Determining the optimal warehouse location

Bachelor Thesis: Industrial Engineering and Management

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Preface

This report is the result of my Bachelor graduation thesis in the field Industrial Engineering and Management, at the University of Twente. I conducted this research for Avebe in the period from February 2019 till July 2019. At Avebe, I did research to determine the optimal storage location to replace their current warehouse in Sweden. I have done this by conducting semi-structured individual in depth interview with the management. Next to that I have applied discrete location modelling.

I would like to thank Erik Pricker and Carlijn Bontjer from Avebe, for their help during this research and their time and energy invested. I would like to thank also all the other employees of Avebe which were involved in my research.

Next to that I would like to thank supervisors from the University of Twente for their critical and good feedback which strongly enhanced the quality of my report. My first supervisor Leo van der Wegen who supervised me during his sabbatical and my second supervisor Eduardo Lalla.

Lastly, I would like to thank my family and Marlinde Vetkamp for their mental support, interest and feedback.

Ruben Zwiers, 7-5-2019, Enschede

Summary

Introduction

Avebe is corporation of approximately 2500 potato farmers, which core business is making starch and protein products out of potatoes. In order to do so, Avebe has production plants and warehouses in Germany, Sweden and The Netherlands to fulfill customer demand all over the world. This is done by approximately 1350 employees.

Motivation and core question of this research

The warehouse in Sweden needs to close since the Swedish government wants to build houses at that location by October 2020. Therefore, Avebe asked to determine the optimal storage location for Avebe to store their products when the currently used warehouse closes. Besides, the customer demand allocation over the warehouse that replaces the warehouse in Sweden and the warehouse in The Netherlands is researched.

Problem solving approach

First the current process between the factory in Sweden and the customers is analyzed. This analysis concerns the following information:

1. The current process layout including the product flows.
2. The costs in the current process split into storage, transportation, labor and handling costs.
3. The CO_2 emission caused by transportation based on the different transportation means.
4. The changes in the process between the factory in Sweden and the customer when the warehouse in Sweden is replaced.
5. An analysis on the stakeholders of the process and their roles.
6. My personal view on how the warehouse scenarios should be assessed, being the costs, sustainability and ethical impact.

Secondly, the problem-solving approach is based on literature in three ways. First, this research provides an overview of the variables on which the warehouse scenarios should be assessed according to professional companies in the field of warehouse solutions. Second, a systematic literature review is conducted to determine the different types of discrete facility location models that exist and when these should be applied. Lastly, based on the systematic literature review the fixed charge uncapacitated facility location model is selected and applied in this research to determine the score of the different warehouse scenarios on the operationalized criterion costs.

Thirdly, semi-structured individual in depth interviews with the management are conducted to determine what important requirements and wishes of the management are when analyzing different warehouse solutions. This together with my personal view and the assessment criteria according to the professionals in the field of warehouse solutions resulted in two things. First, the operationalized criteria in this study being the costs (split into storage, transportation, labor and handling costs) and the CO_2 emission caused by transportation. Secondly, the points of attention for the purchase department, when selecting one specific warehouse. These are mentioned in the advisory report. Besides, during these interviews the warehouse scenarios in scope of this research are determined. This yielded six different warehouse scenarios of which three scenarios have a warehouse in Helsingborg and three scenarios have a warehouse on the factory site in Sweden. The warehouse scenarios with the same warehouse locations differ in their customer demand allocation.

Result, conclusion and recommendation

Based on scores of the different warehouse scenarios analyzed, this research shows that Avebe can best locate its new warehouse on the site of their factory in Sweden. Besides, the allocation of customer demand should stay the same except for the fact that the products of the customers delivered from The Netherlands should directly after production be transported to the warehouses in The Netherlands (without storing these in Sweden). The numbers used in the calculations of this report are the real numbers of financial year 2018, which starts at August 2017 and ends in July 2018.

I recommend Avebe to change to this new warehouse scenario as soon as possible, since this yields Avebe a cost saving of €303,313 per year which is 11.1% of the total costs between the factory and the customer. Besides, the CO_2 emission caused by transportation can be reduced with 1,040 kilograms per year, which is 0.03% of the total CO_2 emission caused by transportation. Next to that, the employees in the current warehouse can be kept and work in the new warehouse, since this is about one kilometer away from the currently used warehouse. Lastly, sensitivity analyses on the outcomes of this research are provided. Based on this analysis can be concluded that the outcome of this research is not likely to be affected by a change in the cost's coefficients "storage costs on the site of the Swedish factory" and "cost per kilogram CO_2 emission".

Summary (in Dutch)

Introductie

Avebe is een coöperatie van ongeveer 2500 aardappelboeren, wiens kernactiviteit het maken van zetmeel- en eiwitproducten uit aardappelen is. Om dit te realiseren heeft Avebe fabrieken en magazijnen in Duitsland, Zweden en Nederland waarmee aan de klanten vraag over de hele wereld wordt voldaan. Dit alles wordt gedaan door de plus minus 1350 werknemers van Avebe.

Motivatie en kernvraag van dit onderzoek

Het magazijn in Zweden moet dicht omdat de Zweedse overheid per Oktober 2020 huizen wil bouwen op deze plek. Daarom heeft Avebe mij gevraagd om te onderzoeken wat de beste opslaglocatie voor de producten van Avebe is, wanneer het huidige magazijn gesloten wordt. Daarnaast moet de allocatie van de klanten over de magazijnen opnieuw bekeken worden.

Probleem aanpak

Allereest is het huidige proces tussen de fabriek in Zweden en de klanten geanalyseerd. Deze analyse bevat de volgende informatie:

1. De huidige proces indeling inclusief de product stromen.
2. De kosten in de huidige situaties opgesplitst in de opslag, transport, arbeid en in- en uitslag kosten.
3. De CO_2-uitstoot veroorzaakt door transport gebaseerd op de verschillende transportmiddelen.
4. De veranderingen in het proces tussen de fabriek in Zweden en de klanten wanneer het magazijn in Zweden vervangen wordt.
5. Een analyse van de stakeholders van dit onderzoek en hun rol.
6. Mijn mening over waarop de verschillende scenario's in dit onderzoek beoordeeld moeten worden. Dit zijn de kosten, duurzaamheid en ethische impact.

Ten tweede is de probleem aanpak gebaseerd op verschillende literaire onderzoeken. Allereerst, geeft dit onderzoek een overzicht van de variabelen waarop de scenario's beoordeeld moeten worden volgens professionele bedrijven die gespecialiseerd zijn in het bieden van magazijn oplossingen. Ten tweede, is er een systematisch literatuuronderzoek gedaan om een overzicht te creëren van de verschillende discrete locatie modellen die bestaan de wanneer deze dienen te worden toegepast. Tot slot, wordt er gekozen voor het "fixed charge uncapacitated facility" locatie model op basis van het uitgevoerde systematische literatuuronderzoek.

Ten derde zijn er semigestructureerde individuele diepte-interviews afgenomen met het management om de belangrijkste eisen en wensen, voor het beoordelen van de magazijn oplossingen, volgens de managers vast te stellen. Deze interviews hebben samen met mijn persoonlijke mening en de beoordelingscriteria van de professionele bedrijven tot twee dingen geleidt. Allereerst, de geoperationaliseerde criteria kosten (opgebouwd uit de opslag, transport, arbeid en in- en uitslag kosten) en CO_2-uitstoot veroorzaakt door transport. Ten tweede, een advies rapport met aandachtpunten voor de inkoopafdeling wanneer ze één specifiek magazijn moeten kiezen naar aanleiding van dit onderzoek.
Daarnaast zijn de magazijn scenario's die onderzocht worden in dit onderzoek bepaald tijdens deze interviews. Dit heeft zes scenario's opgeleverd waarvan drie met een magazijn in Helsingborg en drie met een magazijn op het terrein van de fabriek in Zweden. De drie scenario's met dezelfde magazijn locaties verschillen in de verdeling van de klanten allocatie.

Resultaten, conclusies en aanbevelingen

Gebaseerd op de scores van de verschillende scenario's die geanalyseerd zijn in dit onderzoek, kan ik concluderen dat het nieuwe magazijn het best op de grond van de fabriek in Zweden kan worden geplaatst. Verder kan de allocatie van de klant vraag het beste gelijk blijven aan hoe deze in de huidige situatie is. Alleen moeten de producten voor de klanten die beleverd worden vanaf Nederlands direct na productie in Zweden naar de Nederlandse magazijnen getransporteerd worden (zonder eerst te worden opgeslagen in Zweden). De berekeningen in dit onderzoek om tot deze conclusie te komen zijn gebaseerd op de echte getallen van financieel jaar 2018.

Ik adviseer Avebe om zo snel mogelijk over te gaan op dit nieuw scenario aangezien dit Avebe een kostenbesparing van €303.313,- per jaar oplevert. Dit is gelijk aan 11,1% van de totale kosten tussen de fabriek in Zweden en de klant in de huidige situatie. Daarnaast zal deze verandering een reductie van 1.040 kilogram CO_2-uitstoot per jaar, veroorzaakt door transport, opleveren. Dit is gelijk aan 0,03% van de totale CO_2-uitstoot veroorzaakt door transport in de huidige situatie. Daarnaast kunnen de mensen die in het huidige magazijn werken weer in het nieuwe magazijn werken, aangezien dit één kilometer verderop is. Tot slot is er gevoeligheidsanalyse van de uitkomsten van dit onderzoek gegeven. Op basis van deze gevoeligheidsanalyse kan worden geconcludeerd dat de uitkomsten van dit onderzoek niet veranderen door een realistische verandering in de kosten coëfficiënten "opslagkosten op het terrein van de fabriek in Zweden" en "kosten per kilogram CO_2-uitstoot".

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Reader's guide

In this reader's guide, a short and clear overview is given of what can be found in which chapter of my thesis. This makes it possible to quickly find what you are looking for. In case of reading the whole thesis, the guide gives an idea of the direction in which the research is going.

Chapter 1 Introduction

In this chapter the company description, research motivation, problem statement, scope of research, research objectives, research questions and problem-solving approach are stated.

Chapter 2 The current process between factory and customer

In this chapter the current process between the factory and the final customers is described in terms of product flows, storage and transportation. Special attention is payed to the costs and CO_2 emission in the current situation. Besides, the changes, stakeholders and complexities in the current process are highlighted. Lastly, my personal view on what good assessment criteria are to access warehouse scenarios on is given.

Chapter 3 Background study

In this chapter theoretical background is provided to support my problem-solving approach. A study about what the warehouse scenario assessment criteria should be according to three professional companies in the field of warehouse solutions is given. After that, a systematic literature review to find out what type of discrete location models exists and when these should be used, can be found. Lastly, the discrete location model used in this thesis is chosen. This is done based on the outcomes of the systematic literature review.

Chapter 4 Requirements, wishes and scope of the management

In this chapter the requirements, wishes and warehouses in scope of this research are determined. This is done based on semi-structured individual in depth interviews with the management.

Chapter 5 The best warehouse

In this chapter is determined what the best warehouse scenario is. This is done by scoring the different warehouse scenarios based on the operationalized assessment criteria, which are determined in Chapter 4.

Chapter 6 Conclusions, recommendations and discussion

This chapter covers the conclusions, recommendations and discussion on the assumptions and limitations of the research.

Definition of key concepts and variables

Below I provide a list of the variables and concepts which I use in my research, in order to make sure that the message comes across the way it is intended to.

Avebe
When I am talking about Avebe in relationship to storage capacity, product flows, transportation and CO_2 emission, I am talking about the products made at the factory (Stadex) in Malmö.

The management
When I am talking about the management of Avebe, I mean the supply chain director of Avebe, the supply chain manager of Avebe, the supply chain manager at Stadex, the category manager transport & warehousing of Avebe and the sales and operations planner at Avebe (my supervisor).

The Analytical Hierarchy Process (AHP) tool
The Analytic Hierarchy Process (AHP), introduced by Thomas Saaty (1980), "is a multicriteria model that provides a methodology for comparing alternatives by structuring criteria into a hierarchy, providing for pair-wise comparisons of criteria at the lowest level of the hierarchy to be entered by the user, and synthesizing the results into a single numerical value". (Phillips-Wren G. E., Mora, M. & Forgionne, G., 2008)

Fixed costs
"Fixed costs are the expenses that have to be paid by a company, independent of any business activity" (Investopedia, 2018). Examples of fixed cost in this research are the storage costs and the labor costs.

Variable costs
"Variable costs are expenses that are dependent on the business activity" (Investopedia, 2019). Examples of variable costs in this research are the transportation costs and the handling costs.

Transportation cost
"The expenses involved in moving products or assets to a different place" (Business-Dictionary, 2019). At Avebe, transportation is outsourced. Therefore, the transportation costs are equal to the costs of the contracts with the transportation companies.

CO_2 emission
In this research the CO_2 emission is calculated based on the amount of transportation kilometers, the weight of the products transported (in ton kilograms) and the different CO_2 ratios for transportation by truck, train and ship.

Storage costs
The storage costs are the renting cost for the warehouse. These costs are based on the number of squared meters warehouse rent.

Handling costs
The handling costs are the costs for loading and unloading of the truck, train or ship, when this is done by external people.

Labor costs
The labor costs are the costs of the wages for the Avebe employees working in the warehouse.

1. Introduction

This chapter consist of seven different sections. Section 1.1 gives a short introduction about Avebe. Section 1.2 provides the original reason for this research. In Section 1.3, the core problem of this research is stated. Section 1.4 describes the scope of the research. In Section 1.5, the goal of this research is stated. Section 1.6 mentions the research questions and the approach of answering these research questions. Lastly, in Section 1.7 a summarizing overview of the problem-solving approach is given.

1.1 A few words about Avebe

The organization that this research focusses on, is Avebe. Avebe is a corporation of approximately 2500 potato farmers and has its headquarters in Veendam, The Netherlands. The core business of Avebe is producing starch and protein products out of potatoes. These products do have a lot of different applications in, amongst others, the paper, healthcare, animal feeding and human food industry. The production plants of Avebe are located in Germany, Sweden and The Netherlands. These factories process about three million tons of potatoes each year. From these plants, the products of Avebe are distributed all over the world. All this is done by approximately 1350 employees of Avebe.

1.2 Research motivation

The reason for this research within Avebe is as follows. One of the production plants of Avebe (Stadex) is located in Malmö, Sweden. Next to this plant, Avebe rents a warehouse (called Briggen) where the products, made at the Stadex plant, are stored. Both the Stadex factory and Briggen (the warehouse) are located within the living area of Malmö. This is due to the urban development. Now, Avebe estimates that the odds are large that the Swedish government wants to build houses at the location of their current warehouse. Building these houses can start, worst case scenario, in November 2020 since Avebe’s contract with warehouse Briggen is valid until October 2020. Therefore, Avebe asked to make a business plan which states the current situation and gives an advice about what warehouse Avebe should rent when it is no longer possible to store the products at Briggen. Avebe does not have the money to buy or build a warehouse itself, but it is possible that another company builds a new warehouse for Avebe in exchange for a renting contract with Avebe.[1]

1.3 Problem description

This research is focusing on the following core problem:

“Which warehouse should Avebe rent when it is no longer possible to store products at Briggen?”

The reason for choosing this as the core problem is the following. The government is likely going to build houses at the location of the current warehouse, while Avebe needs a warehouse to store its products. This means that Avebe must look for a new warehouse. Next to this core problem, Avebe also wants to know if the allocation of customer demand over this new warehouse and the existing warehouses can be done in a better way.

[1] I found out that this build and rent back construction is possible during the interviews I conducted with the management in order to write Chapter 4.

1.4 The scope of research

This research focusses on finding the best warehouse solution for Avebe when Briggen needs to close. The warehouse scenarios in analysis of this research do have scenario specific fixed warehouse locations and customer demand allocations over the warehouses. Both the warehouse locations and customer demand allocations are asked for in the interviews with the management which I conduct. The outcome of these interviews can be found in Section 4.3.

Next to that, this research assumes that the factory (Stadex) and the warehouses in the USA stay the same. Besides, the research is based on the numbers of financial year 2018 (which is from August 2017 till July 2018). I chose to base this research on financial year 2018, because this is the latest full year of data available and therefore the most representative data for future calculations.

Lastly, it is important to know that this research concerns products made at the Stadex factory in Sweden. So, the products made at the factories in Germany and The Netherlands are not in scope of this research.

1.5 Research objective

The objective of the research is to find the optimal warehouse location, and related customer demand allocation, for the storage of Stadex products when Briggen needs to be closed. To do so, I deliver the following:

1. Insights into what are criteria on which the potential new warehouse scenarios should be assessed.
2. An advisory report for the purchasing department which states the points of attention when selecting one specific warehouse based on the outcomes of this research.
3. A model which can be used to determine the costs of different warehouse scenarios.
4. A model which can be used to determine the CO_2 emission caused by transportation of different warehouse scenarios.
5. This thesis which describes the research, outcomes and a piece of advice for Avebe. Also, the calculations and underpinning are provided.
6. A well substantiated advice to Avebe about what warehouse Avebe should rent instead of Briggen and which customer demand should be fulfilled from this warehouse.

1.6 Research (sub) questions and plan of approach for answering the research questions

In order to make sure that Avebe does not end up without storage capacity by October 2020, I look for the best warehouse to rent when Briggen indeed needs to close. Below, I briefly describe the content of Chapter 2 up to and including Chapter 6, my problem-solving approach and the questions answered in these chapters. Next to that, I explain why I answer these questions and how I gather the data needed to answer the questions.

(Ch 2.) The current process between factory and customer

In this chapter, I describe and analyze the current situation. Describing and analyzing the current situation helps me to get a good idea about the process I am researching. This yield me useful insights in the complexities of the current process and the stakeholders involved, which help me to analyze possible future warehouse solutions. Next to this, the current process acts as a 'base line' for analyzing the other possible warehouses. For example, once I know what the costs involved in the current process between factory and customers are, I have a better idea of the costs which I find by analyzing other warehouse scenarios (since I do have the current situation to compare with). Lastly, at the end of this chapter, focusing on describing and analyzing the current situation, I ask myself what criteria I think that possible future warehouse should be assessed on, based on the research that I have done so far. I ask myself this question because, the research done so far is mainly based on numbers and facts, which means that I am not yet influenced by personal perceptions of managers at this stage. This makes it possible to have an independent look at the process. Next to that, the list of criteria helps me to execute the background study of Section 3.1 and therefore to have a good structure and good questions for the semi-structured individual in depth interviews. I conduct these interviews to determine the requirements and wishes of the management. The outcomes of the interviews are given in Chapter 4.

Below an overview of sections (2.1-2.4) handling the knowledge questions I ask myself, in order to determine how the current processes are organized, is given. In Section 2.5, the stakeholders in the process are mentioned. When the stakeholders are concerned in the research, the chance of successful implementation of outcomes of the research is bigger. Therefore, it is interesting to know the stakeholders and their roles. Section 2.6 is based on my personal view and handles a decision instead of a knowledge question.

(2.1) What does the process between factory and customer look like?

(2.2) What are the costs and CO_2 emission in the process between factory and customer?

- (2.2.1) What are the storage costs paid in the current warehouse situation?
- (2.2.2) What are the transportation cost of the current process?
- (2.2.3) What are the labor and handling costs of the people working at the current warehouses?
- (2.2.4) What is the CO_2 emission in the current process?

(2.3) What changes in the process between factory and customer?

(2.4) What are the complexities in the process between factory and customer?

(2.5) Who are the stakeholders in this process?

(2.6) What are based on the research so far criteria that I should assess possible future warehouses on, according to myself

I gather the knowledge required to answer the questions of Section 2.1 up to and including Section 2.5 in the following ways. First of all, I ask my supervisor if she can provide me the data needed to answer the questions. She is able to provide most of the data needed to answer these questions. The questions for which she cannot provide the information herself, she is able to tell me, who I should contact to get the information to answer my questions. In case my supervisor is not able to tell me who I should contact, I ask the supply chain manager of Avebe or supply chain manager at Stadex. These people can provide the data needed to answer my questions themselves or to bring me in contact with the people who can provide me the data. In case the data I need does not exist, I gather the data myself.

(Ch 3.) Background study

In this chapter, a background study (Section 3.1) and a systematic literature review (Section 3.2 and Section 3.3) are conducted. Section 3.1 answers to the following knowledge question:

(3.1) What are criteria that possible future warehouses should be assessed on, according to professionals in the field?

The reason for answering this knowledge question, based on the advice of professionals in the field, is that I use the answer as a guideline for the interview questions of Chapter 3, aiming to determine the requirements and wishes of the management. This does not mean that the criteria found by this research are equal to the operationalized criteria that I use in my research, but I mention these criteria to the managers during the interviews, in case they do not mention the criteria themselves. I tell the manager that based on my study also criterion “x” is important and ask whether he or she thinks that this criterion indeed is important for my research. Only when at least one person of the management thinks that it is a good criterion, I assess the possible future warehouses on the criterion or mention this criterion in the advice for the sourcing department. In this way, I make sure that there are no criteria, without reason, not considered in my research that according to expert in the field should be considered in my research.

The second and third section, answer the following knowledge questions:

(3.2) What discrete location models do exist?

(3.3) Which of these discrete location models are suitable for my research?

First of all, I focus on discrete location models, because Avebe asked me to analyze scenarios. These scenarios are always a combination of two predetermined warehouses and a predetermined distribution of demand over these warehouses. Of these two warehouses, one warehouse is always the warehouse in The Netherlands and the other is a warehouse determined in the interviews (Section 4.3). This means that I focus on finding the location of this second warehouse which has a discrete location, since this should be rent. Renting a warehouse implies that the warehouse already exists, therefore the location is discrete[2]. Besides, the allocation of demand over the two warehouses is done on beforehand, by the supply chain manager and myself for each of the scenarios that I analyze (I also ask the managers during the interviews if they have ideas about this and take these into consideration). This means that my study is focusing on the optimal location for the warehouse and the best allocation of demand over these locations. Since the core question of my research is what warehouse should replace Briggen and the sub-question related to this researching the allocation of customer demand, I chose the focus is on discrete location models. I answer the questions of Section 3.2 and Section 3.3, because this yields me a theoretical guideline that I can use to determine the final scores of the warehouse scenarios. The question of Section 3.2 is meant to orientate myself on the discrete location models that exist, while the question of Section 3.3, is meant to theoretically support my decision for the specific discrete location model I use in my research.

All the background studies in this chapter are executed using the database ‘Scopus’ and/or ‘Web of Science’ and/or the book Supply Chain Management (Chopra, S. & Meindl, P., 2013) or by conducting research on the internet. In this way, this chapter enhances the strength of the outcome of my research, since it makes sure that the problem-solving approach is based on literature.

[2] During the interviews in Chapter 4 I found out that Avebe also builds and rents back.

(Ch 4.) Requirements, wishes and scope of the management

This chapter provides answers to three knowledge questions. The first and second section answer the following knowledge questions:

(4.1) What are requirements of the management?

(4.2) What are wishes of the management?

The reason for answering these knowledge questions is the following. The management is, at the end of the day, going to make the decision. So, at the end of my research, these people need to have all information about the possible warehouses that they want to have in order to make a decision. To provide the management with this data for the warehouses that are suitable to solve the action problem, I need to know what the requirements and the wishes (which I translate to criteria) for the possible warehouses are. Otherwise, it can happen that at the end of my research the conclusion is, that I should have researched other things in order to make a decision, which I want to avoid.
The outcome of answering these two knowledge questions is a list of the requirements and wishes (decision criteria) of the management. These are the criteria to measure how good the different warehouses in scope are. Next to that, based on these criteria, I know what data I need to gather about the warehouses.

I gather the data needed to answer these two knowledge questions, by conducting semi-structured individual in depth interviews with the management. In these interviews, I first describe my research and ask the managers what, according to them, are the requirements and wishes related to the warehouses. In case they do not mention the criteria of a good warehouse solution, according to the background study that I have done in Section 3.1, I mention these and ask them whether they think that I also should take those criteria into account. Besides, I always ask why they think the criterion, that they mention as being important, is important.

I chose to conduct interviews, because there is a need for detailed information and the reasoning behind the responses given by the managers is of importance. According to Blackstone (2014, pp. 108-109), these are features of situations in which research can be done best using interviews. Secondly, I chose to conduct individual in-depth interviews instead of group interviews, because this makes it possible to know what the focusses of the different managers are (since not all managers have the same work area). When conducting group interviews, it might happen that one or two managers take the lead and the opinions of the others is not mentioned, while in the end the outcome of this research should be acceptable for all the managers, if possible. Thirdly, I chose for semi-structured interviews, because the research is quite complex. The process of research is big and there are a lot of things to investigate when selecting a new warehouse location. Besides, the answer to the 'why question' is interesting in this research, because this might yield useful insights in what else needs to be considered. According to the book of Miles and Gilbert (2005, pp. 65-67), these are features of situations in which research should be done using semi-structured interviews.

Next to the fact that I need to know the requirements and wishes related to the warehouse I also find an answer to the following question:

(4.3) What are the warehouses scenarios in scope of research?

The reason that I answer this question, is that it is impossible for me to analyze all warehouses in the world. Therefore, I ask the management, in a semi-structured individual in depth interview, to provide specific warehouses or warehouse locations which I should analyze, according to them (including the allocation of customers to this warehouse locations). In order to make sure that the managers have ideas about this, I tell them some days before that I ask this question. This makes it possible to provide well thought out answers. Based on the interviews, I make an overview of warehouses that I include in my research. In this overview, I include all suggestions that are given by the management.

(Ch 5.) The best warehouse

This chapter is spilt into two sections. Section 5.1 provides the scores of the warehouse scenarios on the operationalized criteria. Besides the calculations done to determine these scores can be found. Section 5.2 states which warehouse scenario is the best choice. Next to that, the outcomes of the sensitivity analyses on two important cost coefficients in this research are given. Lastly, I give some insights in the way my problem-solving approach changed during the research. This can be found underneath the header “Insights in the original problem-solving approach of Chapter 5”

The first section handles the following knowledge question:

(5.1) How do the warehouse scenarios score on the operationalized criteria?

The reason for asking this knowledge question, is that I need to know how the warehouse scenarios score on the operationalized criteria, in order to compare these different warehouse scenarios. I answer this question by using the data which is available at Avebe. When the information is lacking, I gather the information myself or together with employees of Avebe.

After I know how the different warehouses score on the operationalized criteria, I look at what the best warehouse scenario is in the following section:

(5.2) The best choice

The reason for having this section is that this research aims to give a piece of advice to Avebe in which is stated what Avebe should do when warehouse Briggen needs to close. Since I want to give a piece of advice, I need to choose between the different warehouse scenarios. This is done based on the scores of the operationalized criteria in Section 5.1. Besides, the outcomes of the sensitivity analyses on two important cost coefficients in this research is given. The reason for doing these sensitivity analyses is that I want to know the impact off small changes in these cost coefficients on the total costs including the costs for CO_2 emission of the warehouse scenarios. I conducted these sensitivity analyses using my own made models in Excel.

Insights in the original problem-solving approach of Chapter 5

Until I had the scores of the warehouse scenarios on the operationalized criteria, I thought that Chapter 5 was going to have the following structure from Section 5.2 onwards:

(5.2) What is the outcome of the AHP-tool on the criteria and scores?
(5.3) What warehouse scenario is best?
(5.4) What is the outcome of the management discussion about the differences between the managers?

I planned to ask the managers to fill out the AHP-tool, on the importance of the criteria and on the different warehouse scenarios, in new semi-structured individual in depth interviews. In this way, I was planning to make ranking of the different warehouse scenarios for each specific manager based on their filled out AHP-tool. After that, I intended to have a management discussion about the possible differences between the managers about what the best warehouse solution is. Based on this discussion I hoped to create a solution which everyone agrees upon, which would have been the outcome of the research.

There are two reasons why I chose to deviate from this original approach. First, I came to know that the board of Avebe has decided that the CO_2 emission tax for CO_2 emission caused by transportation is €0.05 per kilogram CO_2. This made it possible to express all the operationalized criteria into one criterion which is total costs. This made it superfluous to use the AHP-tool since at least two criteria are needed to fill out this tool. Second, the scores of the warehouse scenarios on the two operationalized criteria in Section 5.1 where such, that a quick search on the costs of CO_2 emission yielded almost immediately the conclusion that the differences in CO_2 emission are way too small to have a serious impact on the differences between the costs of the different warehouse scenarios. For these two reasons I decided not to uses the AHP-tool which would not have affected the outcome of this research and therefore only wasted the time of the managers and myself.

In Section 5.2 is stated how I assessed the different warehouse scenarios by ranking them based on the total costs including the costs of CO_2 emission.

(Ch 6.) Conclusions, recommendations and discussion

This chapter mentions the conclusion of my research, the recommendations for Avebe and a discussion about the assumptions and limitations of the research. In order to do so, the following questions are answered:

(6.1) What are the conclusions of the research?
(6.2) What are the recommendations of my research?
(6.3) What should be discussed about the research?

I answer Question 6.1 and 6.2 based on the findings in Sections 5.2. Question 6.3, I answer by critically looking the assumption and limitations of the research. Besides I discuss the impact of these assumptions and limitations on the outcomes of the research. In this way I am fully transparent about the way at which I came to the conclusions.

1.7 Summarizing overview of the problem-solving approach

In this section, I give a short summarizing overview of the problem-solving approach. This can be used as sort of a guide to keep following the logic while reading the report.

Chapter 2 "The current process between factory and customer"

2.1 Product flows
2.2 Costs and CO_2 emission
2.3 Changes
2.4 Complexities
2.5 Stakeholders
2.6 Warehouse scenario assessment criteria according to myself

Chapter 3: "Background study"

3.1 Warehouse scenario assessment criteria according to professionals in the field
3.2 Types of discrete location models that exist and their features
3.3 The discrete location model applied in this research

Chapter 4: "Requirements, wishes and scope of the management"

4.1 The warehouses requirements according to the management
4.2 The warehouses wishes/criteria according to the management
4.3 Warehouse scenarios in scope of this research

All sections of Chapter 4 are based on semi-structured individual in depth interviews with the managers

Chapter 5: "The best warehouse"

5.1 Scores of the warehouse scenarios on the operationalized criteria
5.2 The best warehouse scenarios
- Sensitivity analyses on two important cost coefficients

Chapter 6 "Conclusion, recommendations and discussion"

2. The current process between factory and customer

In this chapter, the current process between the factory (Stadex) and the final customer is analyzed. This analysis is split into six sections, each answering a different question. In Section 2.1, a visualization of the current process can be found. This includes information about the product flows and their size. In Section 2.2, the costs and CO_2 emission (caused by transportation) in the process between factory and customers can be found. The costs are split into warehousing costs, transportation costs and the labor/handling costs of the people working at the warehouses. In Section 2.3, an analysis on what changes to the current process when Briggen needs to be closed, is given. Section 2.4 mentions the most important complexities in the current process. In Section 2.5, the stakeholders in the process are given. Lastly, Section 2.6 provides an overview of what I think that the most important criteria are to assess the possible future warehouse scenarios on.

