, after we've done that we will calculate the score for each alternative per criteria and thirdly we will multiply the score with the weight per criteria and sum everything to a total score per alternative.

Table 1 – Scale of relative importance (according to Saaty (1977; 1980)).

Intensity of importance	Definition
1	**Equal importance**
2	Weak
3	**Moderate importance**
4	Moderate plus
5	**Strong importance**
6	Strong plus
7	**Very strong or demonstrated importance**
8	Very, very strong
9	**Extreme importance**

Transportation Costs	3	Land costs	1	Transportation costs are somewhat more important because transportation costs are continuous and the cost of land is a one time payment. We thus choose for the long run.
Transportation Costs	3	Proximity to CoG	1	We have a slight overlap in these two variables at first sight, but after thinking thoroughly a detour would have no effect on proximity of CoG, but transportation costs would be affected. This is why we think that Transportation costs is a somewhat more important variable than Proximity to CoG
Transportation Costs	6	Proximity to buyer of scrap	1	Transportation Costs is a more important variable than proximity to buyer of scrap, because delivery costs can be (at least partly) be calculated in the requested price. The internal transportation costs are always costs.
Transportation Costs	2	Taxation	1	Transportation Costs is a bit more important than taxation, because if the E-waste is increasing as much as they think it is, the transportation cost will be a
Transportation Costs	4	Modes of transportation	1	Modes of transportation is less important than transportation costs because there is much more

				E-waste which needs transportation than people which need transportation.
Land costs	1	Proximity to CoG	1	Equally important.
Land costs	3	Proximity to buyer of scrap	1	Land costs is more important than proximity to buyer because the costs of transportation to the buyer is shared while the land costs are solely for Twente Milieu/De Beurs
Land costs	1	Taxation	2	Taxation is slightly more important because the costs are continuous.
Land costs	2	Modes of transportation	1	Modes of transportation is slightly less important because the transportation costs are likely to be less than the land costs.
Proximity to CoG	3	Proximity to buyer of scrap	1	Proximity to CoG is more important than Proximity to buyer of scrap because we value a central location higher than a location closer to a buyer. Buyers can change, but its unlikely that the locations of twente milieu and de beurs change.
Proximity to CoG	1	Taxation	2	Taxation is slightly more important because proximity to CoG has less impact on revenue streams than taxation.
Proximity to CoG	1	Modes of transportation	2	Modes of transportation is slightly more important because the modes of transportation is important for the employees while the proximity is about centralness and costs are already taken into account by transportation costs. Also we'd rather have a slightly less central location with more buss stops than a central location with less buss stops.
Proximity to buyer of scrap	1	Taxation	4	Taxation are continuous costs and aren't split while proximity to the buyer are continuous cost but are split.This makes Taxation more important.
Proximity to buyer of scrap	1	Modes of transportation	3	Modes of transportation are more important than the proximity to the buyer of scrap.
Taxation	1	Modes of transportation	1	Equally important

Category		Priority	Rank
1	Transportation Costs	36.9%	1
2	Land Costs	13.3%	4
3	ProximitytoCoG	10.7%	5
4	ProximitytoBuyer	4.5%	6
5	Taxation	21.0%	2
6	Modes of Transportation	13.6%	3

	1	**2**	**3**	**4**	**5**	**6**
1	1	3.00	3.00	6.00	2.00	4.00
2	0.33	1	1.00	3.00	0.33	2.00

3	0.33	1.00	1	3.00	0.50	0.50
4	0.17	0.33	0.33	1	0.25	0.33
5	0.50	3.00	2.00	4.00	1	1.00
6	0.25	0.50	2.00	3.00	1.00	1

The consistency ratio is OK: 0.047 , which means that scores have been given consistently.

Proximity to centre of gravity

Alternative:	**Bedrijventerrein Oosterveld**	**Twentekanaal Noord**	**Twentekanaal Zuid**	**Westermaat Zuid-West**	**Westermaat Noord-Oost**
Distance from CoG	1,86km	3,95km	4,64km	3,03km	2,77km