2.1 What does the process between factory and customer look like?

In order to know what I am exactly researching and to create an overview, I analyzed the current process between the factory (Stadex) in Malmö and the final customers of the products made at Stadex. In Figure 1, the visualization of the current process can be found.

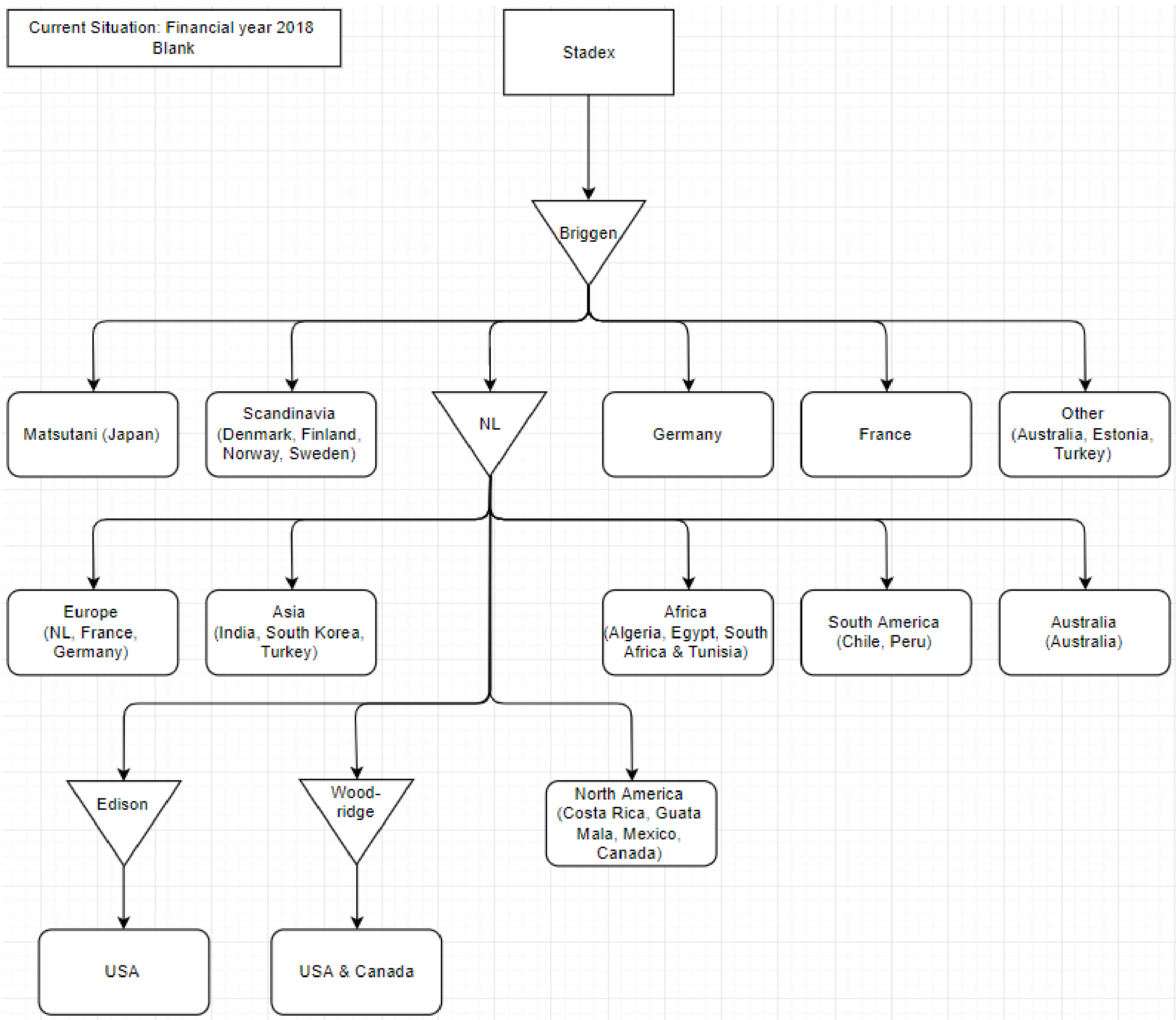

Figure 1: Visualization of the process between factory and customers in financial year 2018

In this figure a rectangle means that it is a factory, a triangle is a warehouse and a rounded rectangle is a final customer. Based on this figure I would like to mention a few things about the process. First of all, all products, in the research and in this visualization, are products made at Stadex. Secondly, there are in total four warehouses in the current process according to the figure. Namely, Briggen in Malmö, NL, Edison (USA close to New York) and Woodridge (USA close to Chicago). This needs a small side note because, in reality there are four storage locations in the Netherlands. These are the “Sample Room” in Foxhol, “Van der Vorst” in Dinteloord, “Teuben” and “Teuben TAK” in Ter Apelkanaal. The last two warehouses, which are located about three and a half kilometers away from each other are located in Ter Apel and in Ter Apelkanaal, are responsible for 99,97% of the storage of Stadex products in the Netherlands. Therefore, I summarized the four warehouses to “NL” meaning storage in Ter Apelkanaal.

Thirdly, the overview shows all the countries where customers are located for the distribution of products from Briggen, from NL to North America, from Edison to the USA and from Woodridge to the USA and Canada. For the distribution of products from NL to Europe, Asia, Africa, South America and Australia I only mention (between brackets) the countries which are responsible for more than 10% of the demand of the continent in which the country is located. I chose to do it like this, otherwise the figure would have become unclear. Since, products are distributed from the Netherlands to 67 countries all over the world.

Lastly, some countries are stated twice in the diagram. This means that the customers in these countries are supplied from different warehouses. Most of the times, this has one of the following two reasons. First, deliveries to different countries are combined. Second, some products need treatment in The Netherlands before delivery to the customers.

After determining the process overview (Figure 1), I determined the quantities related to the different product flows. The result of this research is stated in Figure 2. The underlined numbers are summations of pallet flows.

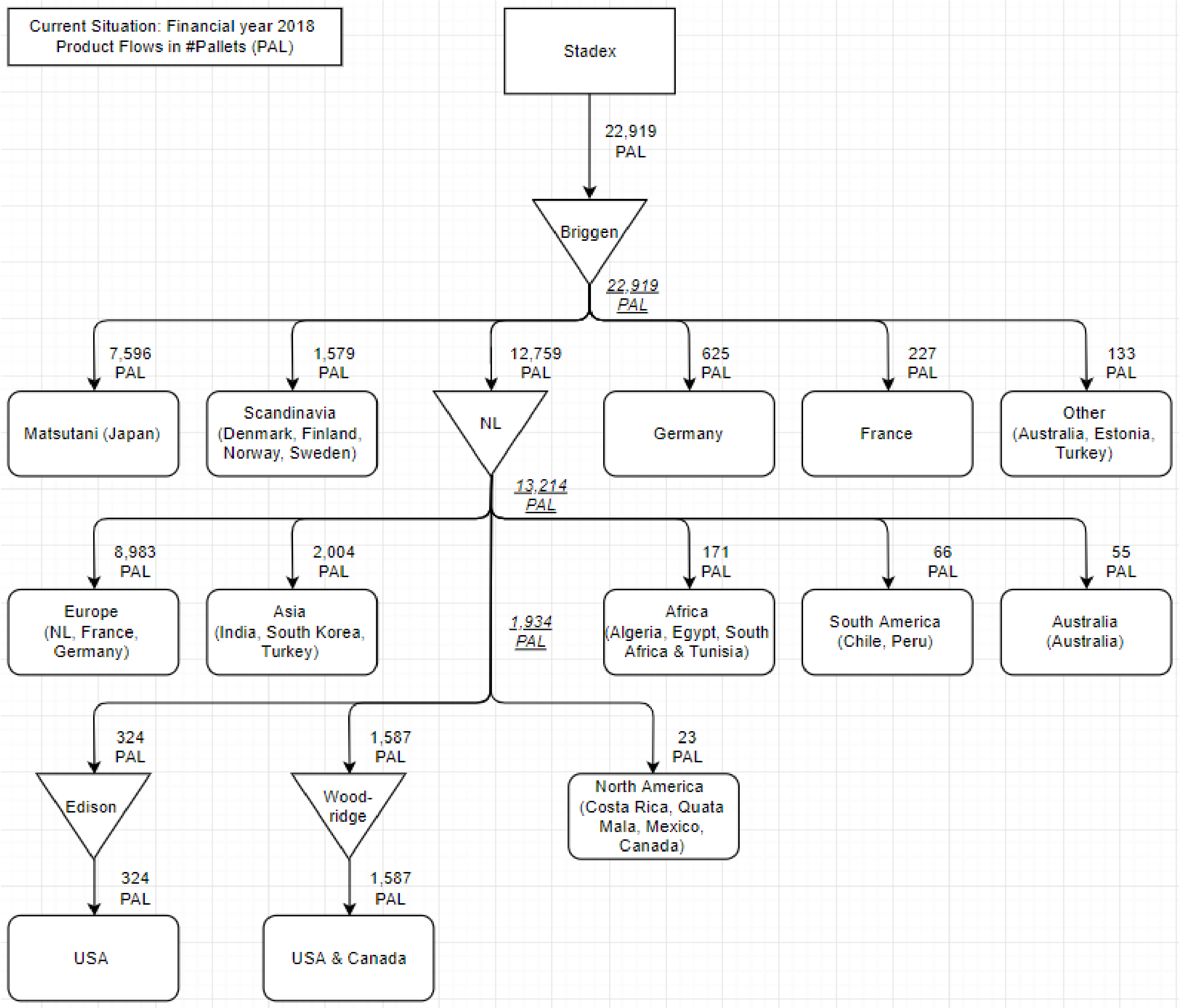

Figure 2: Visualization of the product flow in pallets in financial year 2018

The number of products going to the different countries is important for a few reasons. First of all, it helps to determine what the most important customers are and where these are located. Secondly, it gives an idea of the amount of product that is produced at the factory. Thirdly, this overview makes it possible to quickly see whether locating a possible future warehouse in a certain country makes sense.

The pallet flows stated in Figure 2 are calculated based on two Excel files provided by the logistical engineer of Avebe. The first Excel file provides the sales orders from Briggen to the next station of financial year 2018. The second Excel file states the sales orders from The Netherlands to the next station in the process (being the final customer, warehouse Edison or warehouse Woodridge). Based on these two files, I made the product flow overview on country level expressed in pallets. In order to achieve this, I used filters, pivot tables and the VLOOKUP function in Excel.

In my analysis, I chose to express the product flows in number of pallets (PAL). I have done this, because almost all products are ordered and transported on pallets. Only a small part of products is ordered in bags or in kilograms. In this case, I look how much bags fit on one pallet for each specific material (done using the VLOOKUP function). For the orders in kilograms I use the rule of thumb consisting of 1000 kilograms is equal to one pallet, which is used in Avebe as well. This yields the overview stated in Figure 2.

In Figure 2 can be found that in total 12,759 pallets go from Briggen to The Netherlands. However, adding up the pallets going from NL to the next locations, yields 13,214 pallets. This means that there are 13,214 – 12,759 = 455 pallets more going from The Netherlands than pallets going to The Netherlands. There are two reasons for this difference. First of all, there is a material, Eliane sc160, that is transported from Briggen to the Netherlands on pallets with 45 bags of Eliane sc160. Only part of the bags is distributed on pallets which have place for 25 bags. This means that more pallets are needed to transport the same amount of product from the Netherlands. This explains 101 pallets of the difference. The left-over difference of 354 pallets can be explained in two ways. First, by the differences in the inventory in the warehouses in The Netherlands between the start and the end of financial year 2018. Second, by the assumption that 1000 kilograms of material fits on one pallet.

2.2 What are the costs and CO_2 emission in the process between factory and customer?

In this section, an overview of the costs of the process between factory and customer is provided in three steps. Sub-section 2.2.1 provides the storage costs of the currently used warehouses. Sub-section 2.2.2 gives the transportation costs of the process between factory and customer. Sub-section 2.2.3 states the labor and handling costs of the people working at the current warehouses. Lastly, Sub-section 2.2.4 provides the total CO_2 emission caused by transportation in the current situation.

2.2.1 What are the storage costs in the current warehouse situation?

With the storage costs I mean the costs of having “x” amount of square meters warehouse. These costs are most of the time determined by multiplying the number of square meters with the price per square meter per year. This definition and way of calculating the storage costs I have determined myself, the company agreed on this.

In the current scenario storage costs are paid for the warehouse Briggen and the warehouses in The Netherlands, within the scope of this research. The rent paid for warehouse Briggen is 3,250,000 Swedish Crown (SEK) which is 286,334 euros per year. This number is provided by the manager of the Stadex factory and warehouse Briggen. The storage costs paid for the warehouses in The Netherlands are 127,871 euros per year. This makes the total storage costs of the current scenario €286,334 + €127,876 = 414,220 euros per year.

The calculations done to determine the storage costs in The Netherlands can be found in Appendix 1.1.

2.2.2 What are the transportation costs of the current process?

In Figure 3, the outcome of the research to determine the transportation cost of the distribution of Stadex products in the current situation can be found. The underlined numbers are summations of the transportation costs mentioned below in the figure.

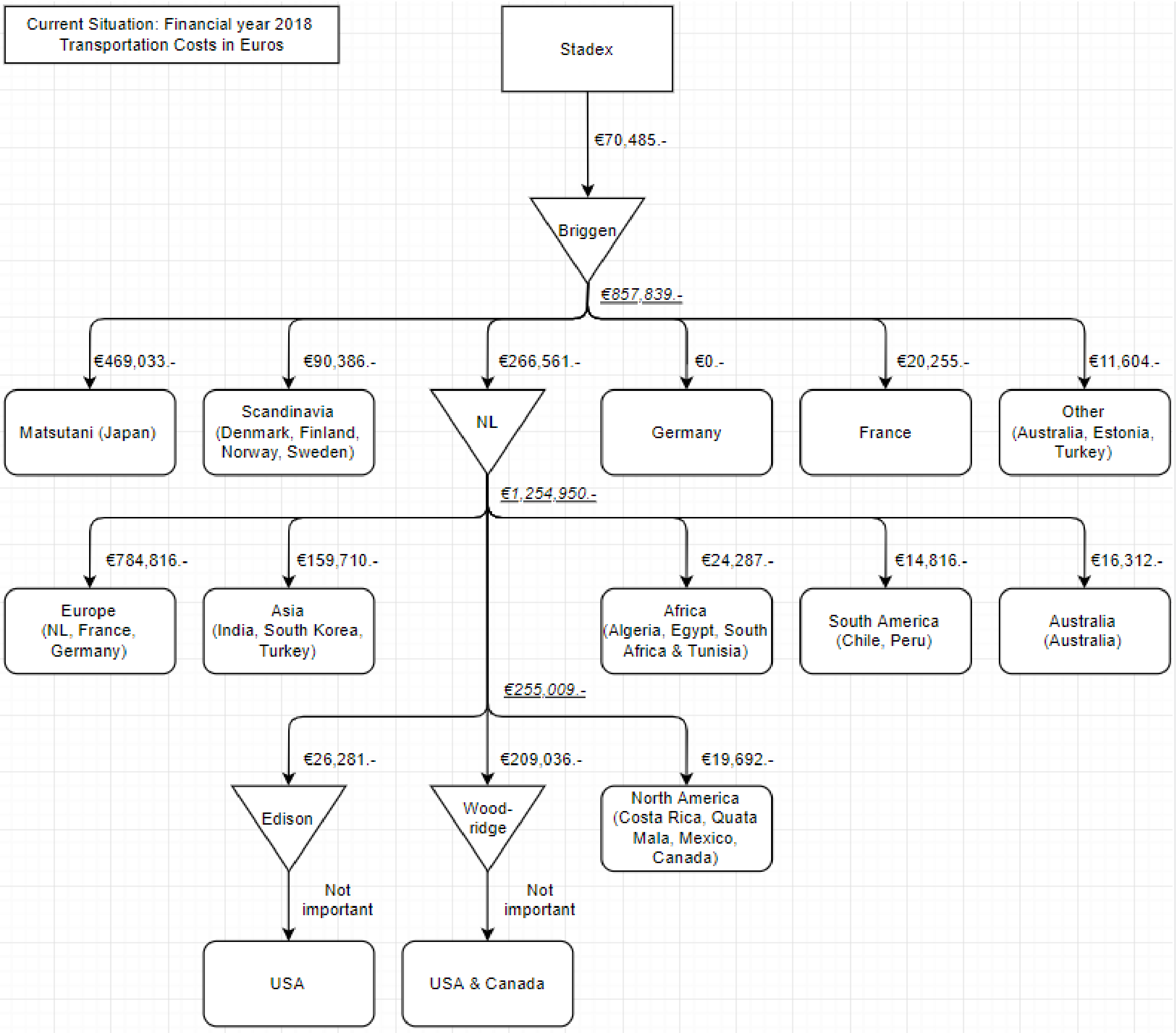

Figure 3: Visualization of the transportation costs in euros in financial year 2018

Looking at this overview two questions are useful to discuss. The first question is: "Why are the transportation costs from warehouse Briggen to the customers in Germany equal to zero?". This is because, Avebe has a contract with these customers, which states that the customers need to pick up the ordered products themselves. So, these customers arrange the transportation and not Avebe.

The second question is: "Why are the transportation costs from the warehouses Edison and Woodridge not important?". The reason for this is that these warehouses do not change in this research. So, the costs of the warehouses, the allocation of these customers and the transportation costs and kilometers do not change from these warehouses onwards.

Adding up all transportation costs, I found that the total transportation costs in the current warehouse situation are equal to 2,183,274 euros. Namely €70,485 + €857,839 + €1,254,950 = €2,183,274

In Appendix 1.2 the explanation of how the numbers in Figure 3 are calculated is stated.

2.2.3 What are the labor and handling costs of the people working at the current warehouses?

In warehouse Briggen nowadays two people are working fulltime. Part of their job is to do the handling (racking and un-racking the pallets) in the warehouse. The labor cost of these employees at Briggen are 800.000 Swedish Crown (SEK) which is 94,803 euros per year. The handling costs are included in this. This number is provided by the supply chain manager of Stadex.

The difference between labor costs and handling costs is the following. When own people work in the warehouses, the company has labor cost. Although, when external people work in the warehouse, they get payed based on the number of pallets that are racked and un-racked. These costs are called “handling costs” instead of “labor costs”.

In the current situation also handling costs are paid for the warehouse in The Netherlands. These handling costs are €42,284 per year. This number is calculated by multiplying the number of pallets stored in the warehouse with the costs for handling, which yield 13,214 pallets times 3.20 euros is equal to 42,284 euros per year. The handling costs are based on the current situation and provided by the sourcing department. The number of pallets stored in The Netherlands can be found in Figure 2.

2.2.4 What is the CO_2 emission in the current processes?

The outcome of calculations done to determine the total CO_2 emission, caused by transportation, in the current warehouse situation is 3,027,300 kilograms CO_2. This number is based on transportation that took place in financial year 2018. I calculated the CO_2 emission by editing the CO_2 emission calculations done by almost all transportation companies (namely by using CO_2 emission ratios) in a customized way for Avebe. This resulted in the following method:

1. I spilt the transportation kilometers in transportation by truck, train and ship.
2. I used different “ratios” for the truck, train and ship. These “ratios” state how much kilograms CO_2 emission is caused by the transportation of 1000 kilograms over one kilometer using a certain transportation means. The ratios I use are 0.0415 kilograms CO_2 per ton kilograms per kilometer for transportation by truck, 0.0160 kilograms CO_2 per ton kilograms per kilometer for transportation by train and 0.0100 kilograms CO_2 per ton kilograms per kilometer for transportation by ship. These “ratios” are based on the report “STREAM Goederenvervoer 2016” (Otten, M., t' Hoen, E. & Den Boer, E.).
3. I calculated the average transportation kilometers and therefore the CO_2 emission on country level based on the known distances (within Avebe) to the postal codes of the customers.
4. I only concerned the transportation kilometers that Avebe is responsible for. Some contracts state “Ex works FCA”, this means that the transportation of the product is done by the customer and therefore Avebe is not responsible for the CO_2 emission caused by this transportation.
5. To determine the number of tons transported I excluded the Ex works FCA and I assumed (on advice of the supply chain manager of Avebe) that one pallet is equal to one ton (1000 kilograms) of product. I only made this assumption for the transportation from the warehouses in The Netherlands. For the transportation between Stadex and Briggen and From Briggen to the next station, I have received the real number of tons transported in financial year 2018 from the transportation companies (DSV, Green Carrier and Vos transport). There are too many different transportation companies that transport products from the warehouses in The Netherlands to do the same here. Therefore, I assumed for these product flows that one pallet is equal to one ton.

A detailed explanation of the calculations done to determine the CO_2 emission can be found in Appendix 1.3.

2.3 What changes in the process between factory and customer?

Looking at the process between Stadex and the final customer several things change, when the warehouse location of Briggen changes. For example, when Briggen is replaced by a warehouse in Helsingborg, the first thing that changes are the transportation costs between the factory and the customers. This is due to the fact that the transportation kilometers change and maybe also the way of transportation. The transportation of certain products from Briggen to The Netherlands is done by truck nowadays, while in a new situation this might be done by ship. This difference in way of transportation and the amount of transportation kilometers affect the amount of CO_2 emission in the process.

Secondly, if there are customers supplied from an illogical warehouse nowadays, according to the managers (being a warehouse in The Netherlands or Briggen), I take the proposed other distribution of customers into analysis for the scenarios of analysis (see Section 4.3). This means that the needed storage capacity in The Netherlands and Sweden can change. Due to other customer demand allocations to the warehouses.

Thirdly, the costs for renting the warehouses changes. When a warehouse has a different location and a different storage capacity, the renting cost of the warehouse is different. For example, the warehouses in Sweden are more than twice as expensive as the warehouses in The Netherlands, according to the purchase department of Avebe.

Fourth, the labor cost of the people working at the warehouses change. These costs highly differ from country to country, since the living costs are also different from country to country. This means that relocation of warehouses effects the labor costs.

Fifth, the number of operations between production and fulfilling demand changes. When, for example, customers are directly delivered from Briggen, the products only need to be transported from Stadex to Briggen and from Briggen to the customer. Whereas, the number of operations is bigger when, for example, the products are first stored at Briggen, then in The Netherlands and then transported from The Netherlands to the customer. The number of operations is not the primary focus in this research but is good to be aware of the impact. Since, more operations also result in more damaged material. The reason for this is that the fork truck drivers sometimes damage the products in the warehouses. Also, the handling/labor and storage costs are likely to be bigger when a product is stored two times instead of once.

Lastly, the costs of licenses for the transportation of the products might differ. Since most of the products made at Stadex are white powders, there are very strict controls. One of the requirements is that the warehouses need to have a license to store these products and the transportation company needs to have a license to transport the products. The costs of these licenses might differ for different countries. I do not think that these licensing costs change the outcome of my research, since these costs are very small compared to the other costs. Therefore, I do not take this into the scope of my research.

2.4 What are the complexities in the process between factory and customer?

Based on the analysis of the current situation of the process between factory and customer I point out some complexities that I encountered. The first thing that makes the process complex, is the fact that there are 52 different products made at Stadex. This makes it hard to get an overview of the different products that are made and what these different products need in terms of storage environment.

Secondly, the same product does not always have the same sales unit. One product can be ordered in number of bags, number of pallets or number of kilograms. Besides, not always the same number of bags fits on one pallet and not all pallets do have the same size. Next to that, there is a difference in the density of the product which means that not always the same number of kilograms fit in one shipment. These differences in sales units make it complex to get an overview of the total product flows within the process.

Lastly, the huge number of customers located in 67 countries all over the world make the process complex. When I change for example the warehouse location from which these customers are supplied nowadays, I must recalculate the transportation kilometers for all these customers. Besides, the contract with these customers differ. Some customers pick up the orders at the warehouse while others get the products delivered.

2.5 Who are the stakeholders in this process?

When doing research which might change company processes, it is good to know who the stakeholders of the process researched are. Therefore, I give an overview of the most important stakeholders in this research. Besides, the reason for being a stakeholder is given.

Employees working at the current warehouses
The employees working at the existing warehouses can be highly affected by the outcome of my research. Imagine that the outcome of my research is, that the new warehouse should be located in Helsingborg. This means that the people currently working at Briggen lose their job. Next to that, in case the outcome of my research is less extreme and more in terms of a change in the customer distribution over the warehouses, the amount of work that needs to be done at the warehouses might change. This implies that the number of employees needed at the warehouse can change. Therefore, the employees working at the existing warehouses are clearly stakeholders in this research.

Transportation companies
Since Avebe outsources transportation, the transportation companies are also affected by the outcome of my research. The result of my study might be that transportation needs to be done from different warehouse locations and in other ways. This changes the transportation costs and the demands from the transportation companies. Transportation which currently is done by truck might change to transportation using ships or the other way around. Therefore, the transportation companies are stakeholders of the research.

The landlords of the current warehouses

The landlords of the current warehouses can also be highly affected by the outcome of my research. Imagine, the outcome of my research is that Avebe should have way less storage capacity in the warehouses in The Netherlands. This means that the landlord of the warehouse in The Netherlands loses part of its income and need to look for new parties to do business with. Although the impact of the outcome of the research on the landlords will not affect the decision making in this research, since it is not Avebe's problem, the landlords are still stakeholders.

The sourcing department of Avebe

A very important stakeholder in this research, is the sourcing department of Avebe. First of all, this department is responsible for finding a new warehouse at the location, determined in this research. Secondly, purchasing needs to find new transportation companies or negotiate with the currently used transportation companies about new contracts to fulfill the changing requirements of Avebe. Therefore, the purchasing department of Avebe is an important stakeholder in this research.

The customers of Avebe

The customers of Avebe are important stakeholders in my research for two reasons. First of all, if the warehouse locations change and/or the distribution of the customer demand over these warehouse locations change, the delivery times to the customers might also change. Secondly, especially the customers picking their orders at the existing warehouses are affected by a change in warehouse locations. Since these customers need to pick their order from other locations, which changes the transportation kilometers and costs. For example, all the customers in Germany pick their orders at the warehouses at Avebe. Avebe, of course, does not want to lose these customers because of relocation of the warehouses. Therefore, the customers of Avebe are important stakeholders of my research.

Stakeholders/members of Avebe

Since Avebe is a corporation of potato farmers, the primary stakeholders are the farmers. These want to have the highest price for their potatoes. This means that when the outcome of my research yields a bigger profit margin, by reducing the costs for example, the primary stakeholders are very happy to implement my proposed solution. Although, when this profit margin is does not improve or even decrease by my purposed solution, it is very unlikely that Avebe implements this solution. Since, the farmers likely do not want that, and the farmers must agree. Therefore, stakeholders/members of Avebe are the primary stakeholders in this research.

The management of Avebe

The managers of Avebe are going to make the final decision. Once they do not agree upon the advised warehouse scenario, the warehouse scenario is not going to be implement. This means that it is very important to stay in contact with the management during the research. In this way, the management knows what the research is about and has the feeling that the solution that I advise is also partly their own work. This results in a bigger chance that the advice is followed by the management.

2.6 What are based on the research so far criteria that I should assess possible future warehouses on, according to myself

Looking at the current process and the research done so far, I think that there are three important categories of criteria on which possible future warehouses should be assessed. I wrote this section explaining my personal few before doing the interviews. This forced me to have an objective and uninfluenced opinion about what important assessment criteria are before having interviews with the management. This approach enhances the independency of this research and helps me to structure the interviews. Below, I explain why I think that the criteria categories costs, sustainability and ethical impact are important.

Costs
I think that the costs of the process between factory to customers is a very important criterion. The reason for this is the fact that the most important stakeholders in this research are the potato farmers. They are the ones that make the decisions at the end of the day. Potato farmers want the highest profit margin on their potatoes which means the lowest cost and the highest sales price. Therefore, the costs are a very good assessment criterion for the quality of a possible scenario. These costs should be based on at least the storage costs of the warehouse and the labor/handling costs. Besides, if it is possible to determine the transportation costs for the different future scenarios as well, it should be added. These three costs categories together give a good overview of the costs of the different scenarios of analysis.

Sustainability
Next to the costs, I think that sustainability is a relevant criterion to assess the warehouse scenarios on. This can be operationalized by looking at the carbon dioxide emission (CO_2). Since the earth is heating up at a rapid pace, because of all the CO_2 emission, the CO_2 emission is becoming more and more important. Besides, Avebe states in its strategic goals that it strives to save energy and to reduce the CO_2 emission.

To measure the CO_2 emission, I should look at the number of transportation kilometers. In order to transform the transportation kilometers into the CO_2 emission, I need to know with what transportation means the products are transported, how much kilograms of product are transported and the transportation distances. Then I can use the existing CO_2 ratios, which state how many CO_2 emission is caused by transporting “x” kilograms of product using transportation means “y”, to calculate the total CO_2 emission of the warehouse scenario caused by transportation.
Of course, sustainability is more than only the CO_2 emission, but I think that the CO_2 emission caused by transportation is good first criteria for measuring the sustainability. Since, the largest changes in the CO_2 emission between the current situations and the warehouse scenarios are caused by the differences in transportation (the production process does not change).

Ethical impact
Lastly, I think that the ethical impact, of the different scenarios, is important to look at. The scenarios that I analyze in this research might have different ethical implications in terms of unemployment and the impact on the environment of the possible future warehouses. Since Avebe states in its mission that Avebe wants to be a reliable employer and strives for a good relationship with the residents. This mission can be affected by the outcome of this research. Therefore, I think that the criterion “unemployment” and the criterion “impact on the local environment” are relevant criteria consider.

Summary of Chapter 2

In this chapter first of all, the process layout of the current situation, including the product flows in pallets is given. Secondly, I determined that the total costs of the current situation are €2,734,581 per year. These costs are split into storage costs (€414,220), transportation costs (€2,183,274) and labor & handling costs (€137,087). Thirdly, I found out that the CO_2 emission in the current situation is 3,027,300 kilograms per year. Fourth, attention is given to what changes in the current process between factory (Stadex) and the final customer, when the warehouse location Briggen changes. I also investigated the stakeholders of the process. Lastly, I mentioned three important categories of criteria on which possible future warehouses should be assessed according to myself. These are costs (split into storage, labor/handling and transportation costs), sustainability (measured in CO_2 emission caused by transportation) and the ethical impact of the warehouse scenarios (unemployment and impact on the local environment).

3. Background Study

This chapter is divided into three sections. In Section 3.1 the outcome of the research to determine what important criteria are to assess warehouse scenarios on, according to three professional warehousing companies, can be found. In Section 3.2 an overview of the different discrete location models and when these should be applied is given, based on a systematic literature review. Lastly, Section 3.3 states what kind of discrete location model suits this research best.

3.1 What are criteria that possible future warehouses should be assessed on, according to professionals in the field?

In order to determine what the criteria to assess the possible future warehouse on should be, I researched what professionals in the field of warehouse selection recommend looking at. These companies are representative for my business, because these companies provide warehouse solutions for production companies like Avebe. The professionals that I have looked at are Conveyco, Taylored Services and APS Fulfillment. Below I give a short introduction to these companies based on their websites.

Conveyco
"Conveyco is a recognized expert in the integration of automated material handling systems." (Conveyco, 2019) The annual turnover of Conveyco is estimated at 5.6 Million dollars and the number of employees at 44. (Owler, Conveyco, 2019)

Taylored Services
"Taylored services is a fully integrated third party logistic provider specializing in wholesale, retail and direct to customer unit fulfillment operating with 1.5 million square feet of distribution space." (TayloredServices, 2019) The annual turnover of Taylored Services is estimated at 26.1 Million dollars and the number of employees at 84. (Owler, Taylored Services, 2019)

APS Fulfillment
"APS Fulfillment is a product fulfillment and direct mail marketing production facility in South Florida with turnkey, state-of-the-art technology that provides fast, flexible and cost-effective solutions for client." (APSFulfillment, 2019) The annual turnover is estimated at 30 Million dollars and the number of employees at 41. (Owler, APS Fulfillment, 2019)

Based on the pieces of advice of these three companies, I made one list of things that should be looked at when choosing a warehouse location. This list is stated below. I have gathered these pieces of advice from the websites of the companies.

1. The accessibility of the warehouse.

    How is the warehouse accessible? By truck, by train, by ship or even by plane and how good is this connection.

2. The accessibility of reliable and cost-effective labor.

    Part of the costs of the warehouse are labor costs. These labor costs should be as low as possible. While the labor itself should be of a certain quality and reliability level.

3. The price of the warehouse itself.

    The renting costs of the warehouse itself, calculated based on the number of squared meters needed.

4. The technology used in the warehouse.

    When comparing warehouses there might be a difference in the technology used in the warehouses. Some warehouses use simple fork trucks while others use automated systems.

5. The distance to the customers.

    A significant part of the costs, CO_2 emission and delivery times is determined by the distance to the customers. Therefore, the transportation distance to the customers is important to look at when choosing between warehouses.

6. Environmental factors that might influence the operations.

    Examples of environmental factors that might influence the operations of the company are the presence of earthquakes or volcanoes but also the presence of living areas nearby the warehouse. Having a warehouse nearby a living area can result in traffic issues or safety issues, when the truck needs to drive on roads where for example children play.

7. The experience of the warehouse.

    Lastly, the experience of the warehouse and the people working at the warehouse. When a warehouse is completely new, it is plausible that more mistakes are made at the beginning.

3.2 What discrete location models do exist?

In this section the outcome of the systematic literature review, to determine what discrete location models exist and when these should be applied, can be found. The execution of the systematic literature review itself, is stated in Appendix 2.

Integration of theory: Answering the knowledge question

Based on the systematic literature review and studying the articles which I selected for reviewing the following answer can be given to my knowledge question.

Broadly speaking there are three categories of discrete location problems. The first category is the category of the covering-based models. “Covering based models assume that there is some critical coverage distance or time within which demand need to be served, if they are counted as covered or served adequately.” (Daskin, 2008). Covering based models are often used in designing emergency services. There are three types of covering-based models. The first is set covering. This model is used when the minimal number of facilities needs to be located in order to cover all customer demands. The second is the maximal covering model. This model aims to find the location of a predetermined number of facilities which result in the maximal number of demands covered. The third is the p-center model. These models aim to find the facility setup that minimize the coverage distance needed to cover all demands with a predetermined number of facilities.

The second category of discrete location problems is the category of the median-based models. Median-based models are used to minimize the demand-weighted average distance between a demand node and the facility to which it is assigned. Median-based models are often used for distribution planning aiming to reduce the transportation cost but also considering the fixed cost of, for example, the facility itself. There are two types of median-based models. The first is the p-median model. This model aims to minimize the demand-weighted average distance between the facilities and the customers. Given a predetermined number of facilities in scope and a predetermined number of facilities used. The second are the fixed charge location models. These models aim to minimize the sum of the fixed facility and transportation costs. A distinction often made related to these models is the distinction between capacitated and uncapacitated Fixed Charge Location models. Capacitated models take the capacity of the facilities into account while uncapacitated models assume the capacity of the facilities to be infinite.

The third category of discrete location problems is the category of other models. These are models that are used in situations that do not fit into the two previously mentioned categories. Two examples of these models are the p-dispersion model and the hub location model. The p-dispersion model aims to find the facility locations that maximize the minimal distance between the pairs of facilities. This type of model is often used when franchise locations need to be determined. In this situation, the aim is to avoid that the two facilities of the same owner compete. The hub location model is a “two stage facility location model in which there is a set of facilities that supply to a set of distribution centers, which in turn supply to a set of demand points.” (Basu, S., Sharma, M. & Ghosh, P. S., 2015)

3.3 Which of these discrete location models are suitable for my research?

Looking at the overview, of the types of discrete location models that exist and their features (See Section 3.2), the Uncapacitated Single Fixed Charge Facility Location model suits this research best for the following reasons.

First of all, an important criterion in this research are the costs of the different warehouse scenarios. These costs can be divided into fixed facility costs (storage costs and labor costs) and variable costs (transportation and handling costs). Therefore, the fixed charge location model should be used. The storage costs are fixed costs since Avebe needs to pay a certain amount of rent for the number square meters that they can use. This rent is also paid when for example half of the warehouse is used in practice. Also, the labor costs are fixed costs, the salary of the employees is independent of the amount of work. This is different for the external people working in the warehouses, these get paid for the number of pallets stored which is defined as handling costs. Therefore, the handling costs are variable costs. Lastly, the transportation costs are also variable costs. The transportation companies get paid based on the number of transportations, the size and the distance.

Secondly, this research is meant to find a new warehouse location when Briggen needs to close. When searching a new warehouse location, the capacity of the warehouses in scope is a requirement that is set up-front. Therefore, it cannot happen that the warehouses that are used in the scenario analysis of this research do not have the needed capacity. This means that the capacity of the warehouses in scope are not going to be a constrain in this research, which implies that an uncapacitated model can be used. Besides, the selection of a specific warehouse is what the sourcing department of Avebe does based on this study. In this study warehouse areas are used, in which more possible warehouses are located that the sourcing department can take into consideration before making the final decision.

Therefore, the Uncapacitated Fixed Charge Facility Location is the discrete location model that I implement in my research. This model is going to be implement in the following way:

1. The fixed (storage and labor) costs and variable (handling and transportation) costs for each warehouse are calculated. I mention "fixed costs" or "variable costs" between brackets in the headers of the calculations done in Section 5.1.
2. The fixed and variable costs are added up for each warehouse scenario.
3. This is the score on the criterion costs for each warehouse scenario.

After looking at the costs, the other operationalized criteria mentioned in Section 4.2, are considered for the different warehouse scenarios. How this done is stated in Section 5.2.

Summary of Chapter 3

In this chapter, an overview of the variables to be considered when choosing between different warehouse scenarios according to professional companies in the field of warehousing, is given. Besides, the different types of discrete location models and their features are mentioned. Lastly, I determined that the Uncapacitated Fixed Charge Location model should be used in this research. This model is implemented in this research by adding up the fixed costs (for storage and labor) and variable costs (for handling and transportation).

4. Requirements, wishes and scope of the management

This chapter contains three sections. Section 4.1 states the requirements of the management. Section 4.2 provides the criteria/wishes on which the warehouse scenarios should be assessed. Lastly, Section 4.3 mentions the different warehouse scenarios in scope of this research. All these sections are based on semi-structured individual in depth interviews with the management. The interview scheme used during these interviews can be found in Appendix 3.

4.1 What are requirements of the management?

In order to determine the requirements of Avebe concerning the warehouse facilities, I have done two things. First of all, I contacted the Quality, Environment, Safety and Health (QESH) officer of Avebe. This person knows everything about the warehouse requirements for the warehouses of Avebe and sent me the documents which state these requirements. However, in the conversation I had with the purchasing department of Avebe, the conclusion was that I am not allowed to get in contact with possible future warehouses myself. The purchasing department does this. Therefore, they check whether the warehouses fulfill the requirements of Avebe. This means that in this research an overview is given of what the managers mentioned during the individual in depth interviews as requirements for the warehouses, which is the second thing that I have done to determine the requirements of Avebe. All requirements mentioned by at least one manager can be found below.

Enough storage capacity
The first thing that is always mentioned by the interviewees is, that the warehouse needs to have enough storage capacity to store the products Avebe wants to store. In case the warehouse is not big enough for the products that Avebe wants to store in the warehouse, the warehouse is dropped immediately. Therefore, storage capacity is a very important requirement.

Licenses and certificates
Secondly the needed licenses and certificates to store the products of Avebe is mentioned. In Table 1, an overview of the different certificates needed to store the Avebe products is given. This overview is copied from the document "Logistics Warehouses and Handling" provided by the QESH officer of Avebe.

	Food	**Feed**	**Non-food**
Certification AEO full	X	X	X
Food safety certification: - Preferably GFSI-recognized certification, e.g. FSSC 22000 - At least ISO 22000 or equivalent	X		
GMP+ certification		X	
ISO 9001 certification	optional	optional	X

Table 1: Overview of required warehouse certificates of Avebe

AEO certificates grant for a certain level physical security of the warehouse. The warehouse should at least have an ISO 22000 certificate but preferably a FSSC 22000 certificate. These certificates grant for a certain level of food safety. Next to these the warehouse must have a GMP+ certificate. This certificate means that the warehouse is allowed to store animal feed. Also, the ISO 9001 certificate is needed, which is a more general criterion of fulfilling the norm of the quality management system. Lastly, the warehouse needs to fulfill the requirement stated by Avebe concerning the fire safety. In case the warehouse does not have these certificates and is not able to get these, the warehouse is dropped immediately.

Environment
Thirdly, there are some requirements concerning the environment of the warehouse. First of all, forests or standing water around the warehouse are unacceptable. These yield insects that come to the warehouse, while the products stored in the warehouse must be totally isolated from insects. Secondly, the neighbors of the warehouse might not be neighbors that produce smell like fish or meat companies. This smell influences the smell of the products stored in the warehouse, which implies that the products cannot be sold anymore and should be thrown away. Thirdly, the existence of neighbors using genetically modified organisms (GMO's) and depot this product into the trucks in the open air is a no go. The reason for this is that Avebe is 100% GMO free. In case, there is a GMO farm next to the warehouse of Avebe, the risk occurs that some of this GMO product ends up in the products of Avebe. When this happens Avebe is in big trouble. Therefore, Avebe does not want to take this risk of having companies close to the warehouse that use GMO's.

Loading dock
Lastly, there should be a loading dock at the warehouse. Loading docks make it possible to drive with your fork truck into the truck or train. This makes it easier and faster to load and unload the truck or train. Besides, rainwater, wind and insects are isolated from your truck or train when a loading dock is used. This is a huge pro for Avebe since the products made at Stadex can be damaged by these occurrences. Therefore, the availability of a loading dock at a warehouse is a requirement.

4.2 What are wishes of the management?

This section is divided into three parts. Firstly, the criteria/wishes that the warehouse scenarios should be assessed on, according to the management, based on what they mentioned themselves during the interviews. Secondly the criteria/wishes that they agreed upon during the interview, which I mentioned based on the research done in Section 3.1 (professionals in the field). Lastly, I mention the operationalized criteria. The three parts are given below.

The criteria/wishes that the warehouse scenarios should be assessed on, according to the management, based on what they mentioned themselves during the interviews:

1. *Transportation distance -> CO_2 emission*

2. *Costs of transportation, storage, handling and people working in the warehouse.*

The criteria/wishes that they agreed upon during the interview, which I mentioned based on the research done in Section 3.1 (professionals in the field):

In case there were any comments of the managers about these criteria, I stated these as well.

1. The accessibility of the warehouse.

How is the warehouse accessible? By truck, by train, by ship or even by plane and how good is this connection.

- *Notes of the management:*
"The more possibilities to access the warehouse the better. Besides, the faster the warehouse is accessible the better."

2. The accessibility of reliable and cost-effective labor.

Part of the costs of the warehouse are labor costs. These labor costs do the company want to be as low as possible of course, but the labor should also be reliable and of a certain quality.

- Notes of the management:
“In case the warehouse is located close to The Netherlands, the same operator ‘Teuben’ can be used, which Avebe is very enthusiast about.”

3. The price of the warehouse itself.

The renting costs of the warehouse itself, calculated based on the number of squared meters needed.

4. The technology used in the warehouse.

When comparing warehouses there might be a difference in the technology used in the warehouses. Some warehouses might use simple fork trucks while others use automated systems.

- Notes of the management:
“The warehouse should be able to make bookings in the SAP system of Avebe.”
“Storing the products in racks instead of cold stacking is a pro, but additional costs compared to cold stacking should be reasonable.”
“In the warehouses both automated systems and fork trucks are fine, but the fork truck that are used should be electric.”

5. The distance to the customers.

A significant part of the costs, CO_2 emission and delivery times is determined by the distance to the customers. Therefore, transportation distance is important to look at when choosing between warehouses.

6. Environmental factors that might influence the operations.

Examples of environmental factors that might influence the operations of the company are the presence of earthquakes or volcanoes but also the presence of living areas near by the warehouse. Having a warehouse nearby a living area can result in traffic issues or safety issues, when the truck needs to drive over roads where for example children play.

- Notes of the management:
“Nature close to the warehouse is a deal breaker, because of the insects.”
“Neighbors that cause a lot of smell damage the products of Avebe, therefore this is a deal breaker as well.”

7. The experience of the warehouse.

Lastly, the experience of the warehouse and the people working at the warehouse. When a warehouse is completely new, it is plausible that there will be made more mistakes at the beginning.

- *Notes of the management:*
"Especially the operator is important."
"The importance of experience of the warehouse is different for own people compared to external people."

The operationalized criteria

Based on the research done in this section and in Section 2.6, I decided to score the scenarios based on the following operationalized criteria:

1. Costs in euros (covers partly or fully Criteria 1, 2, 3 and 5)
    - This score is the sum of the storage costs (per square meter), the transportation costs to the warehouses and customers and the handling/labor in the warehouses.

2. CO_2 emission in kilograms (Covers partly Criteria 1 and 5)
    - The CO_2 emission caused by the transportation of products between the factory and the final customers. This calculation is based on the type of transportation (truck, train, ship) using the CO_2 'ratios', the transportation kilometers and the number of tons (in kilograms) product transported.

I decided to do so, because these are the criteria that are mentioned by the management and by myself in Section 2.6. Besides, attention is payed to the ethical impact, especially the unemployment, in the conclusion and recommendations but not translated into an operationalized criterion. It is just meant to create awareness of the impact of this result on these ethical issues. I leave it to the managers to decide what to do with it. The other criteria can be used as a guideline for the sourcing department of Avebe, since these are warehouse specific criteria instead of warehouse area specific criteria. I am not allowed to get in contact with specific warehouses myself. Therefore, the sourcing department investigates this after my research.

4.3 What are the warehouse scenarios in scope of research?

In a semi-structured individual in-depth interview with the management of Avebe, I asked what the interviewees think that warehouse scenarios are that I should research. As a constraint to this question, I mentioned that the scope of my research is limited to the products made at Stadex. Besides, I mentioned that Stadex and the warehouses in the USA (which are Edison and Woodridge) do not change. I have added these constraints to keep the research feasible in the limited time available for this research. Below, I mention the suggested warehouse scenarios by giving a visualization of the proposed suggestion. Next to that I mention the idea behind the proposed scenario and the difference between the proposed scenario and the current scenario.

Scenario 1

The first scenario that I should analyze according to the interviews, can be found in Figure 4.

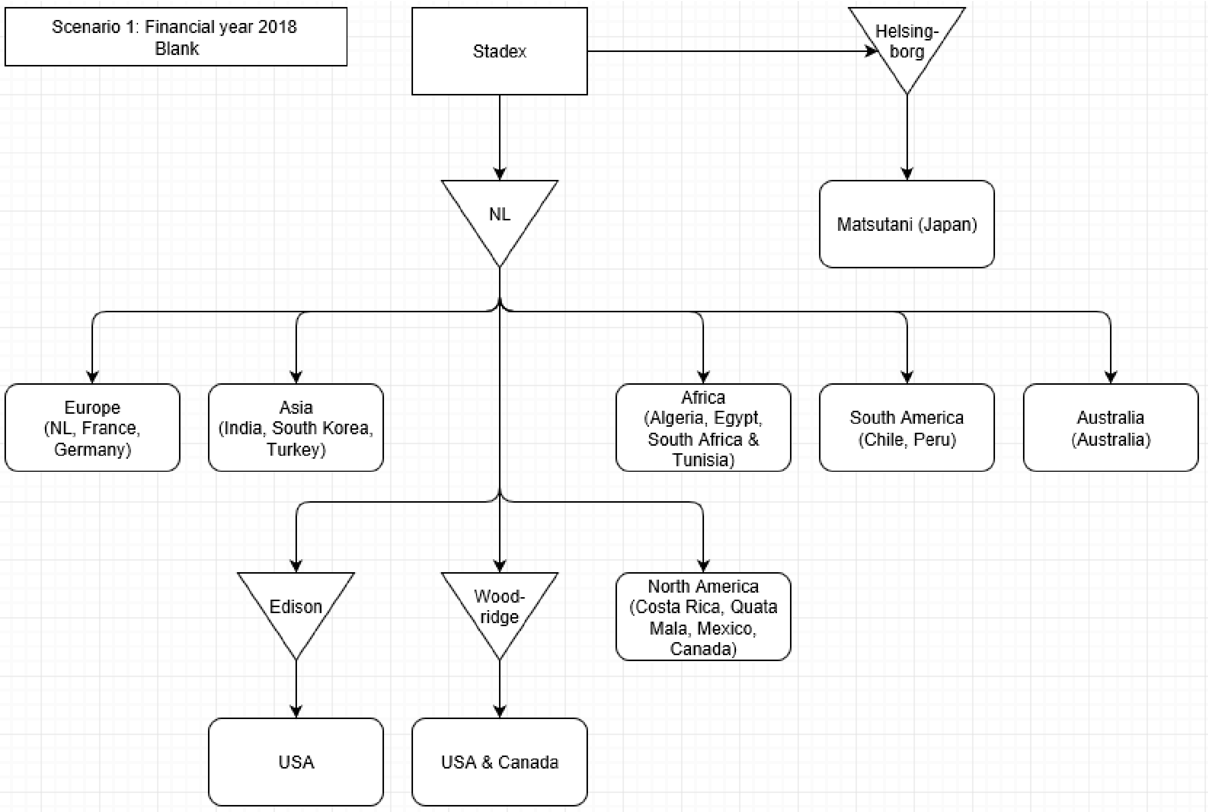

Figure 4: Visualization of Scenario 1

Reason for analyzing Scenario 1

The reason that this warehouse scenario is interesting to research is that storage in Sweden in about two times as expensive as storage in The Netherlands, when looking at the price per square meter. Therefore, only the products made for the biggest customer "Matsutani", which is located in Japan, are stored in Sweden in this scenario. This customer is delivered over seas. Therefore, it would be ridiculous to first transport the products to The Netherlands for storage, after which it should be transported to Japan. This would yield unnecessary transportation kilometers. Next to that, there are strong quality controls on the products made at Stadex, which take about ten days. In case the quality of the product turns out to be insufficient, the products are retreated at Stadex. This means that storing the products far from Stadex results in extra costs when the products turn out to be of insufficient quality.

Difference between the current situation and Scenario 1

There are several differences between the current situation and Scenario 1. First of all, in the current situation products are stored at Briggen and in The Netherlands, while in Scenario 1 products are stored in Helsingborg and in The Netherlands. Secondly, a huge difference between the current situation and Scenario 1 is that in Scenario 1 no longer all product made at Stadex are first stored in Sweden. In Scenario 1 only products for Matsutani are stored in Sweden (Helsingborg) while the other products are directly shipped to The Netherlands. This implies that more products are stored in The Netherlands and less in Sweden. In total this scenario needs less squared meters of storage than the current situation.

Scenario 2

The second scenario that I should analyze according to the interviews, can be found in Figure 5.

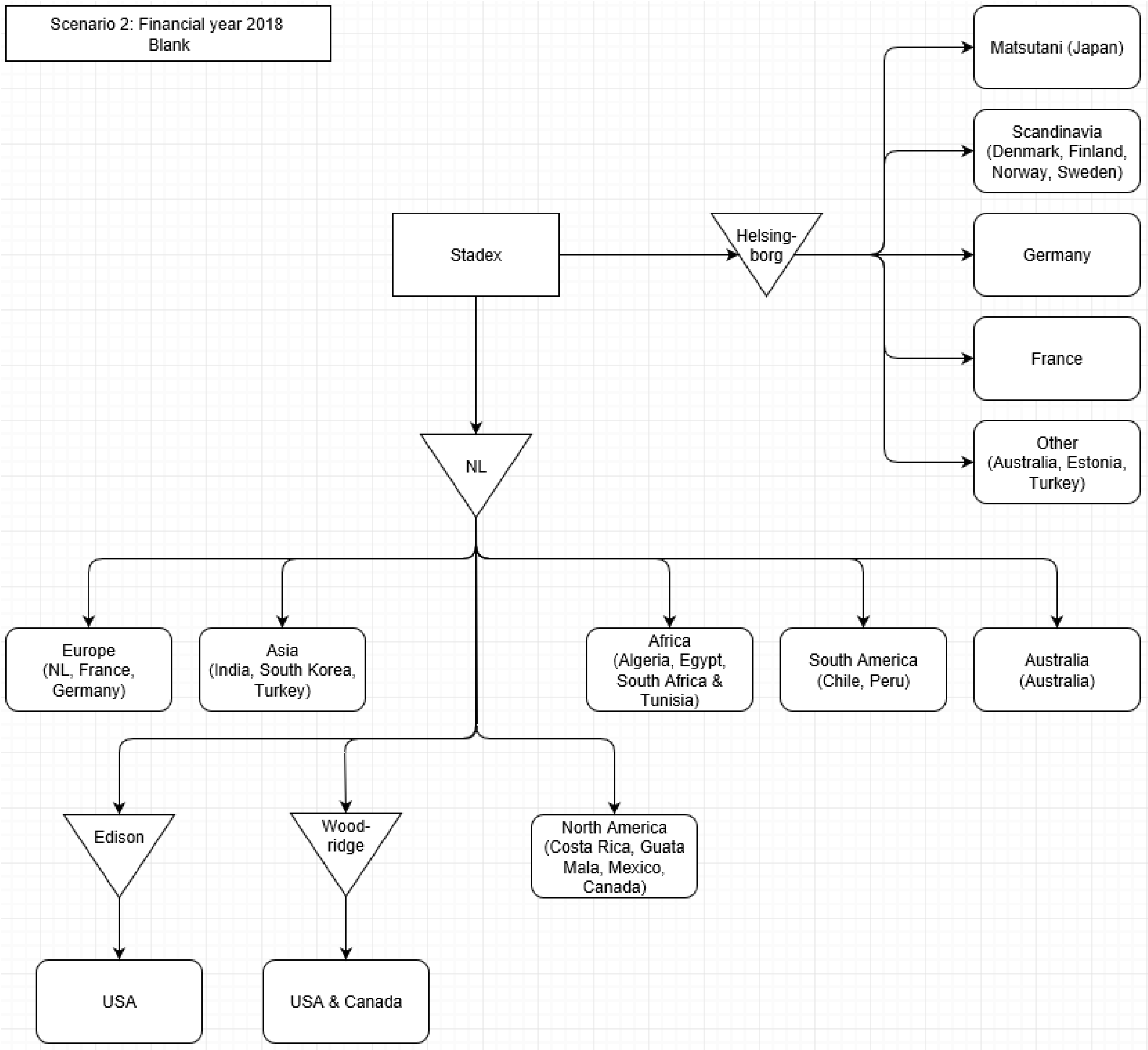

Figure 5: Visualization of Scenario 2

Reason for analyzing Scenario 2

The reason that this warehouse scenario is interesting to research is that it is the same as the current situation except for the fact that the warehouse "Briggen" is replaced by a warehouse in "Helsingborg". This is interesting because, it may be assumed that Avebe has good reasons to make this distinction between directed deliveries from Sweden and deliveries via The Netherlands. The reason for choosing Helsingborg as the storage location in this scenario, and in Scenarios 1 and 3, is that Helsingborg has a big harbor which makes transportation over sea possible and easy.

Difference between the current situation and Scenario 2

The only difference between the current situation and this scenario is that Briggen is replaced by a warehouse in Helsingborg and that not all products are first stored in Sweden, but only the products of customers that are going to be supplied from Sweden. The distribution of the customers over The Netherlands and Sweden is the same.

Scenario 3

The third scenario that I should analyze based on the interviews, can be found in Figure 6.

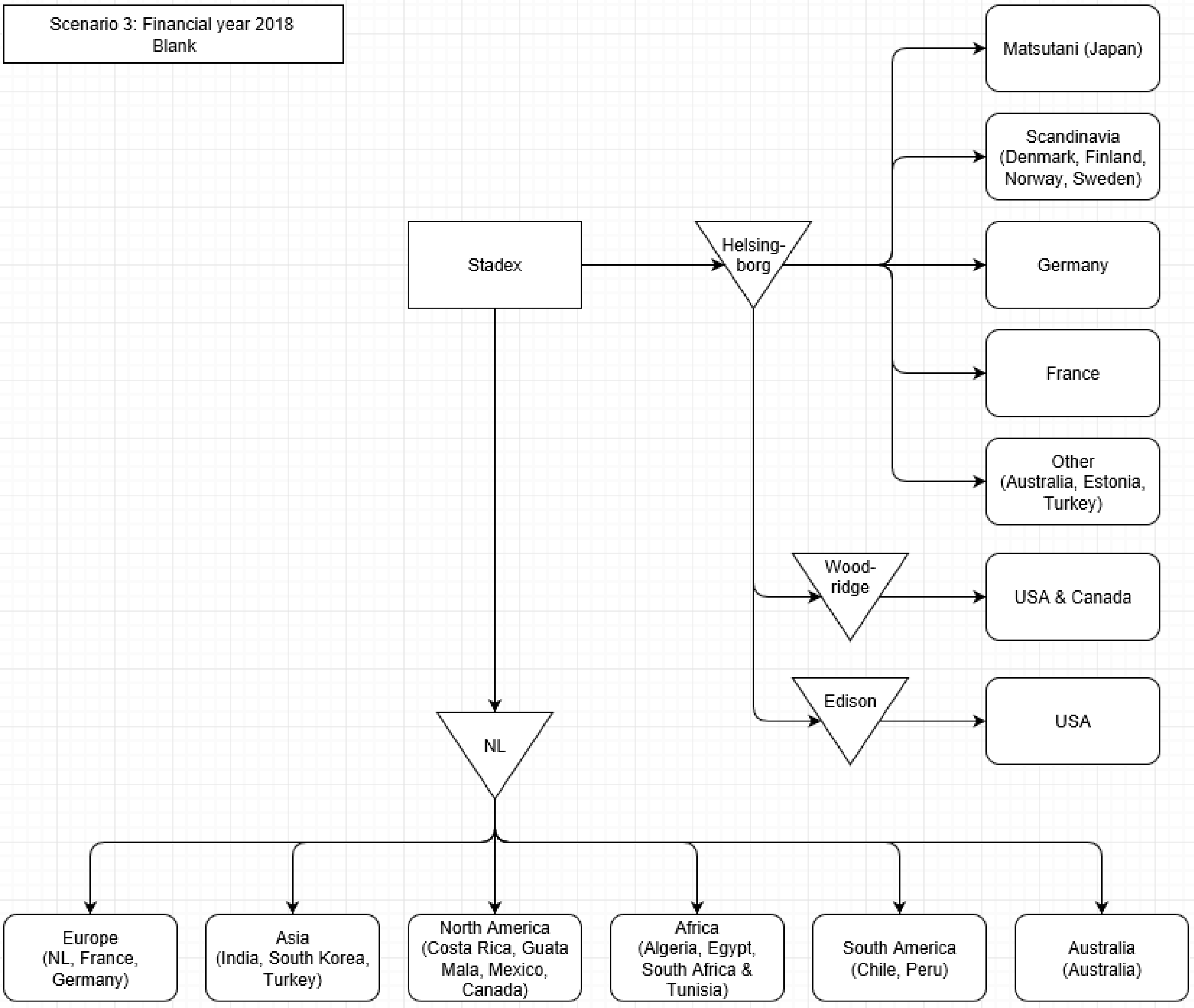

Figure 6: Visualization of Scenario 3

Reason for analyzing Scenario 3

The reason that this warehouse scenario is interesting to research, is that in the current situation the products that go to the warehouse in the USA (Edison and Woodridge) are first stored in Briggen, then transported to the warehouse in Ter Apelkanaal, after which these products are transported to the harbor of Rotterdam to finally go by ship to the warehouses in the USA. This looks very inefficient in terms of transportation kilometers (and therefore CO_2 emission), number of handlings and needed storage capacity. Therefore, storing the products that go from The Netherlands to Woodridge and Edison in Helsingborg sounds as an interesting scenario to look at. Since the products that go to the USA can then be shipped directly from the harbor of Helsingborg.

Difference between the current situation and Scenario 3

There are several differences between the current situation and Scenario 3. Like it is the case in Scenario 1 and 2, in Scenario 3 no longer all products are stored in Sweden (Briggen). Only the products that are directly delivered from Briggen to the customers in the current situation and the products that go to the warehouses in the USA are stored in Helsingborg in Scenario 3. While all the other products are stored in The Netherlands. This means that compared to the current situation less storage capacity is needed in both Sweden and The Netherlands. Comparing this scenario with Scenario 1 and 2 yields the conclusion that a bit more storage is needed in Helsingborg and a bit less in The Netherlands.

Scenario 4

The fourth scenario that I should analyze according to the interviews, can be found in Figure 7.