Bedrijventerrein Oosterveld	**6**	**Twentekanaal Zuid**	**1**
Bedrijventerrein Oosterveld	5	Twentekanaal Noord	1
Bedrijventerrein Oosterveld	3	Westermaat Zuid-West	1
Bedrijventerrein Oosterveld	2	Westermaat Noord-Oost	1
Twentekanaal Zuid	1	Twentekanaal Noord	2
Twentekanaal Zuid	1	Westermaat Zuid-West	2
Twentekanaal Zuid	1	Westermaat Noord-Oost	3
Twentekanaal Noord	1	Westermaat Zuid-West	2
Twentekanaal Noord	1	Westermaat Noord-Oost	3
Westermaat Zuid-West	1	Westermaat Noord-Oost	2

Category		Priority	Rank
1	Bedrijventerrein Oosterveld	44.5%	1
2	Twentekanaal Zuid	6.8%	5
3	Twentekanaal Noord	9.4%	4
4	Westermaat Zuid-West	14.7%	3
5	Westermaat Noord-Oost	24.6%	2

	1	2	3	4	5
1	1	6.00	5.00	3.00	2.00
2	0.17	1	0.50	0.50	0.33
3	0.20	2.00	1	0.50	0.33
4	0.33	2.00	2.00	1	0.50
5	0.50	3.00	3.00	2.00	1

Consistency is ok, CR = 1,4%.

Modes of transportation

Alternative:	Bedrijventerrein Oosterveld	Twentekanaal Noord	Twentekanaal Zuid	Westermaat Zuid-West	Westermaat Noord-Oost
Buss stops per hectare	0	0,075	0,0436	0,048	0,091

Bedrijventerrein Oosterveld	**1**	**Twentekanaal Noord**	**8**
Bedrijventerrein Oosterveld	1	Twentekanaal Zuid	7
Bedrijventerrein Oosterveld	1	Westermaat Zuid-West	7
Bedrijventerrein Oosterveld	1	Westermaat Noord-Oost	9
Twentekanaal Noord	3	Twentekanaal Zuid	1
Twentekanaal Noord	2	Westermaat Zuid-West	1
Twentekanaal Noord	1	Westermaat Noord-Oost	2
Twentekanaal Zuid	1	Westermaat Zuid-West	1
Twentekanaal Zuid	1	Westermaat Noord-Oost	3
Westermaat Zuid-West	1	Westermaat Noord-Oost	4

Category		Priority	Rank
1	Bedrijventerrein Oosterveld	2.9%	5
2	Twentekanaal Noord	27.1%	2
3	Twentekanaal Zuid	13.7%	4
4	Westermaat Zuid-West	13.9%	3
5	Westermaat Noord-Oost	42.4%	1

	1	2	3	4	5
1	1	0.12	0.14	0.14	0.11
2	8.00	1	3.00	2.00	0.50
3	7.00	0.33	1	1.00	0.33
4	7.00	0.50	1.00	1	0.25
5	9.00	2.00	3.00	4.00	1

CR is 3,9%, which is ok consistency.

Industrial taxation

Since all locations based on our research fall within the same municipality, there will be no difference between locations. We've gathered information by calling the municipality of Hengelo and they confirmed that there is no difference in taxation based on these locations. We keep this criteria in the model, even though it has no impact now, because Twente Millieu or De Beurs may want to score a different option which happens to fall in another municipality. In this case the industrial taxation will have an effect on the total score.

Alternative:	**Bedrijventerrein Oosterveld**	**Twentekanaal Noord**	**Twentekanaal Zuid**	**Westermaat Zuid-West**	**Westermaat Noord-Oost**
Taxation score	1	1	1	1	1

Bedrijventerrein Oosterveld	**1**	**Twentekanaal Noord**	**1**
Bedrijventerrein Oosterveld	1	Twentekanaal Zuid	1
Bedrijventerrein Oosterveld	1	Westermaat Zuid-West	1
Bedrijventerrein Oosterveld	1	Westermaat Noord-Oost	1
Twentekanaal Noord	1	Twentekanaal Zuid	1
Twentekanaal Noord	1	Westermaat Zuid-West	1
Twentekanaal Noord	1	Westermaat Noord-Oost	1
Twentekanaal Zuid	1	Westermaat Zuid-West	1
Twentekanaal Zuid	1	Westermaat Noord-Oost	1
Westermaat Zuid-West	1	Westermaat Noord-Oost	1

Category		Priority	Rank
1	Bedrijventerrein Oosterveld	20.0%	1
2	Twentekanaal Noord	20.0%	1
3	Twentekanaal Zuid	20.0%	1
4	Westermaat Zuid-West	20.0%	1
5	Westermaat Noord-Oost	20.0%	1

	1	2	3	4	5	
1	1	1.00	1.00	1.00		1.00
2	1.00	1	1.00	1.00		1.00
3	1.00	1.00	1	1.00		1.00
4	1.00	1.00	1.00	1		1.00
5	1.00	1.00	1.00	1.00		1

CR = 0%, which is OK.