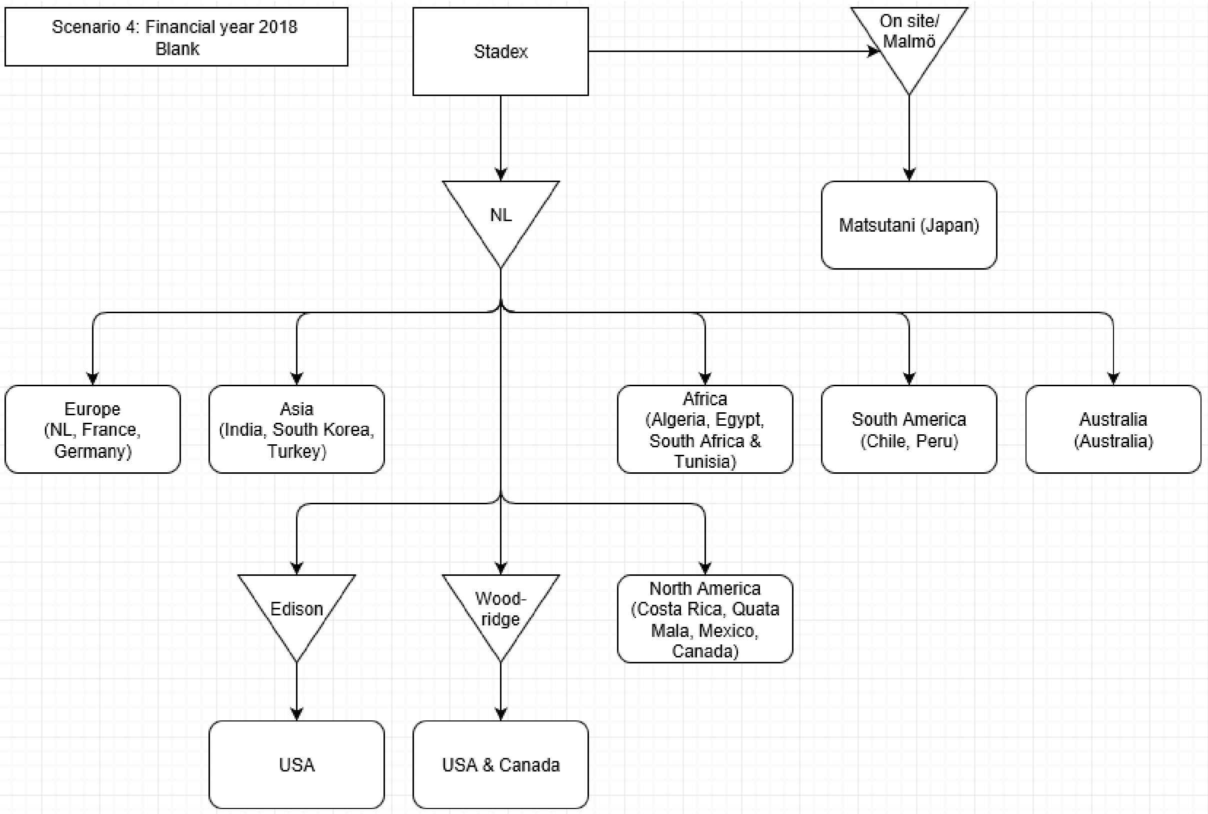

Figure 7: Visualization of Scenario 4

Reason for analyzing Scenario 4

The reason that this warehouse scenario is interesting to research is almost the same as the reason that Scenario 1 is interesting to analyze. What is interesting about this scenario compared to Scenario 1 is that the products for Matsutani (Japan) are stored on the Stadex site (in Malmö) in this scenario. This makes it easy to return products that did not pass the quality control to the factory for retreatment. Next to that, Malmö can be reached by train from The Netherlands and Helsingborg not (yet). Besides, the employees in the warehouse of Briggen can be used in the new warehouse as well. Lastly, I would like to mention that Scenario 4 suits the philosophy of Avebe that storage needs to take place as close as possible to the factory.

Difference between the current situation and Scenario 4

The most important difference between Scenario 4 and the current situation is that only the products meant for Matsutani are stored in Sweden in Scenario 4, whereas in the current situation all products made at Stadex are first stored in Sweden. Next to that, in Scenario 4 only Matsutani is delivered directly from Sweden. All other products are distributed via The Netherlands. This implies that in this scenario more storage capacity is needed in The Netherlands and less in Sweden compared to Scenarios 2,3,5 and 6.

Scenario 5

The fifth scenario that I should analyze according to the interviews, can be found in Figure 8.

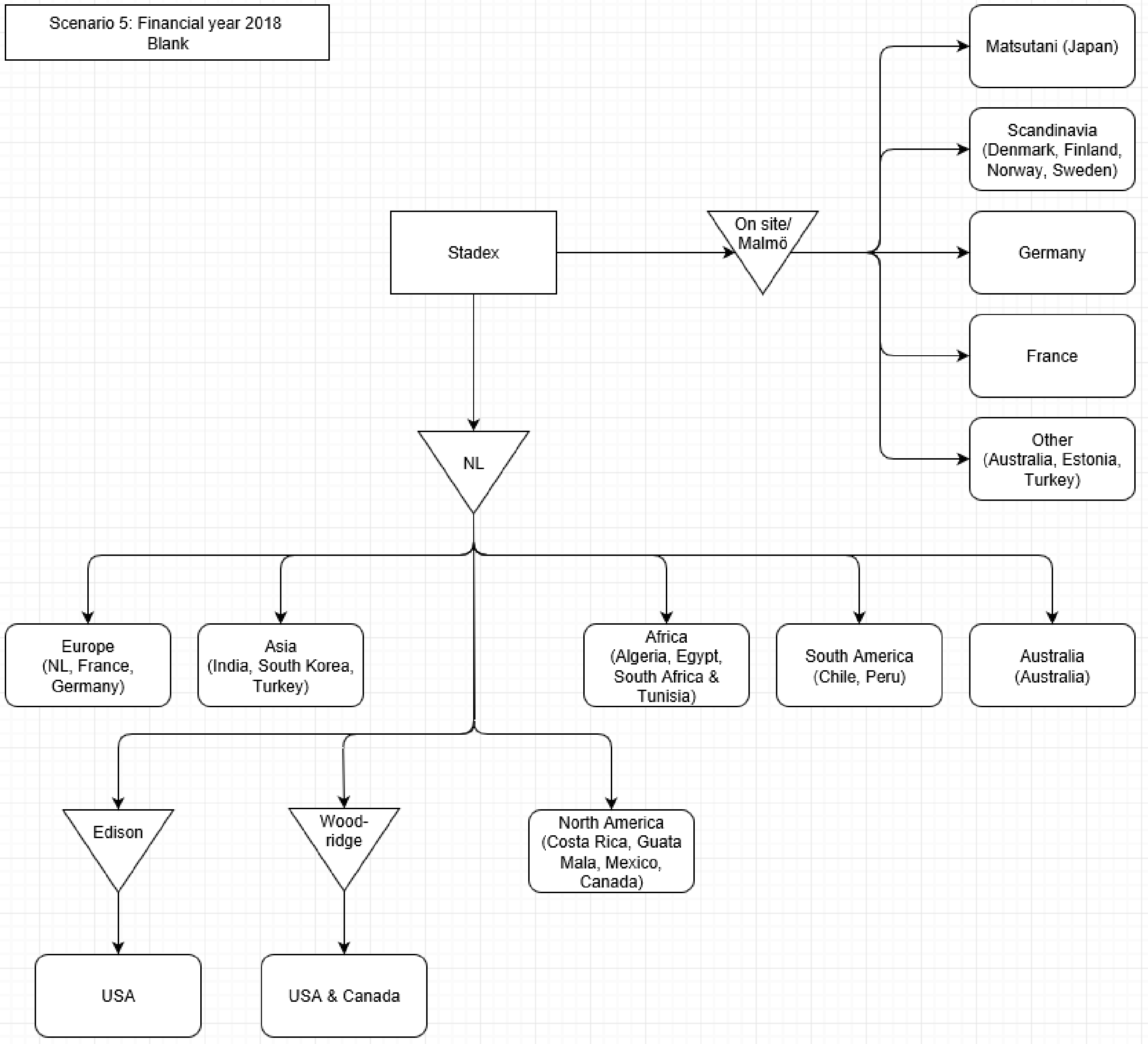

Figure 8: Visualization of Scenario 5

Reason for analyzing Scenario 5

The reason that this warehouse scenario is interesting to research is that it is the same as the current situation except for the fact that the warehouse "Briggen" is replaced by a warehouse on the Stadex site (in Malmö). This is interesting because, it may be assumed that Avebe has good reasons to make this distinction between directed deliveries from Sweden and deliveries via The Netherlands.

Difference between the current situation and Scenario 5

The only difference between the current situation and this scenario is that Briggen is replaced by a warehouse on the Stadex site and that not all products are first stored in Sweden, but only the products of customers that are going to be supplied from Sweden. The distribution of the customers over The Netherlands and Sweden is the same. Besides no more transportation is needed between the Stadex factory and the warehouse in Sweden.

Scenario 6

The sixth scenario that I should analyze according to the interviews, can be found in Figure 9.

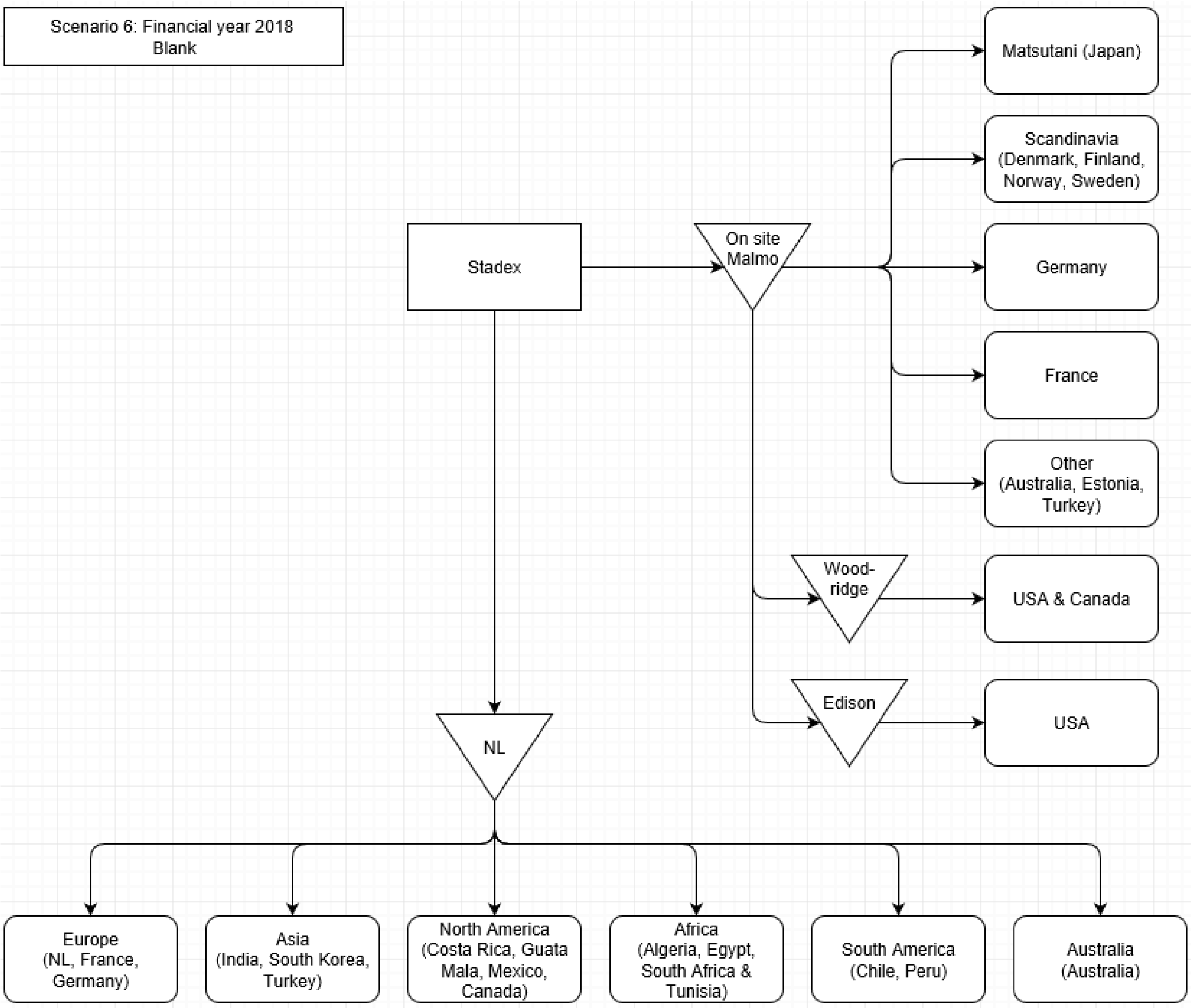

Figure 9: Visualization of Scenario 6

Reason for analyzing Scenario 6

The reason that this warehouse scenario is interesting to research, is that in the current situation the products that go to the warehouse in the USA (Edison and Woodridge) are first stored in Briggen, then transported to the warehouse in Ter Apelkanaal, after which these products are transported to the harbor of Rotterdam to finally go by ship to the warehouses in the USA. This looks very inefficient in terms of transportation kilometers (and therefore CO_2 emission), number of handlings and needed storage capacity. Therefore, storing the products that go from The Netherlands to Woodridge and Edison on the Stadex site is an interesting scenario to look at. Since the products that go to the USA can then be transported 60 kilometers to Helsingborg and from there on directly shipped to the USA. The advantage of this scenario compared to Scenario 3 using a warehouse in Helsingborg, is that products can be easier returned to the factory when the quality is insufficient and the people working in the warehouses can be the same as the people currently working in Briggen. While the advantage of Scenario 3 is that it is likely to be easier and cheaper to get a warehouse in Helsingborg.

Difference between the current situation and Scenario 6

There are several differences between the current situation and Scenario 6. Like it is the case in all scenarios of the research no longer all products are stored in Sweden (Briggen). Only the products that are directly delivered from Briggen to the customers in the current situation and the products that go to the warehouses in the USA are stored on the Stadex site in Scenario 6. While all the other products are stored in The Netherlands. This means that compared to the current situation less storage capacity is needed in both Sweden and The Netherlands. Comparing this scenario with Scenario 4 and 5 yields the conclusion that a bit more storage is needed in Helsingborg and a bit less in The Netherlands.

Summary of Section 4.3

The two tables below, provide a short overview of the differences between the warehouse scenarios in terms of warehouse locations and the related customer allocation. In Table 2 the warehouses used, the countries for which products are stored in the warehouses and the direct deliveries to the countries from each warehouse are stated. For example, in Briggen products for customers in all countries are stored and the total demand of Japan and Estonia is fulfilled directly from Briggen. While the customer demand of Scandinavia, Germany, France, Australia and Turkey is partly fulfilled partly from Briggen and partly from warehouse in The Netherlands. This overview can also be found for the different warehouse scenarios in Table 3.

Warehouse	Stored for countries	Direct delivery to countries
Briggen	All	(1) Total demand: Japan, Estonia (2) Part of demand: Scandinavia, Germany, France, Australia, Turkey
NL	All – ((1) + (2))	(3) Total demand: All countries except for the USA (delivered from warehouses Woodridge and Edison) (4) Part of demand: Canada (also partly delivered from Woodridge)

Table 2: Current situation warehouses and customer allocation

Scenarios	Warehouses	Stored and direct delivered for/to countries
Scenario 1	Helsingborg NL	Japan All – Japan
Scenario 2	Helsingborg NL	Customers delivered from Briggen in CS All – (Customers delivered from Briggen in CS)
Scenario 3	Helsingborg NL	Customers delivered from Briggen in CS + WHs USA All – (Customers delivered from Briggen in CS + WHs USA)
Scenario 4	On site Stadex NL	Japan All – Japan
Scenario 5	On site Stadex NL	Customers delivered from Briggen in CS All – (Customers delivered from Briggen in CS)
Scenario 6	On site Stadex NL	Customers delivered from Briggen in CS + WHs USA All – (Customers delivered from Briggen in CS + WHs USA)

Table 3: Scenarios warehouses and customer allocation

Summary of Chapter 4

In this chapter attention is payed to three different questions. First of all, I determined the warehouse requirements based on semi-structured individual in depth interviews with the managers. These yielded the requirements that there should be enough storage capacity, the warehouse needs to have specific licenses and certificates, the environment should be free of insects, genetically modified organisms, neighbors that produce smell and there must be a loading dock.

Secondly, I determined the wishes of the management by the execution of semi-structured individual in depth interviews. Part of these wishes are used to serve as a piece of advice for the sourcing department when they must select one specific warehouse based on the outcome of this research. The other wishes are the operationalized criteria in this research, being the costs and the CO_2 emission.

Thirdly, I determined the warehouse scenarios that should be researched, according to the managers, by the execution of semi-structured individual in depth interviews. The summary of the outcomes can be found underneath the header “Summary of Section 4.3”

5. The best warehouse

This chapter is split into two sections based on which I tell what the best warehouse scenario is. Section 5.1 provides the product flows and scores on the operationalized criteria (being the costs and CO_2 emission) for each warehouse scenario. Also, the calculations done to determine the scores are shown. At the end of Section 5.1 underneath the header "Summary and validation of the outcomes of Section 5.1" a summarizing table is given which states the scores of the different warehouse scenarios on the operationalized criteria (see Table 28). Besides the different costs which together yield the score of the operationalized criterion total costs are provided in Table 28. Section 5.2 states what the best warehouse scenario is according to this research. Besides, the outcome of the sensitivity analyses on the cost coefficients "storage costs on the Stadex site" and "cost per kilogram CO_2 emission caused by transportation" are given. Lastly, I mention some positive side effects of the best warehouse.

5.1 How do the warehouse scenarios score on the operationalized criteria?

This section shows how the different warehouse scenarios, determined in Section 4.3, score on the operationalized criteria (Section 4.2). For every warehouse scenario an analysis is given in three steps. The first step shows the overview of the warehouse scenario like these are shown in Section 4.3 only now the product flows in number of pallets (PAL) are added. These product flows are a visualization of the overview given in Table 3. After providing the product flow visualization, the warehouse scenarios in scope are scored on the operationalized criteria, which are the second and third step of this analysis. The second step handles the criterion cost split into transportation, storage and handling costs. The third step shows how the scenarios score on the criterion CO_2 emission caused by transportation.

-> Scenario 1

Step 1: Product flows Scenario 1

In Figure 10, an overview of the product flows in Scenario 1 is given. The reason for providing this is that it makes it possible to verify whether the outcomes of the calculations done in Step 2 and Step 3 below are logical. The size of the product flows is calculated based on the same two Excel files that are used to determine the product flows in Figure 2. These are the real numbers of financial year 2018, only different warehouses and customer allocations are used in this warehouse scenario. The underlined numbers are summations of the pallet flows mentioned below in the figure.

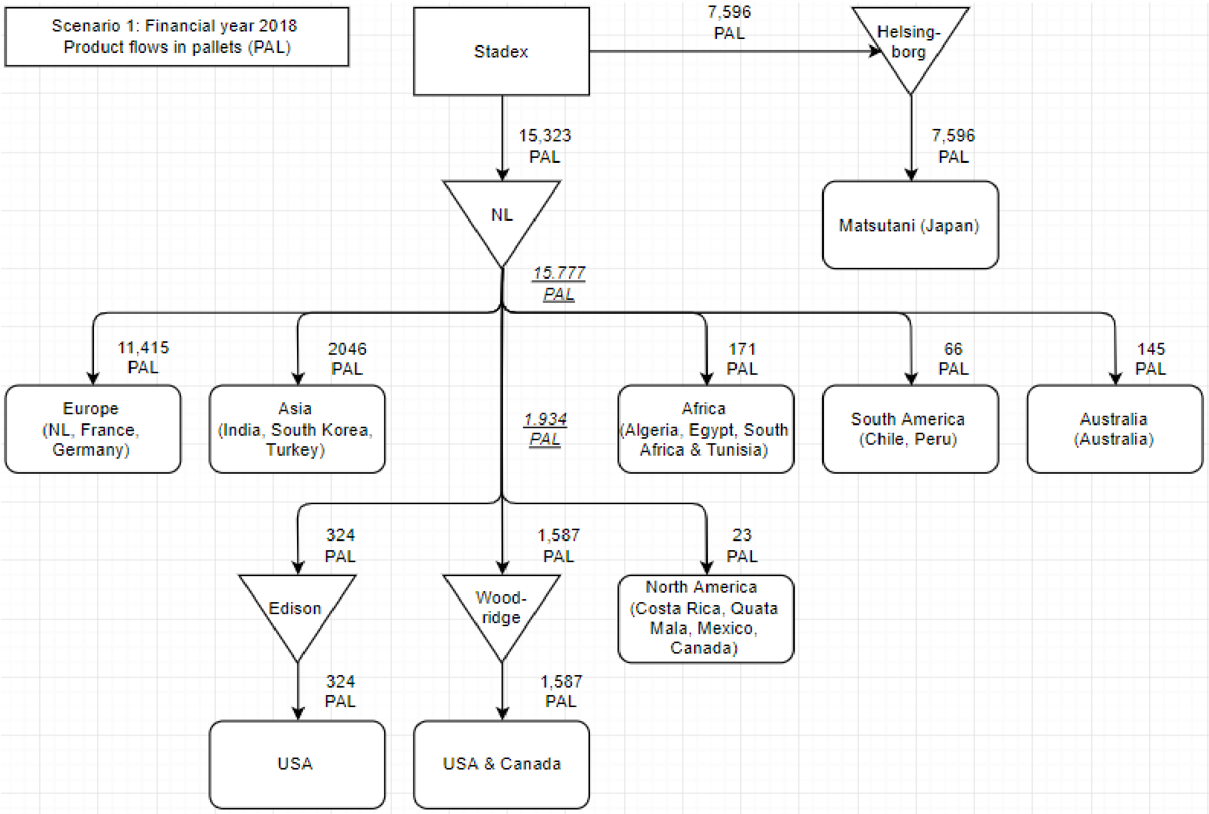

Figure 10: Product flow Scenario 1 in pallets (PAL)

Step 2: Costs in Scenario 1

Step 2 is split into four parts. The first three parts show how this scenario scores on the different criteria on which the total costs are based. These are the transportation costs, storage costs and the handling/labor costs. In Scenarios 1,2 and 3 there are handling costs and in Scenario 4,5 and 6 there are labor costs treated as handling costs in the new warehouses (Helsingborg and on the Stadex site). In the warehouses in The Netherlands there are handling costs. Lastly, part 4 shows a small overview of the total costs of the warehouse scenario which is the outcome of applying the Uncapacitated Fixed Charge Location model by adding up the fixed and variable costs. This structure is used for analyzing all the warehouse scenarios in this section. Therefore, this is not explained again for the next warehouse scenarios.

Part 1: Transportation costs Scenario 1 (variable cost in the model)

In Figure 11, an overview of the transportation costs in Scenario 1 is given. The total costs of transportation in this warehouse scenario are €1,424,322 + €320,123 + €81,345 + €394,323 = €2,220,113. The underlined numbers are summations of the transportation costs mentioned below in the figure.

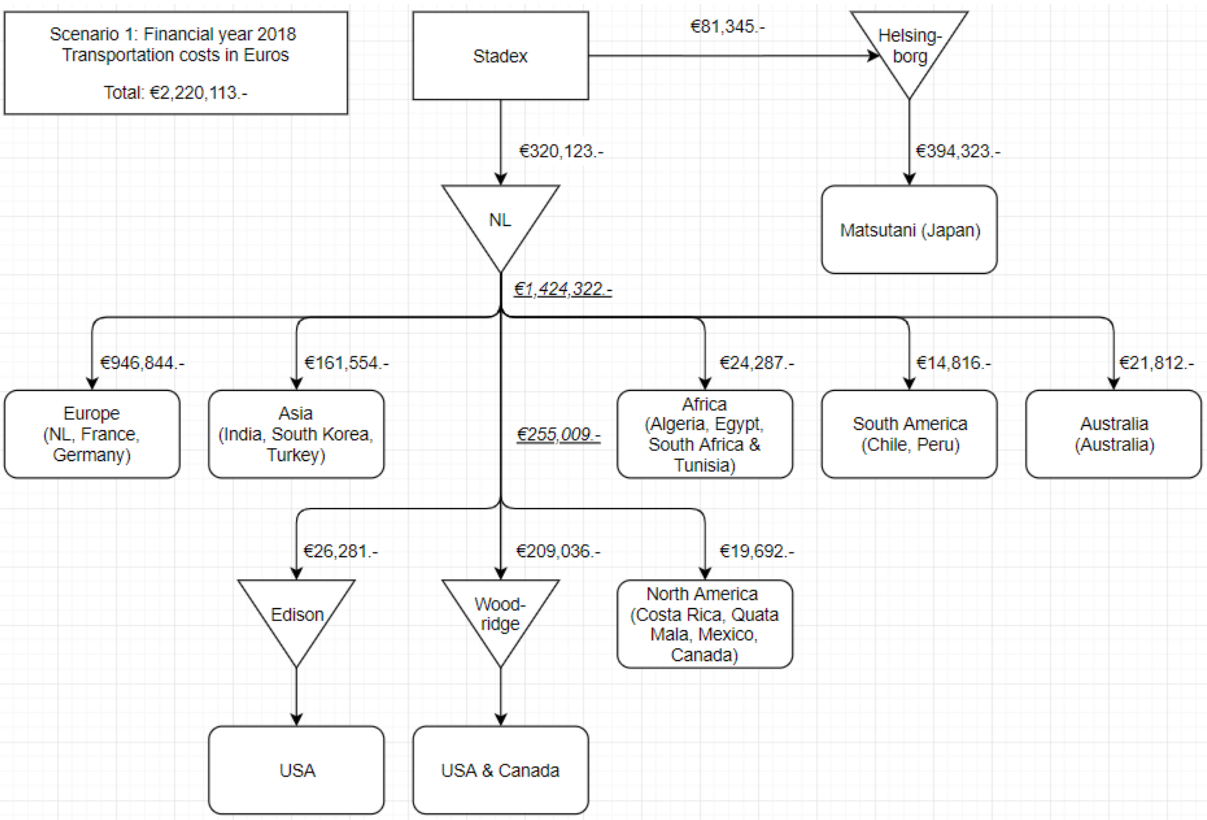

Figure 11: Transportation costs Scenario 1 (in euros)

These transportation costs are determined in the following way:

1. Product flows that stay the same in Scenario 1 as in the current situation have the same transportation costs as in the current situation (Figure 3).
2. The transportation costs to countries delivered from The Netherlands by truck in Scenario 1 that are delivered from Briggen in the current situation are determined based on the postal codes of the customers in these countries. To calculate the transportation costs to these postal codes I have used an Excel file of the sourcing department which provides the costs per pallet for a certain number of pallets in the truck to the postal codes.
3. The transportation costs to countries delivered from The Netherlands by ship in Scenario 1 that are delivered from Briggen in the current situation are determined by the sourcing department.
4. The transportation costs between Stadex and the warehouses in The Netherlands are determined using the following formula: (transportation costs Briggen -> NL current situation / number of pallets from Briggen -> NL current situation) * number of pallets Stadex -> NL in Scenario 1. This can be done since Briggen is located one kilometer from Stadex.
5. The transportation costs Stadex -> Helsingborg and Helsingborg -> Japan are determined by the sourcing department based on the number of pallets.

The exact calculation that I have done to determine the transportation costs of Scenario 1 can be found in Appendix 1.4. In this appendix, I mention how I have determined the unknown costs. Besides, I refer to the calculations done in Appendix 1.2 for the transportation costs that stay the same as in the current situation.

Part 2: Storage costs Scenario 1 (fixed costs in the model)

The total storage costs in Scenario 1 are €298,270 per year (see Table 4).

The storage costs of all scenarios are calculated in the following way:

Storage costs = m^2_{needed} * m^2_{price}

The m^2_{needed} is calculated in the following way:

1. Determine on what type of pallet the products stored in the warehouse are put.
2. Determine at which production line the products that are stored in the warehouse are made.
    - Products made on production lines CSD and HSD are on average 2.5 months in storage.
    - Products made on production lines FB1 and Streba are on average 5 months in storage.
3. Make an overview of how many pallets stored are made on each production line for each type of pallet.
4. Calculate the number of pallet places needed for each type of pallet in the following way:
   = (((#pallets CSD (pallet type 21193) + #pallets HSD (pallet type 21193))/12) * 2.5) + (((#pallets FB1 (pallet type 21193) + #pallets Streba (pallet type 21193))/12) * 5)
   Same formula for pallet type (111942) and N/A.
    - I divide by 12 (months) and multiply by 2.5 or 5 (months), based on the product line at which the product is made, to determine the number of square meters warehouse needed when taking into account the average number of month that a product is stored given the production line the at which the product is made.
5. Calculate m^2 = (#pallets places needed (pallet type 21193) * 1.2) + (#pallets places needed (pallet type 111942) * 1.0816) + (#pallet places needed (pallet type N/A) * 1.2)
    - 1.2 is the size in square meters of pallet type 21193 and 1.0816 is the size in square meters of pallet type 111942
6. Calculate m^2_{needed} = m_2 * 1.15 (15% safety storage capacity to cover peaks in the need of storage capacity, 15% is determined by the supply chain manager).
7. Sum the m^2_{needed} for each type of pallet, this yields the total m^2_{needed} in the warehouse.

The m^2_{price} is warehouse specific. Storage in The Netherlands is €27.60 per square meter per year, Helsingborg is €69 per square meter per year and on site Stadex is €36 per square meter per year. The m^2_{price} in The Netherlands and in Helsingborg are provided by the sourcing department. The m^2_{price} on the Stadex site is determined by the supply chain director.

Now all needed information to complete the formula to determine the storage costs is obtained.

Storage costs = m^2_{needed} * m^2_{price}

I have used this approach to determine the storage costs for all warehouse scenarios. Therefore, these calculations are not stated again underneath the storage costs for the other scenarios. Only the outcomes of these calculations are shown there.

In Table 4, the calculations and outcomes of these calculations done to determine the storage costs in warehouse Scenario 1 are stated.

Type of pallets	CSD	HSD	FB1	Streba	N/A	#pallet places needed	m2	m2 needed Incl. 15% safety stock	Storage costs
HT pallet 1000x1200 (21193)	242	5,025	0	0	0	1,097	1,317	1,514	€ 104,488
HT pallet 1040x1040 (111942)	484	1,788	0	0	0	473	512	589	€ 40,627
N/A	0	57	0	0	0	12	14	16	€ 1,131
Total Helsingborg	726	6,870	0	0	0	**1,583**	**1,843**	**2,120**	**€ 146,246**
Type of pallets	CSD	HSD	FB1	Streba	N/A	#pallet places needed	m2	m2 needed Incl. 15% safety stock	Storage costs
HT pallet 1000x1200 (21193)	1,759	8,057	3,723	210	0	3,684	4,420	5,084	€ 140,306
HT pallet 1040x1040 (111942)	522	981	67	0	0	341	369	424	€ 11,708
N/A	0	1	0	0	3	0	0	0	€ 10
Total NL	2,281	9,039	3,790	210	3	**4,025**	**4,790**	**5,508**	**€ 152,024**
Total Scenario 1	3,007	15,909	3,790	210	3	**5,608**	**6,633**	**7,628**	**€ 298,270**

Table 4: Overview calculations and outcomes of the storage costs in Scenario 1

Part 3: Handling costs Scenario 1 (variable cost in the model)

The handling costs in Scenario 1 are €91,576 per year (see Table 5). These are split into €42,543 per year for the handling in Helsingborg and €49,034 per year for the handling in The Netherlands. The handling cost in Helsingborg are €20.07 per square meter per year. These costs are based on a quotation of a warehouse in Helsingborg. This is an unusual way to give an indication of the handling costs. Normally the handling costs are based on the number of pallets stored, which more defendable since the number of handlings is determined by the throughput size in number of pallets. The handling costs in The Netherlands are €3.20 per pallet. These handling costs are the handling cost Avebe currently pays for handling in the warehouses in The Netherlands. Besides, the number of pallets per year can be found in Figure 10. Lastly the m^2_{needed} including 15% safety stock is already calculated to determine the storage cost and can therefore be found in Table 4.

In Table 5, an overview of the calculation of the handling costs in Scenario 1 can be found.

Warehouse	# Pallets/year	Price/pallet	m2 needed incl. 15% safety stock	Price/m2	Handling costs
Helsingborg	7,596	-	2,120	€ 20.07	€ 42,543
NL	15,323	€ 3.20	-	-	€ 49,034
Total Scenario 1	22,919				**€ 91,576**

Table 5: Calculation handling costs Scenario 1

Part 4: Total costs Scenario 1 (outcome of UCFCFL model)

Based on the handling, storage and transportation costs which are determined above, the total costs for Scenario 1 can be calculated. This is done by simply adding up the fixed and variable costs (see Table 6). The total cost in Scenario 1 are €2,609,960 per year.

	Handling costs	Storage costs	Transportation costs	Total costs
Scenario 1	€ 91,576	€ 298,270	€ 2,220,113	**€ 2,609,960**

Table 6: Total costs Scenario 1

Step 3: CO_2 emission in Scenario 1

To calculate the CO_2 emission in the scenarios I used the same method that I used to determine the CO_2 emission in the current situation. This method is shortly described in Section 2.2.4. A detailed description and application of this method to the current situation can be found in Appendix 1.3.

For all scenarios, I have made comparable calculations to the calculations I made to determine the CO_2 emission in the current situation (see Appendix 1.3). In order to complete the calculations, I had to calculate the average transportation distance by truck, train and ship between Helsingborg and Japan, Denmark, Finland, Norway, Sweden, France, Australia, Turkey, Woodridge and Edison. Next to that, I calculated the average transportation distance by truck, train and ship between Malmö and Japan, Australia, Turkey, Woodridge, Edison, Helsingborg and The Netherlands. The distances I calculated on city level after which I have determined the weighted average transportation distances on country level based on the number of pallets going to each city in the county. I have determined the transportation kilometers by truck using a widget based on a system made by the ANWB (Afstandberekenen, 2019). To determine the transportation kilometers over sea I used the website Port World (S&P Global Platts, 2019).

The rest of the calculations are done in line with the calculations done in Appendix 1.3. Therefore, I do not explain this again for all scenarios. The exact calculations can be found in the Excel file, which is delivered to Avebe together with this thesis.

In Table 7, the total CO_2 emission caused by transportation in Scenario 1 is stated, which is 3,058,810 kilograms CO_2 per year.

Scenario 1	CO2 Truck in KG	CO2 Train in KG	CO2 Ship in KG	Total CO2 in KG
From NL -> ...	284,963	7,803	397,237	690,004
From Helsingborg -> ...	0	0	1,959,965	1,959,965
Stadex -> Helsingborg	23,958	0	0	23,958
Stadex -> NL	384,883	0	0	384,883
Total CO2 emission Scenario 1	693,804	7,803	2,357,203	**3,058,810**

Table 7: Total CO_2 emission Scenario 1

-> Scenario 2

Step 1: Product flows Scenario 2

In Figure 12, an overview of the product flows in Scenario 2 is given. The size of the product flows is calculated based on the same two Excel files that are used to determine the product flows in Figure 2. These are the real numbers of financial year 2018, only different warehouses are used in this warehouse scenario. The underlined numbers are summations of the pallet flows mentioned below in the figure.

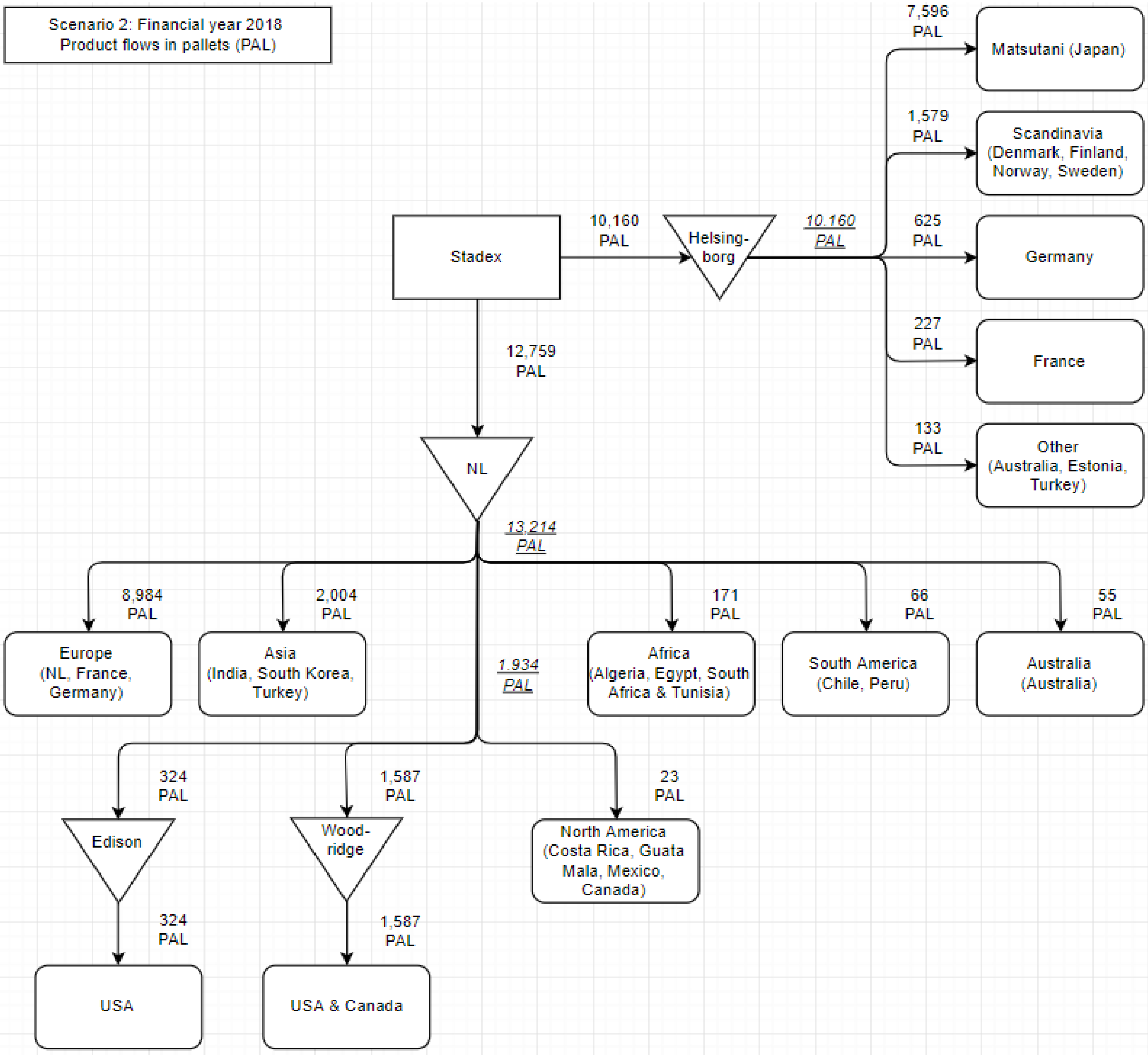

Figure 12: Product flows Scenario 2 in pallets (PAL)

Step 2: Costs in Scenario 2

Part 1: Transportation costs Scenario 2 (variable costs in model)

In Figure 13, an overview of the transportation costs in Scenario 2 is given. The total costs of transportation in this warehouse scenario are €1,254,950 + €266,561 + €108,816 + €510,127 = €2,140,454. The underlined numbers are summations of the transportation costs mentioned below in the figure.

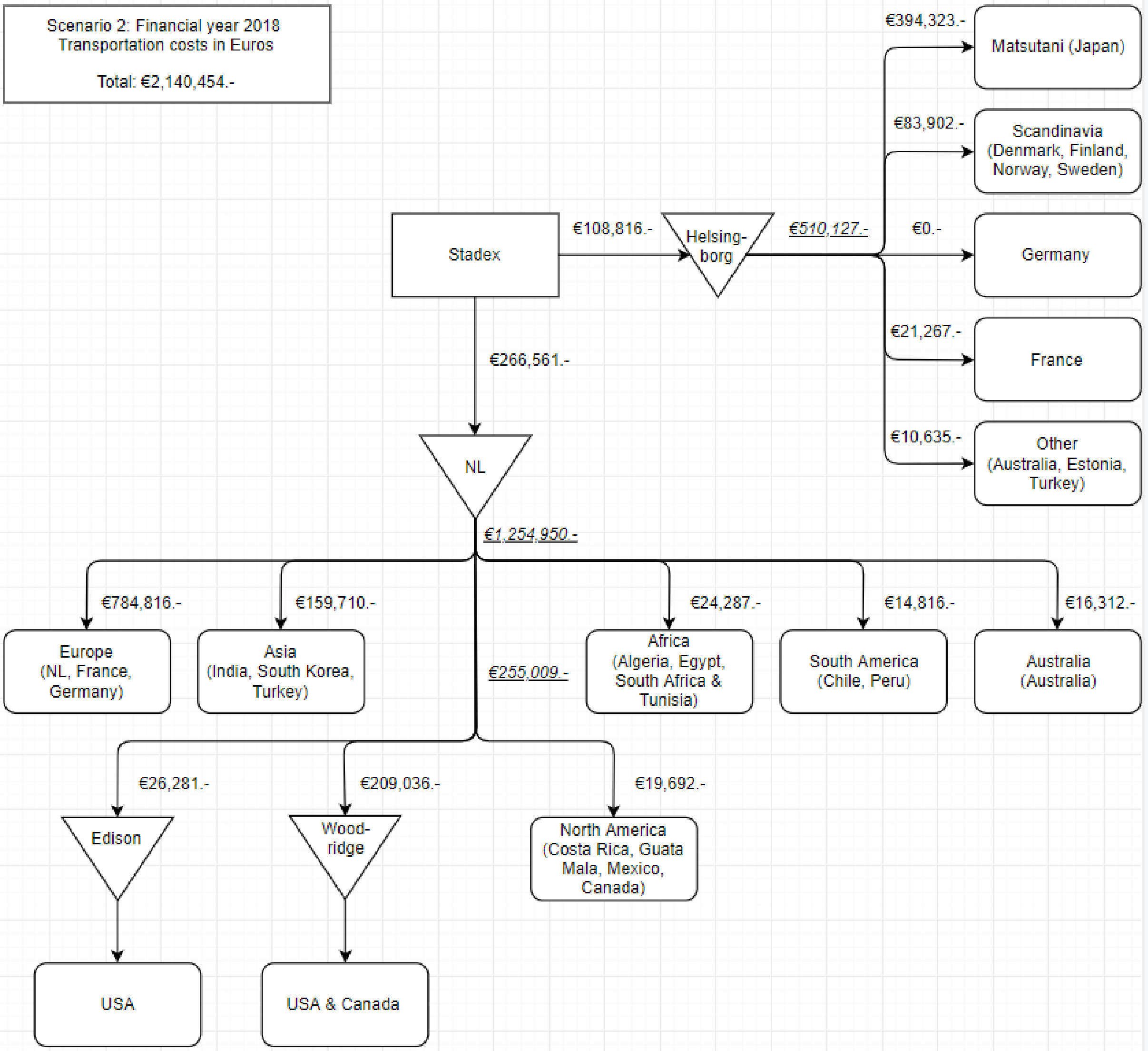

Figure 13: Transportation costs Scenario 2 (in euros)

These transportation costs are calculated in the following way:

1. The transportation costs from the warehouses in The Netherlands -> … and the transportation costs from Stadex to NL are the same as in the current situation (see Figure 3).
2. I determined the other transportation costs together with the sourcing department of Avebe. How this is exactly done is stated in Appendix 1.4.

Part 2: Storage costs Scenario 2 (fixed costs in model)

The total storage costs in Scenario 2 are €334,492 per year (see Table 8). The numbers stated in this table are determined using the approach described underneath the header “Storage costs Scenario 1”.

Type of pallets	CSD	HSD	FB1	Streba	N/A	#pallet places needed	m2	m2 needed Incl. 15% safety stock	Storage costs
HT pallet 1000x1200 (21193)	773	5,799	396	153	0	1,598	1,918	2,205	€ 152,160
HT pallet 1040x1040 (111942)	742	2,239	0	0	0	621	672	773	€ 53,304
N/A	0	58	0	0	0	12	15	17	€ 1,151
Total Helsingborg	1,515	8,096	396	153	0	**2,231**	**2,604**	**2,994**	**€ 206,615**
Type of pallets	CSD	HSD	FB1	Streba	N/A	#pallet places needed	m2	m2 needed Incl. 15% safety stock	Storage costs
HT pallet 1000x1200 (21193)	1,228	7,283	3,327	57	0	3,183	3,820	4,393	€ 121,237
HT pallet 1040x1040 (111942)	264	530	67	0	0	193	209	240	€ 6,637
N/A	0	0	0	0	3	0	0	0	€ 2
Total NL	1,492	7,813	3,394	57	3	**3,376**	**4,029**	**4,633**	**€ 127,876**
Total Scenario 2	3,007	15,909	3,790	210	3	**5,608**	**6,633**	**7,628**	**€ 334,492**

Table 8: Overview calculations and outcomes of the storage costs in Scenario 2

Part 3: Handling costs Scenario 2 (variable costs in model)

The handling costs in Scenario 2 are €100,934 per year (see Table 9). These are split into €60,104 per year for the handling in Helsingborg and €40,830 per year for the handling in The Netherlands. The handling cost in Helsingborg are €20.07 per square meter per year. These costs are based on a quotation of a warehouse in Helsingborg. The handling costs in The Netherlands are €3.20/pallet. These handling costs are the handling cost Avebe currently pays for handling in the warehouses in The Netherlands. Besides the number of pallets per year can be found in Figure 12. Lastly the m^2_{needed} including 15% safety stock is already calculated to determine the storage cost and can therefore be found in Table 8.

In Table 9, an overview of the calculation of the handling costs in Scenario 2 can be found.

Warehouse	# Pallets/year	Price/pallet	m2 needed incl. 15% safety stock	Price/m2	Handling costs
Helsingborg	10,160	-	2,994	€ 20.07	€ 60,104
NL	12,759	€ 3.20	-	-	€ 40,830
Total Scenario 2	22,919				**€ 100,934**

Table 9: Calculation handling costs Scenario 2

Part 4: Total costs Scenario 2 (outcome of UCFCFL model)

Based on the handling, storage and transportation costs which are determined above, the total costs for Scenario 2 can be calculated. This is done by simply adding up the fixed and variable costs (see Table 10). The total cost in Scenario 2 are €2,575,879 per year.

	Handling costs	Storage costs	Transportation costs	Total costs
Scenario 2	€ 100,934	€ 334,492	€ 2,140,454	**€ 2,575,879**

Table 10: Total costs Scenario 2

Step 3: CO_2 emission in Scenario 2

In Table 11, the total CO_2 emission caused by transportation in Scenario 2 is stated, which is 3,037,852 kilograms CO_2 per year.

Scenario 2	CO2 Truck in KG	CO2 Train in KG	CO2 Ship in KG	Total CO2 in KG
From NL -> …	215,913	7,803	376,588	600,303
From Helsingborg -> …	52,670	0	1,975,314	2,027,984
Stadex -> Helsingborg	28,719	0	0	28,719
Stadex -> NL	380,846	0	0	380,846
Total CO2 emission Scenario 2	678,148	7,803	2,351,902	**3,037,852**

Table 11: Total CO_2 emission Scenario 2

This is calculated in a comparable way as described underneath the header "Step 3: CO_2 emission in Scenario 1" above.

-> Scenario 3

Step 1: Product flows Scenario 3

In Figure 14, an overview of the product flows in Scenario 3 is given. The size of the product flows is calculated based on the same two Excel files that are used to determine the product flows in Figure 2. These are the real numbers of financial year 2018, only different warehouses and customer allocations are used in this warehouse scenario. The underlined numbers are summations of the pallet flows mentioned below in the figure.

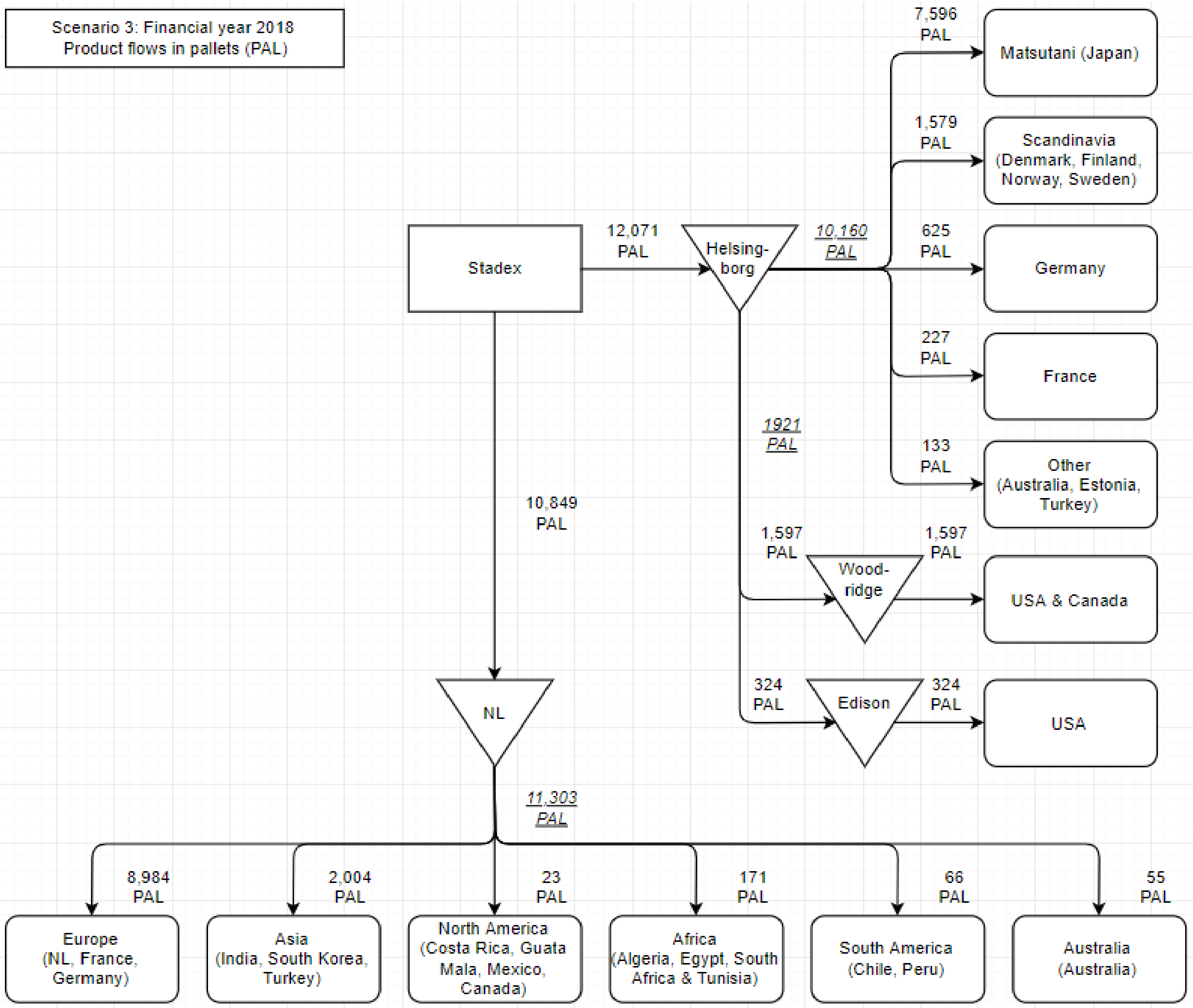

Figure 14: Product flows Scenario 3 in pallets (PAL)

Step 2: Costs in Scenario 3

Part 1: Transportation costs Scenario 3 (variable costs in model)

In Figure 15, an overview of the transportation costs in Scenario 3 is given. The total costs of transportation in this warehouse scenario are €1,019,633 + €226,645 + €129,279 + €510,127 + €311,537 = €2,197,221. The underlined numbers are summations of the transportation costs mentioned below in the figure.

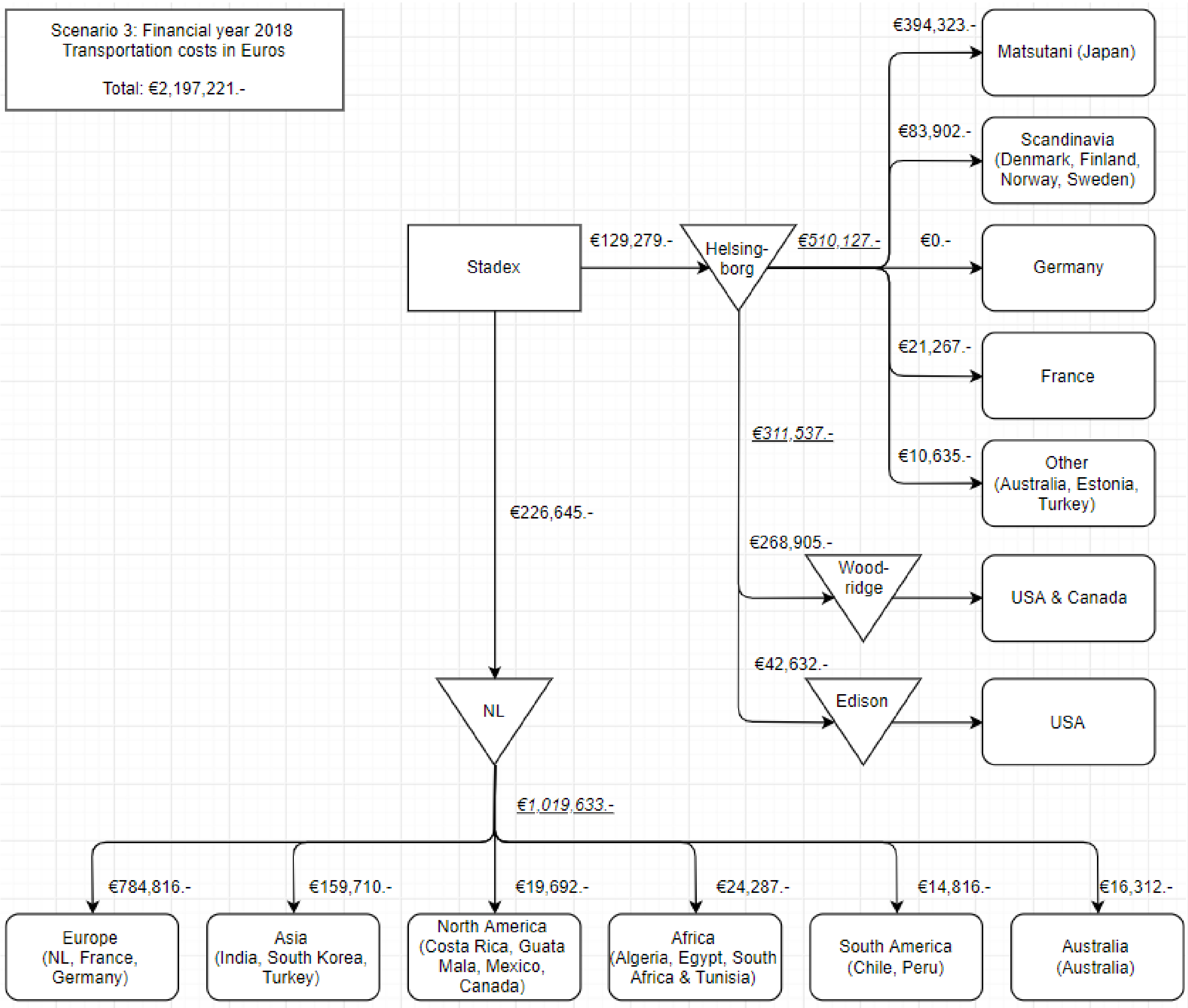

Figure 15: Transportation costs Scenario 3 (in euros)

The transportation costs of this warehouse scenario are the same as in Scenario 2 except for the transportation caused by delivering the warehouses "Woodridge" and "Edison" in the USA. Since, these are delivered from Helsingborg instead of from the warehouses in The Netherlands. Therefore, the following transportation costs need to be recalculated:

1. The transportation costs from Stadex to the warehouses in The Netherlands.
2. The transportation costs from the warehouses in The Netherlands to North America.
3. The transportation costs from Stadex to Helsingborg.
4. The transportation costs from Helsingborg to Woodridge and Edison.

How I have determined these costs is stated in Appendix 1.4.

Part 2: Storage costs Scenario 3 (fixed costs in model)

The total storage costs in Scenario 3 are €357,535 per year (see Table 12). The numbers stated in this table are determined using the approach described underneath the header "Storage costs Scenario 1".

Type of pallets	CSD	HSD	FB1	Streba	N/A	#pallet places needed	m2	m2 needed Incl. 15% safety stock	Storage costs
HT pallet 1000x1200 (21193)	913	7,158	456	153	0	1,935	2,322	2,671	€ 184,290
HT pallet 1040x1040 (111942)	1,022	2,310	0	0	0	694	751	863	€ 59,580
N/A	0	58	0	0	0	12	15	17	€ 1,151
Total Helsingborg	1,935	9,526	456	153	0	**2,642**	**3,088**	**3,551**	**€ 245,021**
Type of pallets	CSD	HSD	FB1	Streba	N/A	#pallet places needed	m2	m2 needed Incl. 15% safety stock	Storage costs
HT pallet 1000x1200 (21193)	1,088	5,924	3,267	57	0	2,846	3,415	3,927	€ 108,385
HT pallet 1040x1040 (111942)	16	459	67	0	0	120	130	150	€ 4,127
N/A	0	0	0	0	3	0	0	0	€ 2
Total NL	1,072	6,383	3,334	57	3	**2,966**	**3,545**	**4,077**	**€ 112,514**
Total Scenario 3	3,007	15,909	3,790	210	3	**5,608**	**6,633**	**7,628**	**€ 357,535**

Table 12: Overview calculations and outcomes of the storage costs in Scenario 3

Part 3: Handling costs Scenario 3 (variable costs in model)

The handling costs in Scenario 3 are €105,992 per year (see Table 13). These are split into €71,276 per year for the handling in Helsingborg and €34,716 per year for the handling in The Netherlands. The handling cost in Helsingborg are €20.07 per square meter per year. These costs are based on a quotation of a warehouse in Helsingborg. The handling costs in The Netherlands are €3.20 per pallet. These handling costs are the handling cost Avebe currently pays for handling in the warehouses in The Netherlands. Besides the number of pallets per year can be found in Figure 14. Lastly the m^2_{needed} including 15% safety stock is already calculated to determine the storage cost and can therefore be found in Table 12.

In Table 13, an overview of the calculation of the handling costs in Scenario 3 can be found.

Warehouse	# Pallets/year	Price/pallet	m2 needed incl. 15% safety stock	Price/m2	Handling costs
Helsingborg	12,071	-	3,551	€ 20.07	€ 71,276
NL	10,849	€ 3.20	-	-	€ 34,716
Total Scenario 3	22,919				**€ 105,992**

Table 13: Calculation handling costs Scenario 3

Part 4: Total costs Scenario 3 (outcome of UCFCFL model)

Based on the handling, storage and transportation costs which are determined above, the total costs for Scenario 3 can be calculated. This is done by simply adding up the fixed and variable costs (see Table 14). The total cost in Scenario 3 are €2,660,747 per year.

	Handling costs	Storage costs	Transportation costs	Total costs
Scenario 3	€ 105,992	€ 357,535	€ 2,197,221	**€ 2,660,747**

Table 14: Total costs Scenario 3

Step 3: CO_2 emission in Scenario 3

In Table 15, the total CO_2 emission caused by transportation in Scenario 3 is stated, which is 2,996,914 kilograms CO_2 per year.

Scenario 3	CO2 Truck in KG	CO2 Train in KG	CO2 Ship in KG	Total CO2 in KG
From NL -> …	207,448	7,803	239,250	454,501
From Helsingborg -> …	56,235	0	2,122,085	2,178,321
Stadex -> Helsingborg	33,857	0	0	33,857
Stadex -> NL	330,235	0	0	330,235
Total CO2 emission Scenario 3	627,775	7,803	2,361,336	**2,996,914**

Table 15: Total CO_2 emission Scenario 3

This is calculated in a comparable way as described underneath the header "Step 3: CO_2 emission in Scenario 1" above.

-> Scenario 4

Step 1: Product flows Scenario 4

In Figure 16, an overview of the product flows in Scenario 4 is given. The size of the product flows is calculated based on the same two Excel files that are used to determine the product flows in Figure 2. These are the real numbers of financial year 2018, only different warehouses and customer allocations are used in this warehouse scenario. The underlined numbers are summations of the pallet flows mentioned below in the figure.

The size of the product flows in this scenario is the same as the size of the product flows in Scenario 1, only warehouse Helsingborg is replaced by a warehouse on the Stadex site (in Malmö).

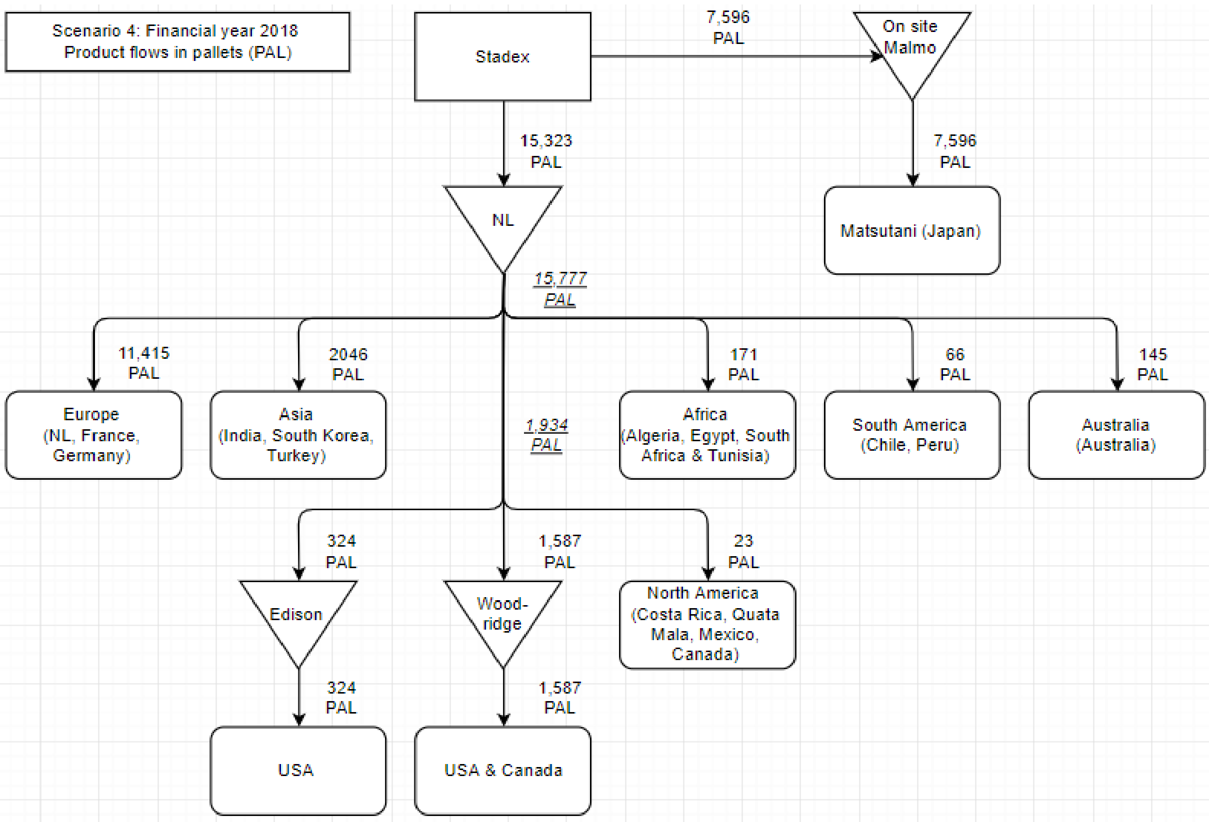

Figure 16: Products flows Scenario 4 in pallets (PAL)

Step 2: Costs in Scenario 4

Part 1: Transportation costs Scenario 4 (variable costs in model)

In Figure 17, an overview of the transportation costs in Scenario 4 is given. The total costs of transportation in this warehouse scenario are €1,424,322 + €320,123 + €0 + €469,033 = €2,213,478. The underlined numbers are summations of the transportation costs mentioned below in the figure.