Transportation Costs

Alternative:	Bedrijventerrein Oosterveld	Twentekanaal Noord	Twentekanaal Zuid	Westermaat Zuid-West	Westermaat Noord-Oost
Total km * kg	14348898	14857938	17315784	13117854	14672214

Bedrijventerrein Oosterveld	**2**	**Twentekanaal Noord**	**1**
Bedrijventerrein Oosterveld	5	Twentekanaal Zuid	1
Bedrijventerrein Oosterveld	1	Westermaat Zuid-West	3
Bedrijventerrein Oosterveld	2	Westermaat Noord-Oost	1
Twentekanaal Noord	4	Twentekanaal Zuid	1
Twentekanaal Noord	1	Westermaat Zuid-West	4
Twentekanaal Noord	1	Westermaat Noord-Oost	1
Twentekanaal Zuid	1	Westermaat Zuid-West	7
Twentekanaal Zuid	1	Westermaat Noord-Oost	4
Westermaat Zuid-West	4	Westermaat Noord-Oost	1

Category		Priority	Rank
1	Bedrijventerrein Oosterveld	21.7%	2
2	Twentekanaal Noord	12.9%	3
3	Twentekanaal Zuid	4.3%	5
4	Westermaat Zuid-West	48.2%	1
5	Westermaat Noord-Oost	12.9%	3

	1	2	3	4	5
1	1	2.00	5.00	0.33	2.00
2	0.50	1	4.00	0.25	1.00
3	0.20	0.25	1	0.14	0.25
4	3.00	4.00	7.00	1	4.00
5	0.50	1.00	4.00	0.25	1

CR is OK, 2,5%.

Land costs

Alternative:	Bedrijventerrein Oosterveld	Twentekanaal Noord	Twentekanaal Zuid	Westermaat Zuid-West	Westermaat Noord-Oost
Average cost in euro per m2	158	125	110	167,50	163,75

Bedrijventerrein Oosterveld	1	Twentekanaal Noord	5
Bedrijventerrein Oosterveld	1	Twentekanaal Zuid	6
Bedrijventerrein Oosterveld	3	Westermaat Zuid-West	1
Bedrijventerrein Oosterveld	2	Westermaat Noord-Oost	1
Twentekanaal Noord	1	Twentekanaal Zuid	3
Twentekanaal Noord	6	Westermaat Zuid-West	1
Twentekanaal Noord	5	Westermaat Noord-Oost	1
Twentekanaal Zuid	8	Westermaat Zuid-West	1
Twentekanaal Zuid	7	Westermaat Noord-Oost	1
Westermaat Zuid-West	1	Westermaat Noord-Oost	1

Category		Priority	Rank
1	Bedrijventerrein Oosterveld	9.4%	3
2	Twentekanaal Noord	28.6%	2
3	Twentekanaal Zuid	51.9%	1
4	Westermaat Zuid-West	4.7%	5
5	Westermaat Noord-Oost	5.4%	4

	1	2	3	4	5
1	1	0.20	0.17	3.00	2.00
2	5.00	1	0.33	6.00	5.00
3	6.00	3.00	1	8.00	7.00
4	0.33	0.17	0.12	1	1.00
5	0.50	0.20	0.14	1.00	1

CR is ok, 4,1%

Proximity to Buyer

Alternative:	Bedrijventerrein Oosterveld	Twentekanaal Noord	Twentekanaal Zuid	Westermaat Zuid-West	Westermaat Noord-Oost
Distance to Omrin	156	156	155	151	152

Bedrijventerrein Oosterveld	**1**	**Twentekanaal Noord**	**1**
Bedrijventerrein Oosterveld	1	Twentekanaal Zuid	2
Bedrijventerrein Oosterveld	1	Westermaat Zuid-West	6
Bedrijventerrein Oosterveld	1	Westermaat Noord-Oost	5
Twentekanaal Noord	1	Twentekanaal Zuid	2
Twentekanaal Noord	1	Westermaat Zuid-West	6
Twentekanaal Noord	1	Westermaat Noord-Oost	5
Twentekanaal Zuid	1	Westermaat Zuid-West	5
Twentekanaal Zuid	1	Westermaat Noord-Oost	4
Westermaat Zuid-West	2	Westermaat Noord-Oost	1