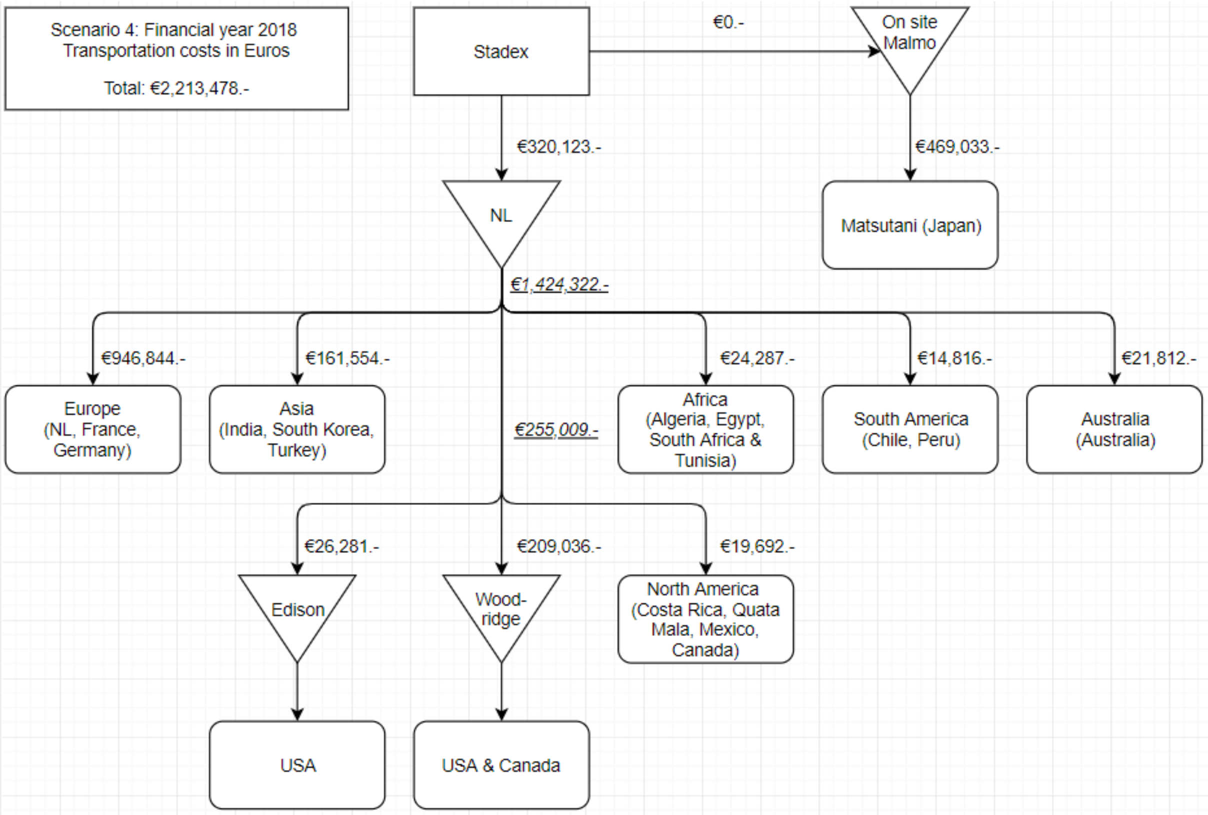

Figure 17: Transportation costs Scenario 4 (in euros)

The transportation costs of this warehouse scenario are the same as in Scenario 1 except for the transportation costs between Stadex and the storage on site Stadex and the transportation costs between on-site Stadex and Matsutani (Japan).

How I have determined these costs is stated in Appendix 1.4.

Part 2: Storage costs Scenario 4 (fixed costs in model)

The total storage costs in Scenario 4 are €228,326 per year (see Table 16). The numbers stated in this table are determined using the approach described underneath the header "Storage costs Scenario 1".

Type of pallets	CSD	HSD	FB1	Streba	N/A	#pallet places needed	m2	m2 needed Incl. 15% safety stock	Storage costs
HT pallet 1000x1200 (21193)	242	5,025	0	0	0	1,097	1,317	1,514	€ 54,516
HT pallet 1040x1040 (111942)	484	1,788	0	0	0	473	512	589	€ 21,197
N/A	0	57	0	0	0	12	14	16	€ 590
Total On site	726	6,870	0	0	0	**1,583**	**1,843**	**2,120**	**€ 76,302**
Type of pallets	CSD	HSD	FB1	Streba	N/A	#pallet places needed	m2	m2 needed Incl. 15% safety stock	Storage costs
HT pallet 1000x1200 (21193)	1,759	8,057	3,723	210	0	3,684	4,420	5,084	€ 140,306
HT pallet 1040x1040 (111942)	522	981	67	0	0	341	369	424	€ 11,708
N/A	0	1	0	0	3	0	0	0	€ 10
Total NL	2,281	9,039	3,790	210	3	**4,025**	**4,790**	**5,508**	**€ 152,024**
Total Scenario 4	3,007	15,909	3,790	210	3	**5,608**	**6,633**	**7,628**	**€ 228,326**

Table 16: Overview calculations and outcomes of the storage costs in Scenario 4

Part 3: Handling costs Scenario 4 (variable costs in model)

The handling costs in Scenario 4 are €80,455 per year (see Table 17). These are split into €31,421 per year for the handling in on the Stadex site and €49,034 per year for the handling in The Netherlands. The handling cost on the Stadex site are €4.14 per pallet per year. These costs are based on the labor cost in Briggen in the current situation. I have expressed these labor costs in costs per pallet (number of pallets stored in Briggen / labor costs Briggen = cost per pallet = €4.14). These costs per pallet are multiplied by the number of pallets stored. This yields the handling costs per year. This way of calculating the handling/labor costs on the Stadex site, is proposed by the manager of Stadex. The handling costs in The Netherlands are €3.20 per pallet. These handling costs are the handling cost Avebe currently pays for handling in the warehouses in The Netherlands. Besides the number of pallets per year can be found in Figure 16. Lastly the m^2_{needed} including 15% safety stock is already calculated to determine the storage cost and can therefore be found in Table 16.

In Table 17, an overview of the calculation of the handling costs in Scenario 4 can be found.

Warehouse	# Pallets/year	Price/pallet	Handling costs
On site	7,596	€ 4.14	€ 31,421
NL	15,323	€ 3.20	€ 49,034
Total Scenario 4	22,919		**€ 80,455**

Table 17: Calculation handling costs Scenario 4

Part 4: Total costs Scenario 4 (outcome of UCFCFL model)

Based on the handling, storage and transportation costs which are determined above, the total costs for Scenario 4 can be calculated. This is done by simply adding up the fixed and variable costs (see Table 18). The total cost in Scenario 4 are €2,522,259 per year.

	Handling costs	Storage costs	Transportation costs	Total costs
Scenario 4	€ 80,455	€ 228,326	€ 2,213,478	**€ 2,522,259**

Table 18: Total costs Scenario 4

Step 3: CO_2 emission in Scenario 4

In Table 19, the total CO_2 emission caused by transportation in Scenario 4 is stated, which is 3,058,810 kilograms CO_2 per year.

Scenario 4	CO2 Truck in KG	CO2 Train in KG	CO2 Ship in KG	Total CO2 in KG
From NL -> …	284,963	7,803	397,237	690,004
From On site Stadex -> …	23,958	0	1,959,965	1,983,923
Stadex -> On site Stadex	0	0	0	0
Stadex -> NL	384,883	0	0	384,883
Total CO2 emission Scenario 4	693,804	7,803	2,357,203	**3,058,810**

Table 19: Total CO_2 emission Scenario 4

This is calculated in a comparable way as described underneath the header "Step 3: CO_2 emission in Scenario 1" above.

-> Scenario 5

Step 1: Product flows Scenario 5

In Figure 18, an overview of the product flows in Scenario 5 is given. The size of the product flows is calculated based on the same two Excel files that are used to determine the product flows in Figure 2. These are the real numbers of financial year 2018, only different warehouses and customer allocations are used in this warehouse scenario. The underlined numbers are summations of the pallet flows mentioned below in the figure.

The size of the product flows in this scenario is the same as the size of the product flows in Scenario 2, only warehouse Helsingborg is replaced by a warehouse on the Stadex site (in Malmö).

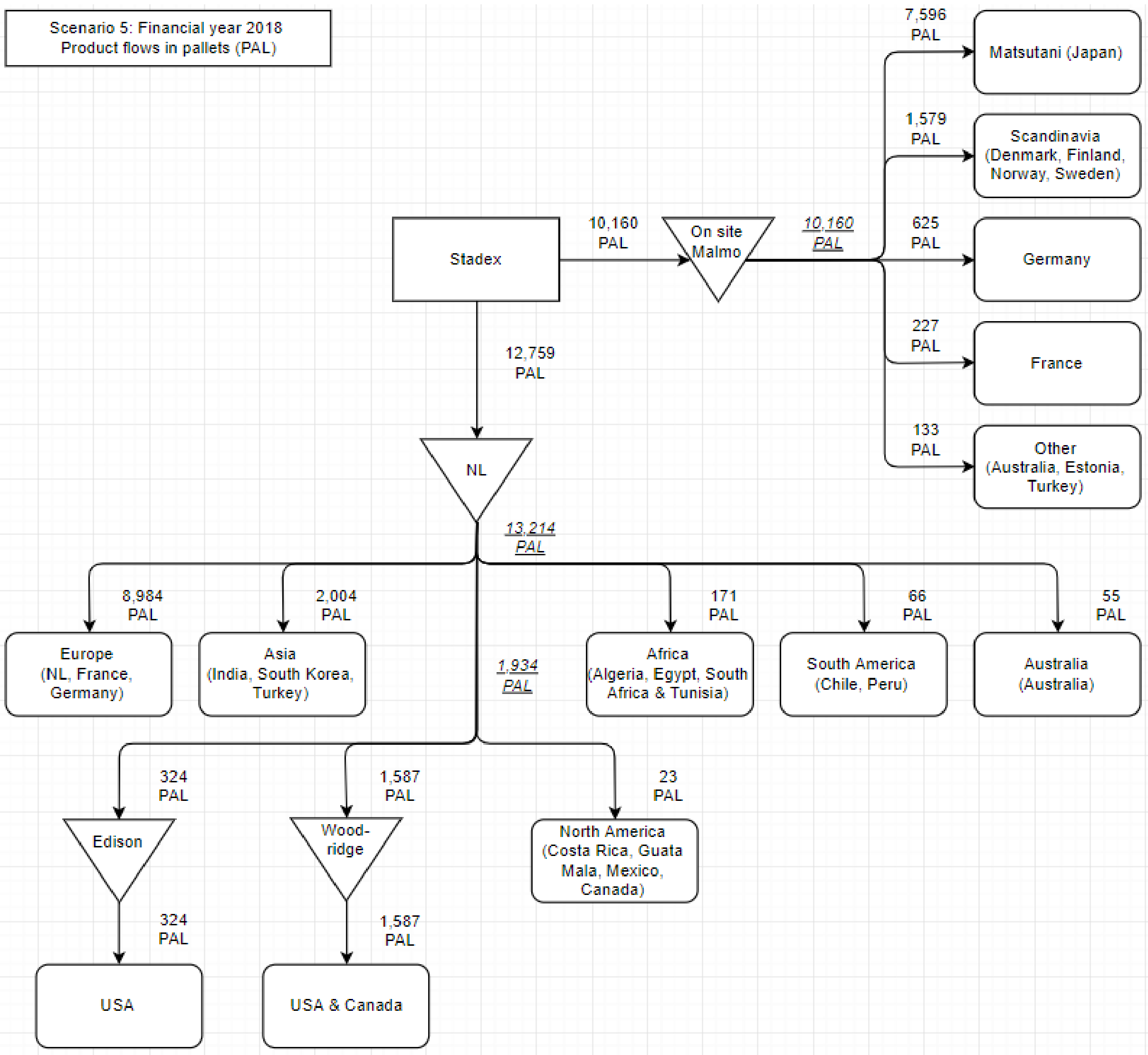

Figure 18: Products flows Scenario 5 in pallets (PAL)

Step 2: Costs in Scenario 5

Part 1: Transportation costs Scenario 5 (variable costs)

In Figure 19, an overview of the transportation costs in Scenario 5 is given. The total costs of transportation in this warehouse scenario are €1,254,950 + €266,561 + €0 + €591,278 = €2,112,789. The underlined numbers are summations of the transportation costs mentioned below in the figure.

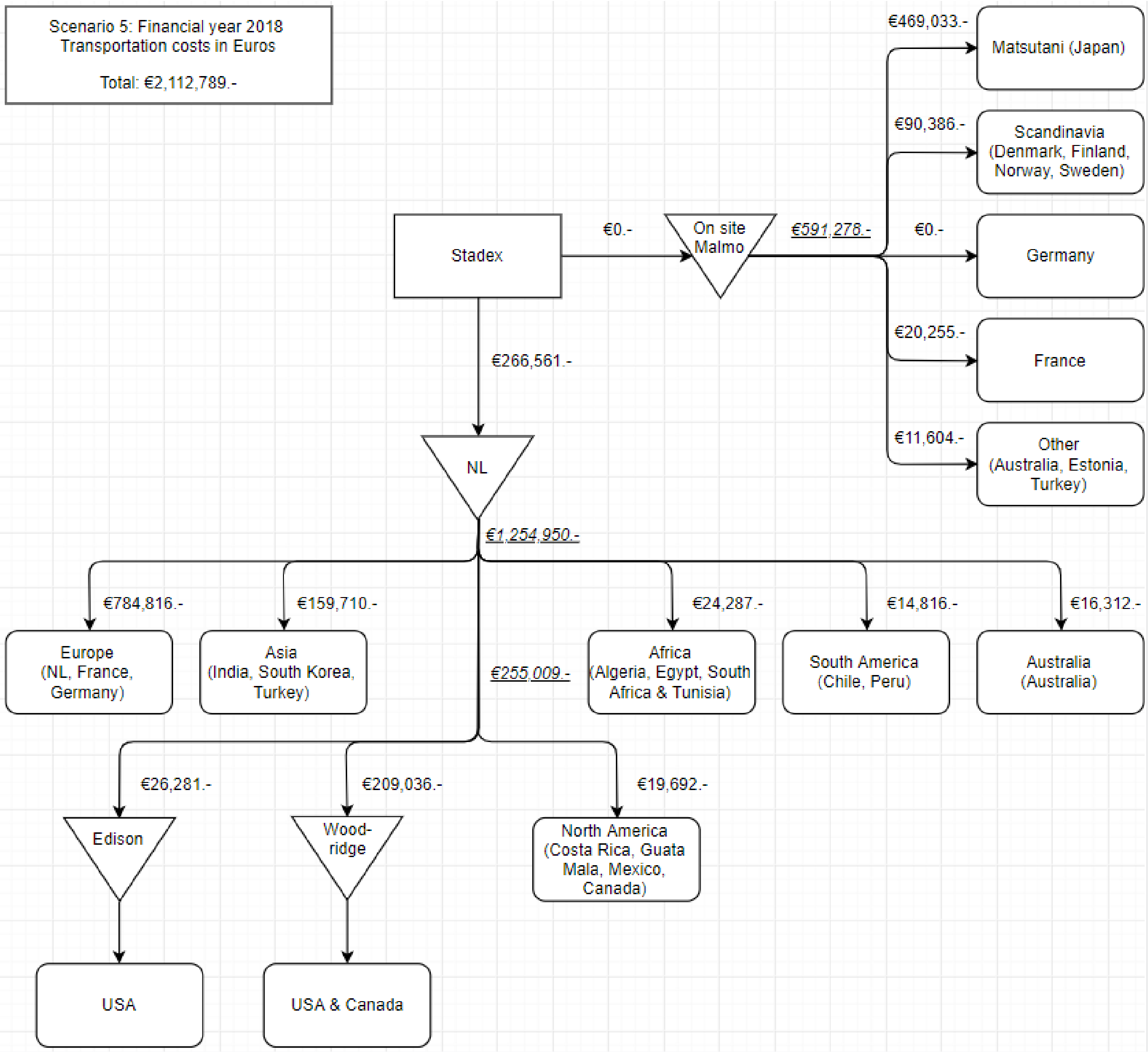

Figure 19: Transportation costs Scenario 5 (in euros)

The transportation costs of this warehouse scenario are the same as in Scenario 2 except for the transportation costs between Stadex and the storage on-site Stadex and the transportation costs between on-site Stadex and the customers that are delivered from on-site Stadex in Scenario 5.

How I have determined these costs is stated in Appendix 1.4.

Part 2: Storage costs Scenario 5 (fixed costs)

The total storage costs in Scenario 5 are €235,676 per year (see Table 20). The numbers stated in this table are determined using the approach described underneath the header “Storage costs Scenario 1”.

Type of pallets	CSD	HSD	FB1	Streba	N/A	#pallet places needed	m2	m2 needed Incl. 15% safety stock	Storage costs
HT pallet 1000x1200 (21193)	773	5,799	396	153	0	1,598	1,918	2,205	€ 79,388
HT pallet 1040x1040 (111942)	742	2,239	0	0	0	621	672	773	€ 27,811
N/A	0	58	0	0	0	12	15	17	€ 600
Total On site	1,515	8,096	396	153	0	**2,231**	**2,604**	**2,994**	**€ 107,799**
Type of pallets	CSD	HSD	FB1	Streba	N/A	#pallet places needed	m2	m2 needed Incl. 15% safety stock	Storage costs
HT pallet 1000x1200 (21193)	1,228	7,283	3,327	57	0	3,183	3,820	4,393	€ 121,237
HT pallet 1040x1040 (111942)	264	530	67	0	0	193	209	240	€ 6,637
N/A	0	0	0	0	3	0	0	0	€ 2
Total NL	1,492	7,813	3,394	57	3	**3,376**	**4,029**	**4,633**	**€ 127,876**
Total Scenario 5	3,007	15,909	3,790	210	3	**5,608**	**6,633**	**7,628**	**€ 235,676**

Table 20: Overview calculations and outcomes of the storage costs in Scenario 5

Part 3: Handling costs Scenario 5 (variable costs)

The handling costs in Scenario 5 are €82,856 per year (see Table 21). These are split into €42,026 per year for the handling in on the Stadex site and €40,830 per year for the handling in The Netherlands. The handling cost on the Stadex site are €4.14 per pallet per year. These costs are based on the labor cost in Briggen in the current situation. I have expressed these labor costs in costs per pallet (number of pallets stored in Briggen / labor costs Briggen = cost per pallet = €4.14). These costs per pallet are multiplied by the number of pallets stored. This yields the handling costs per year. This way of calculating the handling/labor costs on the Stadex site, is proposed by the manager of Stadex. The handling costs in The Netherlands are €3.20 per pallet. These handling costs are the handling cost Avebe currently pays for handling in the warehouses in The Netherlands. Besides the number of pallets per year can be found in Figure 18. Lastly the m^2_{needed} including 15% safety stock is already calculated to determine the storage cost and can therefore be found in Table 20.

In Table 21, an overview of the calculation of the handling costs in Scenario 5 can be found.

Warehouse	# Pallets/year	Price/pallet	Handling costs
On site	10,160	€ 4.14	€ 42,026
NL	12,759	€ 3.20	€ 40,830
Total Scenario 5	22,919		**€ 82,856**

Table 21: Calculation handling costs Scenario 5

Part 4: Total costs Scenario 5 (outcome of UCFCFL model)

Based on the handling, storage and transportation costs which are determined above, the total costs for Scenario 5 can be calculated. This is done by simply adding up the fixed and variable costs (see Table 22). The total cost in Scenario 5 are €2,431,320 per year.

	Handling costs	Storage costs	Transportation costs	Total costs
Scenario 5	€ 82,856	€ 235,676	€ 2,112,789	**€ 2,431,320**

Table 22: Total costs Scenario 5

Step 3: CO_2 emission in Scenario 5

In Table 23, the total CO_2 emission caused by transportation in Scenario 5 is stated, which is 3,026,261 kilograms CO_2 per year.

Scenario 5	CO2 Truck in KG	CO2 Train in KG	CO2 Ship in KG	Total CO2 in KG
From NL -> …	215,913	7,803	376,588	600,303
From On site Stadex -> …	69,124	0	1,975,987	2,045,111
Stadex -> On site Stadex	0	0	0	0
Stadex -> NL	380,846	0	0	380,846
Total CO2 emission Scenario 5	665,883	7,803	2,352,575	**3,026,261**

Table 23: Total CO_2 emission Scenario 5

This is calculated in a comparable way as described underneath the header "Step 3: CO_2 emission in Scenario 1" above.

-> Scenario 6

Step 1: Product flows Scenario 6

In Figure 20, an overview of the product flows in Scenario 6 is given. The size of the product flows is calculated based on the same two Excel files that are used to determine the product flows in Figure 2. These are the real numbers of financial year 2018, only different warehouses and customer allocations are used in this warehouse scenario. The underlined numbers are summations of the pallet flows mentioned below in the figure.

The size of the product flows in this scenario is the same as the size of the product flows in Scenario 3, only warehouse Helsingborg is replaced by a warehouse on the Stadex site (in Malmö).

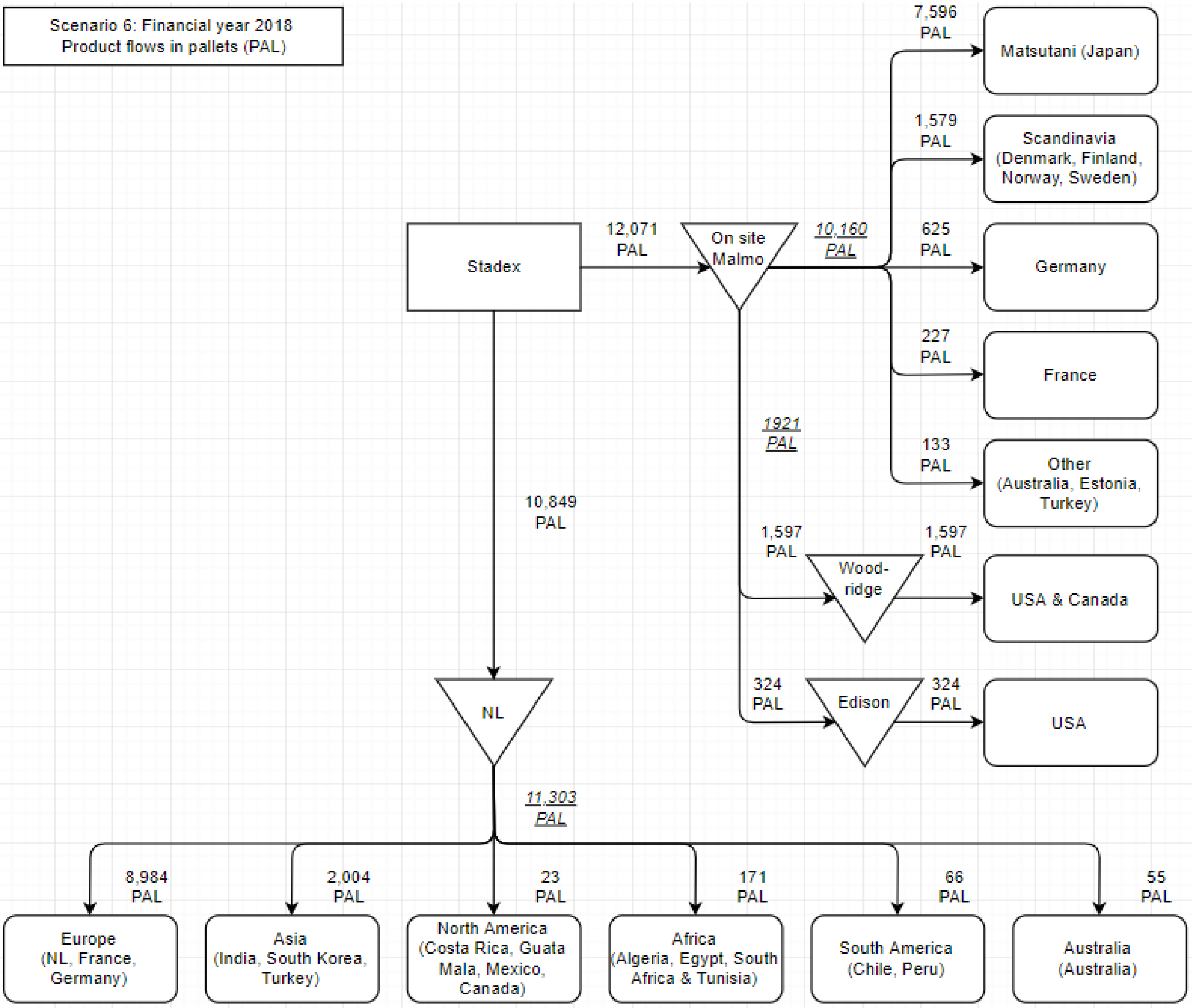

Figure 20: Products flows Scenario 6 in pallets (PAL)

Step 2: Costs in Scenario 6

Part 1: Transportation costs Scenario 6 (variable costs)

In Figure 21, an overview of the transportation costs in Scenario 6 is given. The total costs of transportation in this warehouse scenario are €1,019,633 + €226,645 + €0 + €591,278 + €332,058 = €2,169,614. The underlined numbers are summations of the transportation costs mentioned below in the figure.

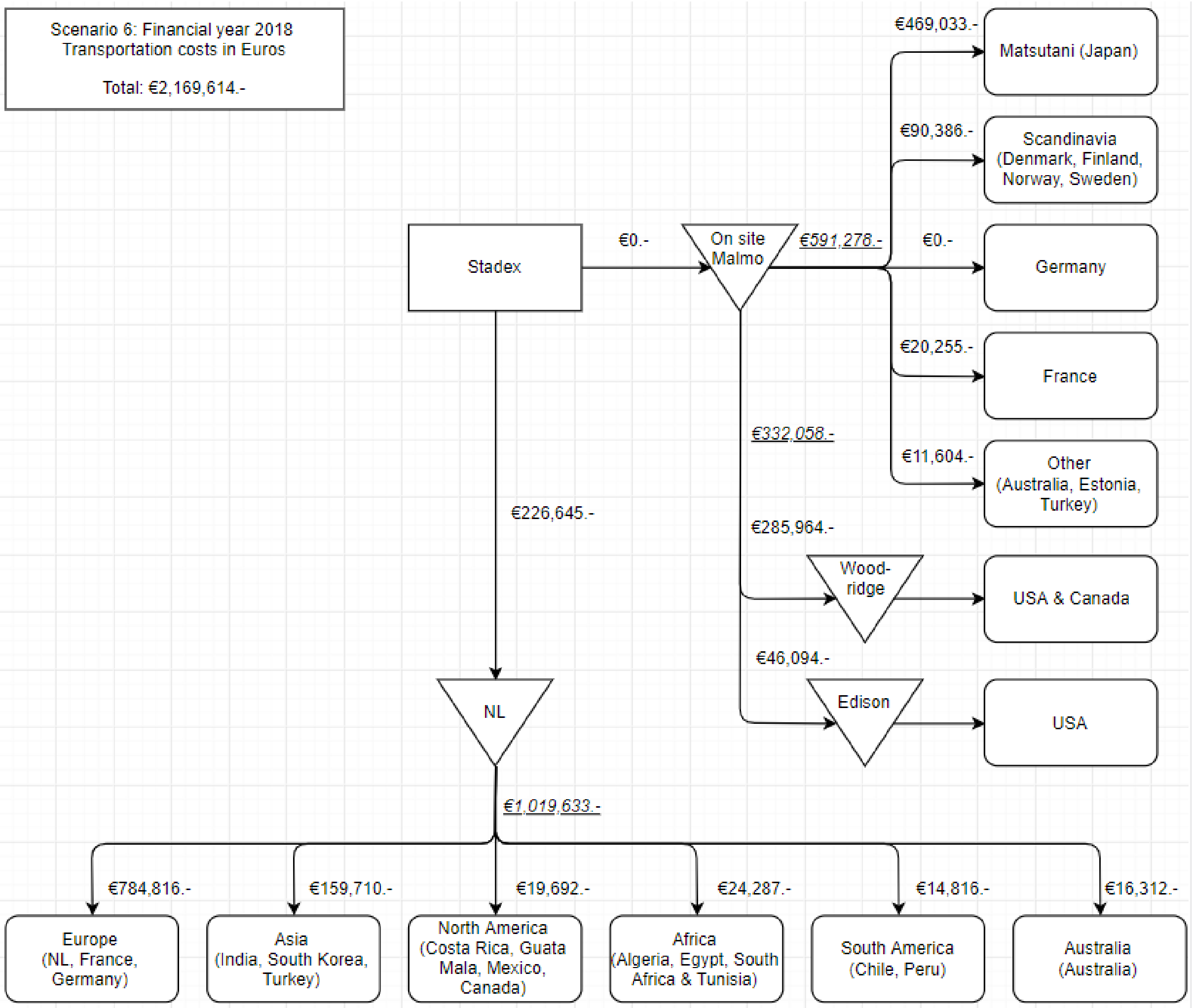

Figure 21: Transportation costs Scenario 6 (in euros)

The transportation costs of this warehouse scenario are the same as in Scenario 3 except for the transportation costs between Stadex and the storage on site Stadex and the transportation costs between on-site Stadex and the customers that are delivered from on-site Stadex in Scenario 6. Also, the transportation costs between on-site Stadex and the warehouses in the USA (Woodridge and Edison) differ in Scenario 6 compared to Scenario 3

How I have determined these costs is stated in Appendix 1.4.

Part 2: Storage costs Scenario 6 (fixed costs)

The total storage costs in Scenario 6 are €240,351 per year (see Table 24). The numbers stated in this table are determined using the approach described underneath the header "Storage costs Scenario 1".

Type of pallets	CSD	HSD	FB1	Streba	N/A	#pallet places needed	m2	m2 needed Incl. 15% safety stock	Storage costs
HT pallet 1000x1200 (21193)	913	7,158	456	153	0	1,935	2,322	2,671	€ 96,151
HT pallet 1040x1040 (111942)	1,022	2,310	0	0	0	694	751	863	€ 31,085
N/A	0	58	0	0	0	12	15	17	€ 600
Tot.	1,935	9,526	456	153	0	**2,642**	**3,088**	**3,551**	**€ 127,837**
Type of pallets	CSD	HSD	FB1	Streba	N/A	#pallet places needed	m2	m2 needed Incl. 15% safety stock	Storage costs
HT pallet 1000x1200 (21193)	1,088	5,924	3,267	57	0	2,846	3,415	3,927	€ 108,385
HT pallet 1040x1040 (111942)	16	459	67	0	0	120	130	150	€ 4,127
N/A	0	0	0	0	3	0	0	0	€ 2
Tot.	1,072	6,383	3,334	57	3	**2,966**	**3,545**	**4,077**	**€ 112,514**
Total Scenario 6	3,007	15,909	3,790	210	3	**5,608**	**6,633**	**7,628**	**€ 240,351**

Table 24: Overview calculations and outcomes of the storage costs in Scenario 6

Part 3: Handling costs Scenario 6 (variable costs)

The handling costs in Scenario 6 are €84,645 per year (see Table 25). These are split into €49,929 per year for the handling in on the Stadex site and €34,716 per year for the handling in The Netherlands. The handling cost on the Stadex site are €4.14 per pallet per year. These costs are based on the labor cost in Briggen in the current situation. I have expressed these labor costs in costs per pallet (number of pallets stored in Briggen / labor costs Briggen = cost per pallet = €4.14). These costs per pallet are multiplied by the number of pallets stored. This yields the handling costs per year. This way of calculating the handling/labor costs on the Stadex site, is proposed by the manager of Stadex. The handling costs in The Netherlands are €3.20 per pallet. These handling costs are the handling cost Avebe currently pays for handling in the warehouses in The Netherlands. Besides the number of pallets per year can be found in Figure 20. Lastly the m^2_{needed} including 15% safety stock is already calculated to determine the storage cost and can therefore be found in Table 24.

In Table 25, an overview of the calculation of the handling costs in Scenario 6 can be found.

Warehouse	# Pallets/year	Price/pallet	Handling costs
On site	12,071	€ 4.14	€ 49,929
NL	10,849	€ 3.20	€ 34,716
Total Scenario 6	22,919		**€ 84,645**

Table 25: Calculation handling costs Scenario 6

Part 4: Total costs Scenario 6 (outcome of UCFCFL model)

Based on the handling, storage and transportation costs which are determined above, the total costs for Scenario 6 can be calculated. This is done by simply adding up the fixed and variable costs (see Table 26). The total cost in Scenario 6 are €2,494,610 per year.

	Handling costs	Storage costs	Transportation costs	Total costs
Scenario 6	€ 84,645	€ 240,351	€ 2,169,614	**€ 2,494,610**

Table 26: Total costs Scenario 6

Step 3: CO_2 emission in Scenario 6

In Table 27, the total CO_2 emission caused by transportation in Scenario 6 is stated, which is 2,985,322 kilograms CO_2 per year.

Scenario 6	CO2 Truck in KG	CO2 Train in KG	CO2 Ship in KG	Total CO2 in KG
From NL -> …	207,448	7,803	239,250	454,501
From On site Stadex -> …	77,827	0	2,122,759	2,200,586
Stadex -> On site Stadex	0	0	0	0
Stadex -> NL	330,235	0	0	330,235
Total CO2 emission Scenario 6	615,510	7,803	2,362,009	**2,985,322**

Table 27: Total CO_2 emission Scenario 6

This is calculated in a comparable way as described underneath the header "Step 3: CO_2 emission in Scenario 1" above.

Summary and validation of the outcomes of Section 5.1

In Table 28, an overview of the final scores on the operationalized criteria, of the different warehouse scenarios including the current situation, are given. Besides, the different types of costs are stated. Adding up these different types of costs yields the total costs in euros per year.

Warehouse scenario	Handling costs	Storage costs	Transportation costs	Total costs in euros/year	CO2 emission in KG/year
Current situation	€ 137,087	€ 414,220	€ 2,183,274	€ 2,734,581	€ 3,027,300
Scenario 1	€ 91,576	€ 298,270	€ 2,220,113	€ 2,609,960	€ 3,058,810
Scenario 2	€ 100,934	€ 334,492	€ 2,140,454	€ 2,575,879	€ 3,037,852
Scenario 3	€ 105,992	€ 357,535	€ 2,197,221	€ 2,660,747	€ 2,996,914
Scenario 4	€ 80,455	€ 228,326	€ 2,213,478	€ 2,522,259	€ 3,058,810
Scenario 5	€ 82,856	€ 235,676	€ 2,112,789	€ 2,431,320	€ 3,026,261
Scenario 6	€ 84,645	€ 240,351	€ 2,169,614	€ 2,494,610	€ 2,985,322

Table 28: Scores of warehouse scenarios on the operationalized criteria

All calculations done to determine these scores are checked and agreed upon by the supervisor at the company. In this way I validated the calculations and outcomes of my research and the calculation methods used.

5.2 The best choice

During a discussion focused on the outcomes of the total costs and the total CO_2 emission with the supply chain manager of Avebe (see Table 28), I came to know that the board of Avebe has stated that one kilogram of CO_2 emission caused by transportation is equal to €0.05. This number is based on the price per ton CO_2 emission at the auction platform of the European Union Emission Trading System (EU ETS), which is €0.027 per kilogram CO_2 emission (European Union, 2019). The board of Avebe decided to use cost coefficient €0.05 per kilogram CO_2 emission for two reasons. First, the strategy of Avebe states that Avebe strives for sustainability. By applying higher costs for the CO_2 emission in the business cases, sustainability becomes more important which results in choosing for more sustainable solutions. Second, Avebe anticipates on the expected increase in the price of CO_2 emission in the near future.

Knowing that Avebe uses the cost coefficient €0.05 is equal to one kilogram of CO_2 emission, made it possible to quickly compare the different scenarios by expressing the CO_2 emission in costs as well. This yielded the overview in Table 29.

Warehouse scenario	Total costs in Euros/year	CO2 emission in KG/year	Costs CO2 emission (€0,05/KG)	Total costs incl. CO2	Rank	Costs (Sc 5) - other	CO2 Sc 5 - other
Current situation	€ 2,734,581	3,027,300	€ 151,365	€ 2,885,946	7	€ -303,313	€ -1,040
Scenario 1	€ 2,609,960	3,058,810	€ 152,940	€ 2,762,900	5	€ -180,267	€ -32,549
Scenario 2	€ 2,575,879	3,037,852	€ 151,893	€ 2,727,772	4	€ -145,139	€ -11,592
Scenario 3	€ 2,660,747	2,996,914	€ 149,846	€ 2,810,593	6	€ -227,960	€ 29,347
Scenario 4	€ 2,522,259	3,058,810	€ 152,940	€ 2,675,199	3	€ -92,566	€ -32,549
Scenario 5	€ 2,431,320	3,026,261	€ 151,313	€ 2,582,633	1	€ -	€ -
Scenario 6	€ 2,494,610	2,985,322	€ 149,266	€ 2,643,876	2	€ -61,243	€ 40,939

Table 29: Comparison of scenarios based on the score "Total costs including CO_2 emission"

In Table 29, first the scores of the warehouse scenarios on the criteria "total costs" and "CO_2 emission" are stated. Based on the knowledge that within Avebe a cost of €0.05 per kilogram CO_2 emission caused by transportation is calculated, I have made the column "Costs CO_2 emission (€0.05 per kilogram)". The values in this column are calculated by multiplying "CO_2 emission in kilograms per year" with €0.05. Based on this, the score "total costs including CO_2" can be calculated by adding up "Total costs in euros per year" and "Costs CO_2 emission (€0.05 per kilogram)". Based on the values in the column "Total costs including CO_2" the rank of the scenarios is determined. The lowest score yields the highest rank. In Table 29 can be found that Scenario 5 has the lowest "Total costs including CO_2" which implies that Scenario 5 gets rank 1. This means that warehouse Scenario 5 is the best choice.

The last two columns compare the scenario that scores best on "Total costs including CO_2" with the other scenarios on costs and CO_2 emission. In this way can be stated that Scenario 5 is €61,243 cheaper than Scenario 6 and that the CO_2 emission in Scenario 5 is 40,939 kilograms per year more than in Scenario 6.

Sensitivity analysis on the cost coefficient "storage costs on the Stadex site"

Since the storage costs in the warehouse on the Stadex site are hard to estimate, I decided to do a sensitivity analysis on the impact of these costs on the outcome of the research.
Based on the sensitivity analysis I have done on the impact of the storage costs on the Stadex site, I can conclude that Scenario 5 is the best warehouse scenario as long as the costs per square meter per year is less than or equal to €84 including the transportation costs from Stadex to the warehouse on the Stadex site. Otherwise warehouse Scenario 2 becomes the best choice. The storage costs on the Stadex site are estimated by the supply chain director on €36 per square meter per year, including the transportation costs for the Stadex site to the warehouse. This means that it is very unlikely that another scenario turns out to be better than Scenario 5, because of a wrong estimation of the storage costs on the Stadex site.

Sensitivity analysis on cost coefficient "cost per kilogram CO_2 emission"

Since the CO_2 emission becomes more and more important, it is expected that the taxes for CO_2 emission rise in the future. Therefore, I decided to do a sensitivity analysis to determine up to what tax per kilogram CO_2 emission caused by transportation warehouse Scenario 5 still has the lowest total costs including the costs for CO_2 emission. The outcome of this sensitivity analysis is, that warehouse Scenario 5 is the best warehouse scenario when the tax per kilogram CO_2 emission, caused by transportation, is less than or equal to €1.54. When this CO_2 tax is more than €1.54 per kilogram, Scenario 6 becomes the best warehouse solution. The tax for CO_2 emission caused by transportation Avebe calculates at this moment is only €0.05 per kilogram. Therefore, it is very unlikely that warehouse Scenario 6 becomes a better solution than warehouse Scenario 5 in the coming years.

Positive side effects of warehouse Scenario 5

Besides the fact that warehouse Scenario 5 scores best on the operationalized criteria, this scenario also has some other positive side effects. First, choosing for this warehouse scenario means that the employees currently working at warehouse Briggen can work in the new warehouse at the Stadex site. The reason for this is the new warehouse is located within one kilometer from the currently used warehouse. This is ethically speaking in line with the mission of Avebe, which I mention in Section 2.6. Second, building a new warehouse (which is done in Scenario 5) makes it possible to fulfill all requirements and wishes of Avebe. Besides, it is possible to make a fully automated warehouse which Avebe is interested in after doing this in a recently new build warehouse in The Netherlands. Thirdly, compared to the current situation the products are stored less often which means shorter delivery times to customers and less handling. The reduction in handling yields a smaller chance of damaging the products which of course is a positive effect.

Summary of Chapter 5

In this chapter, I determined the product flows and scores on the operationalized criteria (costs and CO_2 emission) for the different warehouse scenarios. Secondly, I found out that according to the board of Avebe there exists a number to transfer the CO_2 emission caused by transportation to costs. This made it possible to express the CO_2 emission caused by transportation in costs. Namely, one-kilogram CO_2 emission caused by transportation is equal to a tax of five eurocents.

Based on this knowledge I determined that the total costs including the cost of the CO_2 emission is lowest in warehouse Scenario 5. Therefore, I determined that warehouse Scenario 5 is the best warehouse solution for Avebe. To check the impact of other values for the cost coefficients "storage cost at the Stadex site" and "cost per kilogram CO_2 emission caused by transportation" I did a sensitivity analyses on these coefficients. Based on the first sensitivity analysis I concluded that warehouse Scenario 5 is the best warehouse scenario as long as the storage costs on the Stadex site are less than or equal to €84 per square meter per year. Otherwise, warehouse Scenario 2 becomes the best choice. According to the second sensitivity analysis warehouse Scenario 5 is the best warehouse scenario as long as the costs per kilogram CO_2 emission caused by transportation are less than €1.55. Otherwise, warehouse Scenario 6 is the best choice.

In Scenario 5, warehouse Briggen is replaced with a warehouse on the Stadex site and the same customer allocation as currently used is applied. The only difference is that not all products are first stored in Sweden but only the products of the customers that are delivered from Sweden. The products meant for the customers which are delivered from The Netherlands are immediately after production transported to The Netherlands.

6. Conclusions, recommendations and discussion

This chapter is split into three sections. Section 6.1 states the conclusion of this research. Section 6.2 mentions my recommendations for Avebe based on the outcomes of this research. In Section 6.3 the discussion of the research is stated. In this discussion attention is payed to the assumptions and limitations in this research and their impact on the outcomes of this research.

6.1 What are the conclusions of the research?

Based on the outcomes of the research, which are shown in Chapter 5, I conclude that warehouse Scenario 5 is best. This means that Avebe should replace Briggen with a warehouse on the Stadex site, which should be built by the Swedish government and rent by Avebe. Besides, the allocation of the customers delivered from the warehouses in The Netherlands and the warehouse on the Stadex site can best be kept the same as the customer demand distribution between Briggen and The Netherlands in the current situation. This means that all demand of Japan and Estonia, and part of the demand of Germany, France, Australia, Turkey and Scandinavia (Denmark, Norway, Sweden and Finland) should be fulfilled from the Stadex site. All other products should directly be transported to the warehouses in The Netherlands, from where the other customer demand should be fulfilled.

Warehouse Scenario 5 scores better than the current situation in terms of costs in the process between factory and final customer, and CO_2 emission caused by transportation (see Table 29). Choosing for warehouse Scenario 5 saves €303,313 euros (= 11.1%) and 1,040 kilograms CO_2 emission per year (= 0.03%). When, for whatever reason, the warehouse scenarios making use of a warehouse on the Stadex site (Scenarios 4,5 and 6) turn out to be impossible, warehouse Scenario 2 is the best option. Comparing warehouse Scenario 2 with the current situation yields the conclusion that €158,174 euros per year can be saved and the yearly CO_2 emission increases with 10,552 kilograms (= 0.3%). Another reason to choose for warehouse Scenario 2 instead of warehouse Scenario 5 is when the costs per square meter for storage on the Stadex site turn out to be more than €84 per square meter per year (see Section 5.2). This is very unlikely to happen, since the supply chain director of Avebe estimated the storage cost on the Stadex site to be €36 per square meter per year. In case the CO_2 emission tax rises above €1.54 per kilogram, warehouse Scenario 6 becomes the best warehouse scenario instead of Scenario 5. This is also very unlikely to happen since the price per kilogram CO_2 emission used by Avebe is €0.05, which is already high compared to the €0.027 on the auction platform of the European Union Emission Trading System (EU ETS).

When looking at the different warehouse scenarios analyzed, conclusions can be drawn on both the warehouses that should be used and the customer demand allocation over the new warehouse and the warehouses in The Netherlands.

The warehouses

The conclusion is that the warehouse Briggen can better be replace by a warehouse on the Stadex site than by a warehouse in Helsingborg. This conclusion is based on comparing these warehouses looking at the transportation, storage, handling/labor and CO_2 emission costs (caused by transportation). Next to this I conclude that both replacing warehouse Briggen with a warehouse on the Stadex site or a warehouse in Helsingborg influences the total outcome in a positive way.

Customer demand allocation

In case of storage on the Stadex site and in case of storage in Helsingborg the customer demand can best be allocated in the following way:

1. Customer demand fulfilled from Briggen in the current situation can best fulfilled from the new warehouse (Stadex site/Helsingborg).
2. The other customer demand can best be fulfilled from the warehouses in The Netherlands (same as in the current situation).

The other two customer demand allocations analyzed are:

1. Only the customer demand of Japan is fulfilled from the new warehouse and the other demand is fulfilled from the warehouses in The Netherlands.
2. The customer demand currently fulfilled from warehouse Briggen and the products going to Woodridge and Edison are fulfilled from the new warehouse. The other demand is fulfilled from the warehouses in The Netherlands.

Comparing these customer demand allocations, the following can be concluded. In case the warehouse Helsingborg is used the first customer demand allocation is better than the second. This is mainly caused by the fact that the storage and handling costs are way more expensive in Helsingborg than in The Netherlands. Therefore, storing more products in Helsingborg instead of in The Netherlands results in higher total costs.

Looking at the scenarios in which the products are stored on the Stadex site, the second customer demand allocation is better than the first. The reasons for this are the lower storage and handling costs on the Stadex site than in The Netherlands. Therefore, it is better to store more product on the Stadex site than in The Netherlands. This is the case when comparing the first customer demand allocation with the second.

The last important conclusion is that Avebe thought that the current situation was the cheapest possible option and that the costs for Avebe would increase when warehouse Briggen needs to close. Nevertheless, based on this research can be concluded that the current situation is not the cheapest but the most expensive warehouse scenarios in scope of this research. Therefore, this research yielded important new insights for the company.

6.2 What are the recommendations of my research?

I recommend Avebe to contact the Swedish government to try to arrange that they build the warehouse on the Stadex site in the way assumed in this research. So, the warehouse should be 3000 square meters and the costs per square meter per year should be around €36. When this is achieved, warehouse Scenario 5 should be implemented. This means that the transportation companies DSV, Vos transport and Green carrier must be informed that the products are no longer stored at Briggen but on the Stadex site. Lastly, Avebe needs to inform the customers that pick up their products at warehouse Briggen that the warehouse is replaced by a warehouse on the Stadex site.

6.3 What should be discussed about my research?

This section is split into two sub-sections. Sub-section 6.3.1 provides a critical view to the assumptions made in this research and their impact. Sub-section 6.3.2 states the limitations of this research.

6.3.1 What are the assumptions made in my research?

In this section, I mention the assumptions made in this research and their impact on the outcomes of this research.

Transportation kilometers

Not all transportation kilometers are available, so I made assumptions based on the known transportation distances to the customers in each country. This assumption is only made for the customers that are delivered from the warehouses in The Netherlands. The other transportation distances are determined based on the postal codes of the customers.

The impact of this assumption is hard to determine since I do not know what the real transportation distances from the warehouse in The Netherlands to the customers are. Based on the calculations I have done using the assumption, I can mention that for most countries quite some transportation distances were available. This makes that I think that the error between the average transportation distance I calculated, and reality is limited. Therefore, I think that the impact of this assumption is very small. Besides, I want to mention that this assumption has a bigger impact on the transportation distances to the customers close to the warehouses, than on the transportation distances to customers located at the other side of the world.

Treatment of the warehouses in The Netherlands

In this research I treat the warehouses in The Netherlands as if there is one big warehouse in Ter Apelkanaal where all products are stored. In reality, the warehouses “Teuben” and “Teuben TAK” are responsible for 99.97% of the storage in The Netherlands. These two warehouses are located about 3.5 kilometers from each other. Next to these warehouses Avebe has a sample room in Foxhol and Van der Vorst in Dinteloord where products are stored. These are exceptionally used storage locations which are too small to take into consideration (0.03% of products are stored here).

Since the impact of 3.5 kilometer on the total transportation distances is neglectable and in reality, almost all products are stored within a range of 3.5 kilometers, I think that this assumption is very accurate. Therefore, I think that this assumption does not influence the outcome of this research at all.

Storage costs on the Stadex site

Warehouse on Stadex site will be built by the Swedish government. The rent/storage costs for Avebe will be €36 per square meter per year. This price includes the costs for transportation between Stadex and the warehouse on site. The transportation is done by automated vehicles. I made this assumption based on the advice of the supply chain director of Avebe.

The impact of this assumption is tested by the execution of a sensitivity analysis (See Section 5.2). The outcome of this analysis is that Scenario 5 stays the best warehouse scenario as long as the storage costs are less than or equal to €84 per square meter per year (including the costs for transportation between Stadex and the storage on the Stadex site).

Translation of the product flows in kilograms to the products flows in pallets

In order to determine the product flows I have assumed that 1000 kilograms of product is equal to one pallet. I made this assumption based on the advice and experience of the supply chain manager of Avebe.

By far most of the products are distributed on pallets or in bags only a very small part is administrated in kilograms. For this small part I have made this assumption. Therefore, I think that the impact of this assumption is very small on the outcome of this research.

Costs of the CO_2 emission caused by transportation

In order to compare the different warehouse scenarios, I have expressed the CO_2 emission caused by transportation in euros. I have done this using the cost coefficient one kilogram of CO_2 emission caused by transportation is equal to €0.05. This determined by the board of Avebe.

Since the impact of the cost caused by CO_2 emission compared to the total costs are very small and in all warehouse scenarios the costs of the CO_2 emission are determined in the same way, the impact of this assumption on the outcome of my research is very small. Next to that the difference between the warehouse scenario with the most CO_2 emission and the warehouse with the least CO_2 emission is 52,530 kilograms. This is about 1.7% of the total CO_2 emission caused by transportation in the current situation, which I think is quite small.

Next to these arguments based on logical thinking I have done a sensitivity analysis on the cost coefficient one kilogram of CO_2 emission is equal to 0.05 eurocents (see Section 5.2). The outcome of this analysis is that the increase in price per kilogram CO_2 emission needs to be €1.50 per kilogram (€1.55 - €0.05) before it affects the choice for warehouse Scenario 5. This is extremely unlikely to happen within the coming few years. Therefore, this assumption/cost coefficient does not impact the outcome of this research.

Handling/labor costs on the Stadex site

The handling/labor costs for storage on Stadex site are determined using the following formula:

(number of pallets stored at Briggen in current situation / labor cost current situation) * number of pallets stored on Stadex site = handling or labor costs for storage on the Stadex site

This means that fixed costs are treated as variable cost. Since these costs are based on the two employees of Avebe currently working in warehouse Briggen which cannot be told that they will be paid based on the number of pallets stored from now onwards. This assumption is based on the advice of the supply chain manager at Stadex and approved by the supply chain manager of Avebe.

I think that the impact of this assumption is that the handling/labor costs in warehouse Scenario 5 are estimated €52,777 per year to low (= €94,803 - €42,026 see Section 2.2.4 and Table 21), because the two employees currently working in warehouse Briggen need to get the same amount of money as in the current situation for contractual reasons.

Calculation of the needed square meters of storage capacity in the warehouses

The m^2_{needed} in the warehouse locations is based on the numbers of pallets of each type of pallet that needs to be stored. Besides, I have accounted for the average time a product made on a production line is stored. According to the supply chain manager this number accounts for stacking and walking paths, this assumption is based the experience of a warehouse which Avebe has built this year.

According to the supply chain manager the impact of this assumption on the calculation of the number of square meters warehouse needed is negligible. Besides I have calculated the number of square meters warehouse needed in the same way in all warehouse scenarios. Therefore, I think that the impact of this assumption can be neglected.

Based on the analysis of the impact of the assumption made in this research I can conclude that the assumptions are very unlikely to influence the outcomes of this research.

6.3.2 What are the limitations of my research?

A limitation of my research is that it was not possible to validate the way of calculating CO_2 emission caused by transportation based on real values since these are not available. Since I had limited time for this research, I had to make assumptions to calculate the CO_2 emission in all scenarios including the current situation. This resulted in working with CO_2 "ratios" for transportation by truck, train and ship. Besides, I have used average transportation distances to the countries based on the known transportation distances from the warehouses in The Netherlands and based on postal codes for the customers delivered from Briggen in the current situation. Nevertheless, I think that the way in which I calculated the CO_2 emission caused by transportation is quite precise. Besides, all calculations done in this research are checked and agreed upon (validated) by the supervisor at the company. Therefore, I do not think that using the precise CO_2 emissions changes the outcome of this research. Another limitation of this research is that it is based on the sales orders of Stadex products in financial year 2018. When Avebe loses a huge customer or costs change, the number calculated in this research will change as well. It is impossible to take this into account in this research since having a starting point is necessary in order to do research. Therefore, the outcomes of the research must be updated when Avebe wants to know what is optimal in 2030 for example.

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Appendices

Below the three appendices can be found. In Appendix 1, the detailed explanations of the calculations done in this research can be found. Appendix 2 provides a detailed description of the systematic literature review. Appendix 3 shows the interview scheme which is used for the interviews of Chapter 4.

Appendix 1 Detailed explanations of calculations

This appendix is spilt into four sub-appendices. In Appendix 1.1 the calculation of the storage costs in the current situation is explained. Appendix 1.2 handles the calculation of the transportation costs in the current situation. Appendix 1.3 shows how the CO_2 emission in the current situation is determined. Lastly, Appendix 1.4 states how the transportation costs of the different warehouse scenarios are calculated.

Appendix 1.1 Calculation of the storage costs in the current situation

In this appendix the calculations done to determine the storage costs of the warehouse in The Netherlands can be found.

The storage costs paid for the for the warehouse in The Netherlands in financial year 2018 is calculated using the following formula:

$m^2_{needed} * m^2_{price}$ = Storage costs NL

In order to complete this formula, the I calculated the m^2_{needed} and the m^2_{price} should be calculated. The calculation of these variables can be found below.

The variable m^2_{needed} is calculated in the following way:

1. My supervisor provided an overview of all products made at Stadex, the pallet type on which these products are stored and on which production line the product is made.
2. My supervisor and I determined the average time a product made at a certain production line is stored (production lines CSD & HSD on average 2.5 months and production lines FB1 & Streba 5 months).
3. I added a column in which I state the type of pallet on which the product is stored for each sales order of financial year 2018 (using VLOOKUP).
4. I have added a column which mentions for every sales order on which product line the product is made (using VLOOKUP).
5. I made an overview of how many pallets are made on each production line that were stored in The Netherlands, see Table 30. Based on this I have calculated the total m^2_{needed} in The Netherlands, which is 4029 square meters, considering the size of the pallets and how long the products need to be stored. The supply chain manager told me that when I calculate the needed square meters of storage capacity is calculated in this way, I can assume that there is enough space for paths in the warehouse and there is no compensation needed for the number of pallets that can be stored on top of each other.
6. Lastly, I calculated the square meters needed to account for peaks in the needed storage capacity. To cover this, Avebe uses 15% extra storage capacity. This number is based on experience. So, the final m^2_{needed} = 4029 * 1.15 = 4633.

Type of pallets	CSD	HSD	FB1	Streba	N/A	#pallet places needed	m2
HT pallet 1000x1200 (21193)	1,228	7,283	3,327	57	0	3,183	3,820
HT pallet 1040x1040 (111942)	264	530	67	0	0	193	209
N/A	0	0	0	0	3	0	0
Total NL	1,492	7,813	3,394	57	3	**3,376**	**4,029**

Table 30: Calculation storage capacity warehouse The Netherlands current situation

The variable m^2_{price} is determined by the sourcing department of Avebe.
The price per square meter per year of the warehouse in The Netherlands is €27.60.

Based on this knowledge the storage costs of the warehouse in The Netherlands in financial year 2018 can be calculated in the following way:

Storage costs warehouse the Netherlands = $m^2_{needed} * m^2_{price}$ = 4633 * €27.60 = €127,876

Appendix 1.2 Explanation of the calculation of the transportation costs in the current situation

In this appendix the calculations done to determine the transportation costs in the current situation are explained (see Figure 3). This is done step by step below.

First, I have looked into the same two Excel files that I used to calculate the products flows in Figure 2, which are provided by the logistical engineer of Avebe. The first Excel file states the sales orders of financial year 2018 from warehouse Briggen and the second Excel file the sales orders of financial year 2018 for the warehouses in the Netherlands and the in the USA (Woodridge and Edison).

Secondly, I made the following pivot table in both Excel files:

Columns: ShipTo_CountryText
Rows: Shipment_Number
Values: Max of ShipmentCosts_NetValue

In the second Excel file I also added the filter “ShippingPoint” since I am only interested the transportation costs from the warehouses in The Netherlands. The warehouses in the USA do not change in my research and therefore I am not interested in the transportation costs from these warehouses onwards.

The reason for picking the Shipment_Number instead of the sales numbers is the possibility of having more than one sales number with the same Shipment_Number. Therefore, adding up the costs based on the sales numbers yields way the high transportation costs, because of adding up the same costs more than once. This is also the reason that I took the Max of the ShipmentCosts_NetValue. In this way I prevent adding up the costs for the same shipment more than once.

This pivot table provides the Max of the ShipmentCost per Shipment_Number for each country. Simply using the “sum function” in Excel provides the Shipment costs paid to transport the products to the approved place in the current situation based on financial year 2018.

Appendix 1.3 Explanation of the calculations done to determine the CO_2 emission of the current warehouse situation

In this appendix the calculations done to determine the CO_2 emission in the current warehouse situation are explained. The calculations done to determine the CO_2 emission in the other warehouse scenarios are very comparable to the calculations done below. The differences are stated in Section 5.1.

To calculate the total CO_2 emission, caused by transportation, in the current warehouse situation I divided the calculation into four steps. These steps and the calculations done in these steps can be found below. For the first three steps I need to know the following:

1. The average transportation kilometers (by truck, train and ship for each country).
2. The number of tons product transported to each country.
3. The CO_2 “ratios” for transportation by the truck, train and ship.

In the fourth step the CO_2 emission determined in the first three steps are added up. This yields the total CO_2 emission caused by transportation.

Step 1: Transportation from the warehouses in The Netherlands to the next station

1. The average transportation kilometers (by truck, train and ship for each country) from NL ->….
To calculate this, I use the known transportation kilometers to the postal codes per country. The transportation distances from the warehouses in The Netherlands to the postal codes of the customers are only partly known within Avebe. Since, there are a lot of customers I decided not to calculate all the distances myself. This would take me weeks. Therefore, I calculate the average transportation distance per country based on the distances known. This yields the average transportation distance by truck, train and ship when transportation is done from the warehouses in The Netherlands to each country.

2. The number of tons product transported to each country from NL -> ….
To calculate this, I only look at the transportation for which Avebe is responsible. This means that I did not take into consideration the ShipmentType_Category “Ex-works FCA”, since this means that the customer is responsible for the transportation of the product. Therefore, Avebe is not responsible for the CO_2 emission caused by this transportation. Besides, I assume that one pallet is equal to one ton (=1000 kilograms). The supply chain manager of Avebe told me to do so.