Category		Priority	Rank
1	Bedrijventerrein Oosterveld	6.2%	4
2	Twentekanaal Noord	6.2%	4
3	Twentekanaal Zuid	10.3%	3
4	Westermaat Zuid-West	46.2%	1
5	Westermaat Noord-Oost	31.1%	2

	1	**2**	**3**	**4**	**5**
1	1	1.00	0.50	0.17	0.20
2	1.00	1	0.50	0.17	0.20
3	2.00	2.00	1	0.20	0.25
4	6.00	6.00	5.00	1	2.00
5	5.00	5.00	4.00	0.50	1

CR = 1,5%, which is ok.

Appendix 4: Handleiding AHP Tool excel

Handleiding AHP excel tool

1. Identificeer welke opties er zijn voor de beslissing die je wil maken.
2. Identificeer de criteria die invloed hebben op de beslissing.
3. Selecteer de criteria die je meeneemt in het model, wij adviseren een selectie gebasseerd op: Toepasbaarheid, Overlap, Meetbaarheid. Beperk het aantal criteria zo veel mogelijk. Overlap zorgt voor een slechte bepaling van de weging, dus neem overlappende (sub)criteria samen tot 1 criteria. Toepasbaarheid zorgt ervoor dat alleen relevante criteria die de beslissing beïnvloeden. Meetbaarheid zorgt ervoor dat de het proces objectiever kan worden uitgevoerd.
4. Bepaal / bereken de waarde van iedere optie per geselecteerde criteria.

AHP calculator

1. Ga naar http://bpmsg.com/academic/ahp_calc.php
2. Linksbovenin, vul het aantal criteria in die je geselecteerd hebt, druk op GO.
3. Geef het model een titel en vul de namen van de criteria in, druk op OK.
4. Je gaat nu voor de criteria één-op-één bepalen welke belangrijker is, klik op de 1e of 2e kolom (indien even belangrijk, maakt het niet uit welke je aanklikt).
5. Geef in de 3e en 4e kolom aan hoeveel belangrijker dit criteria is t.o.v. de andere. Dit is op en schaal van 1 tot 9. De uitleg van de waarden staat onder de tabel.
6. Nadat je dit voor alle vergelijkingen hebt gedaan, druk je op Calculate Result.
7. Kijk of de CR (onderaan in de tabel gelabeld is als OK), indien niet OK dan laat de tabel je zien waar de scores niet consistent genoeg gegeven zijn.
8. Kopieer de tabel linksonderin met de prioriteiten (dit is de berekende wegingsfactor per criteria).

1. Linksbovenin, vul het aantal opties in die je geselecteerd hebt, druk op GO.
2. Geef het model in de titel de naam van de criteria waarvoor je de verschillende opties tegen elkaar gaat afwegen en vul de namen van de opties eronder in, druk op OK.
3. Je gaat nu voor de opties één-op-één bepalen welke beter scoort op dit criteria, klik op de 1e of 2e kolom (indien even belangrijk, maakt het niet uit welke je aanklikt).
4. Geef in de 3e en 4e kolom aan hoeveel beter deze optie is t.o.v. de andere. Dit is op een schaal van 1 tot 9. De uitleg van de waarden staat onder de tabel.
5. Nadat je dit voor alle vergelijkingen hebt gedaan, druk je op Calculate Result.
6. Kijk of de CR (onderaan in de tabel gelabeld is als OK), indien niet OK dan laat de tabel je zien waar de scores niet consistent genoeg gegeven zijn.
7. Kopieer de tabel linksonderin met de prioriteiten (dit is de score van de opties op dit criteria) en herhaal deze 7 stappen voor ieder criteria.

Excel

1. Maak een tabel met het aantal kolommen = aantal opties + 1, aantal rijen = aantal criteria + 2. De cel linksbovenaan heet Criteria, de cel linksonderaan heet Totaal. De opties zet je bovenaan en de criteria links.
2. Vul de cellen in door de weging van het criteria wat links staat maal de score van de optie die erboven staat te berekenen. Doe dit voor ieder vakje.
3. Tel voor iedere optie de score per criteria op en zet dit in Totaal.
4. De optie met de hoogste totaalscore is de beste beslissing.