3. The CO_2 “Ratios” for transportation by the truck, train and ship.
In order to calculate the CO_2 emission, I have used the following “ratios”:

- Truck = 0.0415 kilograms CO_2 per ton per kilometer
- Train = 0.0160 kilograms CO_2 per ton per kilometer
- Ship = 0.0100 kilograms CO_2 per ton per kilometer

These numbers are based on the report STREAM Goederenvervoer 2016 (Otten, M., t' Hoen, E. & Den Boer, E.)

This made it possible to complete the following formula, which yields the total CO_2 emission in kilograms of the current situation from NL ->…

$$CO_2 \text{ emission in kilograms} =$$

$$\sum_{i=1}^{I} \left(\left(i\text{"average km truck"} * i\text{"\#ton"} * i\text{"ratio truck"} \right) + \left(i\text{"average km train"} * i\text{"\#ton"} * i\text{"ratio train"} \right) + \left(i\text{"average km ship"} * i\text{"\#ton"} * i\text{"ratio ship"} \right) \right)$$

i ∈ I, with i = Algeria, Argentina, …, Vietnam (in total 67 countries).
I = All countries delivered from the warehouses in The Netherlands.

This summation over all countries delivered from the warehouses in The Netherlands yields 600,303 kilograms CO_2 emission.

Step 2: Transportation from the warehouse Briggen to the next station

1. The average transportation kilometers (by truck, train and ship for each country) from Briggen ->….
Since the transportation kilometers from warehouse Briggen to the next station are not known within Avebe I determined these myself. I have done this based on the postal codes in which the customers are located using the online widget (Afstandberekenen, 2019), based on a system made by the ANWB to determine the transportation kilometers over land. To determine the transportation kilometers over sea I used the website Portworld (APSFulfillment, 2019). Based on all these distances, I made a country weighted average distance for the customers in the countries supplied from warehouse Briggen.

2. The number of tons product transported to each country from Briggen -> ….
For the number of tons product transported from Briggen to the next station, I have asked and received the real number of tons transported in financial year 2018 from the transportation companies (DSV, Green Carrier and Vos transport). There are too many different transportation companies that transport product from the warehouses in The Netherlands to do the same. Therefore, I made in Step 1 the assumption for these flows that one pallet is equal to one ton. While in this step I use the real exact numbers. These numbers are, of course, also without ShipmentType_Category “Ex-works FCA” for the same reason.

3. The CO_2 emission *“ratios” for transportation by the truck, train and ship.*
The “ratios” I use are the same as the “ratios” I use in Step 1.

Filling out the same equation as used in Step 1 yields a total of 2,425,957 kilograms CO_2 emission from warehouse Briggen to the next station.

Step 3: Transportation from Stadex to Briggen

1. The average transportation kilometers (by truck, train and ship for each country) from Briggen ->….
The average transportation kilometers between Stadex and Briggen are equal to the distance between Stadex and Briggen which is one kilometer. This transportation is always done by truck.

2. The number of tons product transported to each country from Stadex to Briggen.
The number of tons product transported from Stadex to Briggen is equal to the number of tons product transported from Briggen ->… . This is, like mentioned above, calculated based on the numbers provided by the transportation companies.

3. The CO_2 "Ratios" for transportation by the truck, train and ship.
The "ratios" I use are the same as the "ratios" I use in Step 1.

Filling out the same equation as used in Step 1 yields a total 1,040 kilograms CO_2 emission from Stadex to Briggen

Step 4: Total CO_2 emission in the current situation

Lastly, in order to calculate the total CO_2 emission caused by transportation in the current situation, I filled out the following equation:

$$Total\ CO_2\ emission\ current\ situation$$

$$= Total\ CO_2\ emission\ \text{"From NL} \rightarrow \text{..."} + Total\ CO_2\ emission\ \text{"From Briggen..."} + Total\ CO_2\ emission\ \text{"between Stadex and Briggen"}$$

$$= 600{,}303 + 2{,}425{,}957 + 1{,}040 = 3{,}027{,}300\ kilograms\ CO_2\ per\ year$$

Appendix 1.4 Calculations done to determine the transportation costs of the warehouse scenarios

In this appendix, first the calculations done to determine the transportation costs to the customers delivered from The Netherlands, in warehouse Scenarios 1 and 4, that are delivered from warehouse Briggen in the current situation are explained (see Table 31). After that, the calculations done to determine the transportation costs for each of the warehouse scenarios can be found. The transportation costs that are not explained in the tables given in this appendix, are the same as the costs in the current situation which can be checked by comparing the transportation cost overviews in Chapter 5 with Figure 3 (the transportation cost in the current situation). The explanation of the calculations done to determine the transportation costs in the current situation are stated in Appendix 1.2.

In Table 31 calculations of the unknown transportation costs from The Netherlands, for customers that are delivered from Briggen in the current situation, can be found. The blue numbers are used in the calculation of the transportation costs from The Netherlands in Scenario 1 and Scenario 4 (Table 32 and Table 36)

Country	Total cost	Postal code	#Pallets	Average #Pallets per shipment	Rounded #Pallets per shipment	Number of shipments	Cost per pallet	Cost per shipment	Transportation costs	Transportation company
France	€ 15,134	FR.56	136	17	17	8.00	€ 81.79	€ 1,390.43	€ 11,123	Brant Visser
		FR.77	91	22.75	23	3.96	Full truck load	€ 1,013.60	€ 4,010	Brant Visser
Denmark	€ 12,672	DK.42	53	3.3125	3	17.67	€ 100.08	€ 300.24	€ 5,304	Beens
		DK.52	35	7	7	5.00	€ 47.42	€ 331.94	€ 1,660	Beens
		DK.67	30	6	6	5.00	€ 47.24	€ 283.44	€ 1,417	Beens
		DK.71	62	6.2	6	10.33	€ 61.55	€ 369.30	€ 3,816	Beens
		DK.73	6	3	3	2.00	€ 79.16	€ 237.48	€ 475	Beens
Finland	€ 18,322	FI.01	124	6.2	6	20.67	€ 147.76	€ 886.56	€ 18,322	Oldenburger
Norway	€ 75,553	NO.05	14.05	2.81	3	4.68	€ 123.71	€ 371.13	€ 1,738	Oldenburger
		NO.23	18	3	3	6.00	€ 174.93	€ 524.79	€ 3,149	Oldenburger
		NO.52	137	6.5238	7	19.57	€ 134.07	€ 938.49	€ 18,368	Oldenburger
		NO.60	313.5	16.5	17	18.44	€ 166.82	€ 2,835.94	€ 52,298	Oldenburger
Sweden	€ 40,347	SE.24	3	1.5	2	1.50	€ 85.59	€ 171.18	€ 257	Oldenburger
		SE.25	75	5	5	15.00	€ 68.68	€ 343.40	€ 5,151	Oldenburger
		SE.26	153.225	8.5125	9	17.03	€ 69.06	€ 621.54	€ 10,582	Oldenburger
		SE.29	7	1.75	2	3.50	€ 89.16	€ 178.32	€ 624	Oldenburger
		SE.37	40.125	8.025	8	5.02	€ 73.87	€ 590.96	€ 2,964	Oldenburger
		SE.41	2	2	2	1.00	€ 101.39	€ 202.78	€ 203	Oldenburger
		SE.42	1	1	1	1.00	€ 114.13	€ 114.13	€ 114	Oldenburger
		SE.69	193.875	21.5417	22	8.81	Full truck load	€ 2,116.91	€ 18,655	Vos Deventer
		SE.70	18	6	6	3.00	€ 99.86	€ 599.16	€ 1,797	Oldenburger
Total	**€ 162,028**									

Table 31: Calculation of the transportation costs to customers delivered from Briggen in the current situation

In Table 31, the "Cost per pallet" are derived from the data available at the sourcing department of Avebe. This data mentions the transportation costs per pallet for a certain number of pallets in the truck to the postal codes from the warehouse in The Netherlands. "The Postal codes", "Number of pallets" and "Average number of pallets per shipment" are determined based on the Excel file which is provided by the logistical engineer of Avebe on which the product flows in Figure 2 are based as well. The other numbers in Table 31 can be determined based on these numbers.

Transportation costs in Scenario 1

Table 32, provides an overview of how the unknown transportation costs of Scenario 1 are determined. The explanation of how the costs are calculated can be found under the column header "Remark" in Table 32. Besides, if the cell is blue it means that the number is determined by the calculations done in tab "From NL based on postal code" (see Table 31) and if the cell is yellow it means that the number is determined by the sourcing department of Avebe. All bolded numbers can be found in Figure 11.

Europe				
From	To	#Pallets	Costs	Remark
NL	Estonia	1	€ -	Currently picked by the customer at the warehouse, in the future as well
NL	France	227	€ 15,134	Based on calculations done in tab "From NL based on postal code"
NL	Germany	625	€ -	Currently picked by the customer at the warehouse, in the future as well
NL	Denmark	285	€ 12,672	Based on calculations done in tab "From NL based on postal code"
NL	Finland	148	€ 18,322	Based on calculations done in tab "From NL based on postal code"
NL	Norway	483	€ 75,553	Based on calculations done in tab "From NL based on postal code"
NL	Sweden	663	€ 40,347	Based on calculations done in tab "From NL based on postal code"
Total new costs			€ 162,028	Total new transportation costs from NL to countries in Europe
Total costs			**€ 946,844**	Total new transporation costs NL-> Europe + costs current situation NL -> Europe
Asia				
From	To	#Pallets	Costs	Remark
NL	Turkey	42	€ 1,844	Sea Transport + Pre-carriage (determined by the sourcing department)
Total new costs			€ 1,844	Total new transportation costs from NL to countries in Asia
Total costs			**€ 161,554**	Total new transporation costs NL -> Asia + costs current situation NL -> Asia
Australia				
From	To	#Pallets	Costs	Remark
NL	Australia	90	€ 5,500	Sea Transport + Pre-carriage (determined by the sourcing department)
Total new costs			€ 5,500	Total new transportation costs from NL to countries in Australia
Total costs			**€ 21,812**	Total new transporation costs NL -> Australia + costs current situation NL -> Australia
Stadex				
From	To	#Pallets	Costs	Remark
Stadex	NL	15,323	**€ 320,123**	(costs current situation/#pallets current situation from Briggen -> NL) * # Pallets Stadex -> NL in Scenario 1
Stadex	Helsingborg	7,596	**€ 81,345**	Determined by sourcing department
Helsingborg				
From	To	#Pallets	Costs	Remark
Helsingborg	Japan	7,596	**€ 394,323**	Determined by sourcing department

Table 32: Determination of the unknown transportation costs in Scenario 1

Lastly, Table 33 provides an overview of the transportation costs from the warehouses in The Netherlands to each continent in Scenario 1. Also, the total transportation costs from the warehouses in The Netherlands are stated.

From -> to	Costs	Remark
Costs NL -> Europe	€ 946,844	Determined for Scenario 1
Costs NL -> Asia	€ 161,554	Determined for Scenario 1
Costs NL -> North America	€ 255,009	Same as the current situation
Costs NL -> Africa	€ 24,287	Same as the current situation
Costs NL -> South America	€ 14,816	Same as the current situation
Costs NL -> Australia	€ 21,812	Determined for Scenario 1
Total transp. costs NL ->	**€ 1,424,322**	Total transporation costs from NL in Scenario 1

Table 33: Calculation of the total transportation costs for The Netherlands -> ...

Transportation costs in Scenario 2

Table 34, provides an overview of how the unknown transportation costs of Scenario 2 are determined. The explanation of how the costs are calculated can be found under the column header "Remark" in Table 34. Besides, if the cell is yellow it means that the number is determined by the sourcing department of Avebe. All bolded numbers can be found in Figure 13.

Stadex				
From	To	#Pallets	Cost	Remark
Stadex	Helsingborg	10,160	**€ 108,816**	Determined by sourcing department
Stadex	NL	12,759	**€ 266,561**	Same as Briggen -> NL (current situation)
Helsingborg				
From	To	#Pallets	Cost	Remark
Helsingborg	Japan	7,596	€ 394,323	Determined by sourcing department (same as Scenario 1)
Helsingborg	Denmark	285	€ 10,000	Current situation + 15% estimation sourcing department
Helsingborg	Finland	148	€ 13,824	Current situation + 10,5% estimation sourcing department
Helsingborg	Norway	483	€ 47,971	Current situation - 15% estimation sourcing department
Helsingborg	Sweden	663	€ 12,108	Current situation - 5% estimation sourcing department
Helsingborg	Germany	625	€ -	Currently picked by the customer at the warehouse, in the future as well
Helsingborg	France	227	€ 21,267	Current situation + 5% estimation sourcing department
Helsingborg	Australia	90	€ 7,835	Determined by sourcing department
Helsingborg	Estonia	1	€ -	Currently picked by the customer at the warehouse, in the future as well
Helsingborg	Turkey	42	€ 2,800	Determined by sourcing department
Total Helsingborg ->			**€ 510,127**	
Total NL ->			**€ 1,254,950**	Same as current situation

Table 34: Determination of the unknown transportation costs in Scenario 2

Transportation costs in Scenario 3

Table 35, provides an overview of how the unknown transportation costs of Scenario 3 are determined. The explanation of how the costs are calculated can be found under the column header "Remark" in Table 35. Besides, if the cell is yellow it means that the number is determined by the sourcing department of Avebe. All bolded numbers can be found in Figure 15.

Stadex				
From	To	#Pallets	Cost	Remark
Stadex	Helsingborg	12,071	**€ 129,279**	Determined by sourcing department
Stadex	NL	10,849	**€ 226,645**	(costs current situation/#pallets current situation from Briggen -> NL) * # Pallets Stadex -> NL in Scenario 3
Helsingborg				
From	To	#Pallets	Cost	Remark
Helsingborg	Japan	7,596	€ 394,323	Same as Scenario 2
Helsingborg	Denmark	285	€ 10,000	Same as Scenario 2
Helsingborg	Finland	148	€ 13,824	Same as Scenario 2
Helsingborg	Norway	483	€ 47,971	Same as Scenario 2
Helsingborg	Sweden	663	€ 12,108	Same as Scenario 2
Helsingborg	Germany	625	€ -	Currently picked by the customer at the warehouse, in the future as well
Helsingborg	France	227	€ 21,267	Same as Scenario 2
Helsingborg	Australia	90	€ 7,835	Same as Scenario 2
Helsingborg	Estonia	1	€ -	Currently picked by the customer at the warehouse, in the future as well
Helsingborg	Turkey	42	€ 2,800	Same as Scenario 2
Total			**€ 510,127**	Total transporation costs from Helsingborg to customers
Helsingborg	Woodridge	1,597	€ 268,905	Determined by sourcing department
Helsingborg	Edison	324	€ 42,632	Determined by sourcing department
Total			**€ 311,537**	Total transportation costs from Helsingborg to the warehouses in the USA
NL				
From	To	#Pallets	Cost	Remark
NL	North America	23	**€ 19,692**	Transportation costs to North America - warehouses Woodridge and Edison

Table 35: Determination of the unknown transportation costs in Scenario 3

Transportation costs in Scenario 4

Table 36, provides an overview of how the unknown transportation costs of Scenario 4 are determined. The explanation of how the costs are calculated can be found under the column header “Remark” in Table 36. Besides, all bolded numbers can be found in Figure 17.

Europe				
From	To	#Pallets	Cost	Remark
NL	Estonia	1	€ -	Currently picked by the customer at the warehouse, in the future as well
NL	France	227	€ 15,134	Same as Scenario 1
NL	Germany	625	€ -	Currently picked by the customer at the warehouse, in the future as well
NL	Denmark	285	€ 12,672	Same as Scenario 1
NL	Finland	148	€ 18,322	Same as Scenario 1
NL	Norway	483	€ 75,553	Same as Scenario 1
NL	Sweden	663	€ 40,347	Same as Scenario 1
Total new costs			€ 162,028	Total new transportation costs from NL to countries in Europe
Total costs			**€ 946,844**	Total new transporation costs NL-> Europe + costs current situation NL -> Europe
Asia				
From	To	#Pallets	Cost	Remark
NL	Turkey	42	€ 1,844	Same as Scenario 1
Total new costs			€ 1,844	Total new transportation costs from NL to countries in Asia
Total costs			**€ 161,554**	Total new transporation costs NL -> Asia + costs current situation NL -> Asia
Australia				
From	To	#Pallets	Cost	Remark
NL	Australia	90	€ 5,500	Same as Scenario 1
Total new costs			€ 5,500	Total new transportation costs from NL to countries in Australia
Total costs			**€ 21,812**	Total new transporation costs NL -> Australia + costs current situation NL -> Australia
Stadex				
From	To	#Pallets	Cost	Remark
Stadex	NL	15,323	**€ 320,123**	Same as Scenario 1
Stadex	On site Stadex	7,596	**€ -**	No transport needed, done by automated systems (costs of systems included in storage costs)
On site Stadex				
From	To	#Pallets	Cost	Remark
On site Stadex	Japan	7,596	**€ 469,033**	Same as Briggen -> Japan (Current situation)

Table 36: Determination of the unknown transportation costs in Scenario 4

Transportation costs in Scenario 5

Table 37, provides an overview of how the unknown transportation costs of Scenario 5 are determined. The explanation of how the costs are calculated can be found under the column header “Remark” in Table 37. Besides, all bolded numbers can be found in Figure 19.

Stadex				
From	To	#Pallets	Cost	Remark
Stadex	On site Stadex	10,160	€ -	No transport needed, done by automated systems (costs of systems included in storage costs)
Stadex	NL	12,759	**€ 266,561**	Same as Briggen -> NL (current situation)
On site Stadex				
From	To	#Pallets	Cost	Remark
On site Stadex	Japan	7,596	€ 469,033	Same as from Briggen (current situation)
On site Stadex	Denmark	285	€ 8,695	Same as from Briggen (current situation)
On site Stadex	Finland	148	€ 12,510	Same as from Briggen (current situation)
On site Stadex	Norway	483	€ 56,436	Same as from Briggen (current situation)
On site Stadex	Sweden	663	€ 12,745	Same as from Briggen (current situation)
On site Stadex	Germany	625	€ -	Currently picked by the customer at the warehouse, in the future as well
On site Stadex	France	227	€ 20,255	Same as from Briggen (current situation)
On site Stadex	Australia	90	€ 8,524	Same as from Briggen (current situation)
On site Stadex	Estonia	1	€ -	Currently picked by the customer at the warehouse, in the future as well
On site Stadex	Turkey	42	€ 3,080	Same as from Briggen (current situation)
Total On site Stadex ->			**€ 591,278**	Total transportation costs from On site Stadex to customers

Table 37: Determination of the unknown transportation costs in Scenario 5

Transportation costs in Scenario 6

Table 38, provides an overview of how the unknown transportation costs of Scenario 6 are determined. The explanation of how the costs are calculated can be found under the column header "Remark" in Table 38. Besides, if the cell is yellow it means that the number is determined by the sourcing department of Avebe. All bolded numbers can be found in Figure 21.

Stadex				
From	To	#Pallets	Cost	Remark
Stadex	On site Stadex	12,071	€ -	No transport needed, done by automated systems (costs of systems included in storage costs)
Stadex	NL	10,849	**€ 226,645**	Same as Scenario 3
On site Stadex				
From	To	#Pallets	Cost	Remark
On site Stadex	Japan	7,596	€ 469,033	Same as from Briggen (current situation)
On site Stadex	Denmark	285	€ 8,695	Same as from Briggen (current situation)
On site Stadex	Finland	148	€ 12,510	Same as from Briggen (current situation)
On site Stadex	Norway	483	€ 56,436	Same as from Briggen (current situation)
On site Stadex	Sweden	663	€ 12,745	Same as from Briggen (current situation)
On site Stadex	Germany	625	€ -	Currently picked by the customer at the warehouse, in the future as well
On site Stadex	France	227	€ 20,255	Same as from Briggen (current situation)
On site Stadex	Australia	90	€ 8,524	Same as from Briggen (current situation)
On site Stadex	Estonia	1	€ -	Currently picked by the customer at the warehouse, in the future as well
On site Stadex	Turkey	42	€ 3,080	Same as from Briggen (current situation)
Total			**€ 591,278**	Total transporation costs from On site Stadex to customers
On site Stadex	Woodridge	1,597	€ 285,964	Determined by sourcing department
On site Stadex	Edison	324	€ 46,094	Determined by sourcing department
Total			**€ 332,058**	Total transportation costs from On site Stadex to the warehouses in the USA
NL				
From	To	#Pallets	Cost	Remark
NL	North America	23	**€ 19,692**	Same as Scenario 3

Table 38: Determination of the unknown transportation costs in Scenario 6

Appendix 2 The systematic literature review

This appendix contains two sub-appendices. Appendix 2.1 concerns the fixed and variable key theoretical concepts of the systematic literature review. Appendix 2.2 provides a detailed description and argumentation of the execution on the systematic literature review.

Appendix 2.1 The variable and fixed key theoretical concepts of the systematic literature review

In this appendix, I show the execution of the systematic literature review which I conducted to get an overview of the discrete location models that exist and their features. This made that the following question is the research question of this systematic literature review:

"What types of **discrete facility location** models/problems do exist, and in what situation should these be applied?

Based on this research question the following fixed key theoretical concepts can be distinguished:

Discrete
"Discrete" is one of the fixed key theoretical concepts, because in my research I am determining what specific warehouse scenario is the best warehouse scenario for Avebe. These warehouses in scope do have a predetermined location, because Avebe only wants to rent a warehouse[3]. The determination of these warehouses in scope is done by conducting individual in depth interviews. These can be found in Section 4.3.

Facility location
"Facility location" is one of the fixed key theoretical concepts, because in my research I am looking for a new warehouse location for Avebe. This fits with discrete facility location models. Besides I am looking for a physical place (location) namely a warehouse, that is why I am not searching for facility allocation models. This decision, I make together with the supply chain manager of Avebe, before calculating the different scenarios.

Next to these fixed key theoretical concepts I also include the following variable key theoretical concepts:

The first two fixed key theoretical concepts that I include in my search string are "**model**" and "**problem**". The reason for this is that both terms "discrete facility location model" and "discrete facility location problem" yield me the application of models or the solution of problems which I am going to use in my research.

The other variable key theoretical concepts that I use in my search string are "**taxonomy**", "**review**", "**comparison**", "**distinction**" and "**classification**". I am adding these terms to my search string because these yields me sources which provide an overview of the different discrete facility location models that exist, instead of articles about very specific situations and models.

[3] I found out that a build and rent back construction is also possible during the interviews I conducted with the management in order to write Chapter 4.

These fixed and variable key theoretical concepts yield the following search string which I used:

(discrete and “facility location” and (model or problem) and (taxonomy or review or comparison or distinction or classification))

In the systematic literature research, I have used two data bases, in which I used this search string. These data bases are Scopus and Web of Science. I chose these data bases because both are multidisciplinary databases which are relatively user friendly. In these databases I search in the title, abstracts and key words as can be seen in Table 41 in Appendix 2.2. The whole execution of my systematic literature review can be found in Appendix 2.2.

Appendix 2.2 Detailed description and argumentation of the systematic literature review

In this appendix a detailed description and argumentation of my systematic literature review can be found.

The fixed and variable key theoretical concepts which have described in the text yielded the following search string which I used:

(discrete and “facility location” and (model or problem) and (taxonomy or review or comparison or distinction or classification))

In my systematic literature research, I have used two data bases, in which I have used this search string. These data bases are Scopus and Web of Science. I chose these data bases because both are multidisciplinary databases which are relatively user friendly. In these databases I search in the title, abstracts and key words as can be seen in Table 41.

After determining the fixed and variable key theoretical concepts and my search string I used the following exclusion criteria.

Number	Exclusion criteria	Reason for exclusion criteria
1	Source is not written in English or Dutch	I can only read English or Dutch texts
2	Full text of source is not free accessible for me as student of The University of Twente.	I want to have the full text for my research, since only having the abstract does not provide enough information for the research.
3	Sources only describing competitive facility location models	In my bachelor assignment competition is not considered so sources that only describe competitive facility location models are not interesting for the research.

Table 39: The exclusion criteria

After applying these exclusion criteria, I removed the duplicates. The reason for this is, that I use two databases which yield me some sources that I found in both databases. This means that I am going to remove the duplicates. In order to do so, I used the Mendeley software.

After removing the duplicates, I applied my inclusion criteria. In order to do this in a good way, I have read the title and abstracts of the sources and only kept the sources that fulfilled the inclusion criteria stated in Table 40.

Number	Inclusion criteria	Reason for inclusion criteria
1	I only keep sources which describe more than one discrete facility location model	Since I want to have an overview of the different discrete facility location models that exist, I will focus on entities describing more than just one very specific type of model.
2	I only keep sources which give some explanation about when or how the models described should be implemented	Since I am also interested in when and how to use the different types of discrete facility location models for my bachelor assignment. Only based on the names of the different models, I am not able to decide whether the models are applicable in my bachelor assignment.

Table 40: The inclusion criteria

After selecting the sources based on these two inclusion criteria, I had twelve sources left. In order to find out whether these sources give the information that I am looking for I read the whole text. I only kept the sources which provide information that I can use to answer my knowledge question. This made me end up with the following six sources: (the search log can be found in Table 41)

Source 1
Source type: Article
Article title: What you should know about location modeling
Journal: Naval Research Logistics
Authors: Daskin, M. S.

Source 2
Source type: Article
Article title: Metaheuristic applications on discrete facility location problems: a survey
Journal: OPSEARCH
Authors: Basu, S., Sharma, M., Ghosh, P. S.

Source 3
Source type: Review
Review title: Location and layout planning: A survey
Journal: OR Spectrum
Authors: Domschke, W. & Krispin, G.

Source 4
Source type: Journal
Article title: Location analysis: A synthesis and survey
Journal: European Journal of Operation Research
Authors: Revelle, C. S. & Eiselt, H. A.

Source 5
Source type: Article
Article title: A bibliography for some fundamental problem categories in discrete location science
Journal: European Journal of Operational Research
Authors: ReVelle, C. S., Eiselt, H. A. & Daskin, M. S.

Source 6
Source type: Book
Book title: Supply Chain Management
Edition: 5th
Authors: Chopra, S. & Meindl, P.

In Table 41, I provide the search log of the systematic literature review.

Search string	**Scope**	**Date of search**	**Number of sources**
Search in Scopus			
TITLE-ABS-KEY (discrete and "facility location" and (model or problem) and (taxonomy or review or comparison or distinction or classification))	Title, Abstract and key words	15-4-2019	42
Web of science			
TOPIC: (discrete and "facility location" and (model or problem) and (taxonomy or review or comparison or distinction or classification))	Title, abstract, author keywords and Keywords Plus	15-4-2019	37
Total number of sources Scopus			42
Total number of sources Web of Science			37
Other sources found on the internet		15-4-2019	1
Books included		15-4-2019	1
Total number of sources			**81**
Selecting based on exclusion criteria			-32 (49 left)
Removing duplicates			-10 (39 left)
Selecting based on inclusion criteria			-27 (12 left)
Removed after complete reading			-6 (6 left)
Total selected for review			**6**

Table 41: The search log

After I selected the six sources that I am going to use answer my knowledge question, I made the conceptual matrix which can be found in Table 42. This matrix helped me to analyze and structure the information found in the articles.

Source number	Covering-based models	Median-based models	Other Models	Key findings
1	X	X	X (P-dispersion problem)	Giving a very clear overview of the different discrete location models. Besides this source tells for every type of discrete location model when the certain type should be used. Also, concrete applications of the models are shown.
2	X	X	X (Hub Location Problem)	Very clear distinction between the different discrete location models is provided. Besides for every type of model a reference is added to a study in which the type of model is applied.
3	X	X	X	Clear distinction between facility location planning and layout planning. Clear description of difference between discrete and continuous location planning. Mentioning pros of discrete location planning models and applications. Given short overview of objective functions for a lot of facility location models.
4	X	X	X	Should be used to find solutions to specific problems which I will have executing the model in my research. Descriptions and references are given in a very detailed and theoretical way.
5	X	X		Overview of types of location models and application. Mentions objective function and how to apply plant and media problems and covering problems. Besides a very large list of studies using specific types of these models is provided!
6		X		Detailed description of discrete (single) capacitated fixed plant location model's application is given. Also, how to implement this in Excel.

Table 42: The concept matrix

The outcome of my systematic literature review and the answer to my knowledge question can be found in the text underneath the header "Integration of theory: Answering the knowledge question".

Appendix 3 The interview scheme

Interview 14-5-2019, with…

Goal:
1. Find out what the requirements of the management are when looking at warehouses.
2. Find out what the wishes of the management are when looking at warehouse scenarios.
    -> Find out the criteria to assess the warehouses in scope on.
3. Find out what warehouse scenarios I should involve in my research.

Requirements according to research that I have already done:
1. Enough storage capacity
2. Licenses and certificates needed to store Stadex products

Wishes/criteria were the warehouses in scope should be assessed on according to professionals in the field of warehousing: (Conveyco, Taylored Services and APS Fulfillment)

Criterion	**Reason/explanation**	**Agreed upon by interviewee**
1. The accessibility of the warehouse	How is the warehouse accessible? By truck, by train, by ship or even by plane and how good is this connection.	
2. The accessibility of reliable and cost-effective labor.	Part of the costs of the warehouse are labor costs. These labor costs do the company want to be as low as possible of course, but the labor should also be reliable and of a certain quality.	
3. The price of the warehouse itself.	The renting cost of the warehouse for the number of squared meters needed.	
4. The technology used in the warehouse.	When comparing warehouses there might be a difference in the technology used in the warehouses. Some warehouses might use simple fork trucks while others use automated systems.	
5. The distance to the customers.	A significant part of the costs, CO_2 emission and delivery times is determined by the distance to the customers. Therefore, this is an important thing to look at when choosing between warehouses.	
6. Environmental factors that might influence the operations.	Examples of environmental factors that might influence the operations of the company are the presence of earthquakes or volcanoes but also the presence of living areas near by the warehouse. Having a warehouse nearby a living area can result in traffic issues or safety issues, when the truck needs to drive over roads where for example children play.	
7. The experience of the warehouse.	Lastly can be looked at the experience of the warehouse and the people working at the warehouse. When a warehouse is completely new, it is plausible that more mistakes will be made at the beginning.	

"What are the requirements that I should take into consideration when looking at new warehouse scenarios, according to you?"

The requirements of the warehouses mentioned by the interviewee:

1.
2.
3.
4.
5.

"Do you agree upon the requirements for warehouse locations based on my research?" (See previous page!)

"What are the wishes/criteria that I should assess the warehouse scenarios on, according to you?"

The wishes/criteria mentioned by the interviewee:

1.
2.
3.
4.
5.

"Do you agree upon the criteria on which warehouse locations should be assessed on according to professionals in the field of warehousing?" (See previous page!)

"What warehouse scenario should I involve in my research according to you?"

The warehouse scenarios mentioned by the interviewee:

Scenario	Warehouse locations	Customers assigned

"Why do you think the warehouse scenario, that you have mentioned, is interesting to research?"

Scenario 1:

Scenario 2:

Scenario 3:

"Can you please fill out the feedback form about my interviewing skills?" -> Thanks for your time!