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Decision support model for hub localisation

- A study at a company in the 3PL industry

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Supervisors: Stefan Jansson, Company X
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Preface

This thesis was written during the spring semester of 2012 as the final part of our five year long education in Industrial Engineering and Management at Lund University, Faculty of Engineering. Our 20 weeks of thesis writing have been interesting and exciting to manage a project like this.

The project was initiated by Company X and we would like to express our gratitude to our supervisor Stefan Jansson who has given us valuable feedback during the way. He has also given us insight in the organisation by arranging study visits at terminals and interviews with employees. The time and effort, which the employees have dedicated to us and this thesis, have been much appreciated. Moreover, we would like to thank the initiator of the project, Mats Rosenqvist, for the opportunity to perform this assignment at Company X. We would also like to thank our supervisor Fredrik Eng Larsson at Lund University for all feedback and comments which in many ways have improved our thesis.

Finally, we would like to thank our family and friends who have supported and helped us during these five years at Lund University.

Lund, May 2012

Sara Josefsson

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Abstract

Title: Decision support model for hub localisation
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Background: With todays' requirement of shorter product life cycles and faster time-to-market, producing companies experience an increased demand for faster transports in the supply chain. This puts pressure on freight forwarders to offer their customers a timely and reliable transport service at a reasonable price. Another challenge for the freight forwarders in Sweden is to provide such services in all parts of the country. Therefore, the actors in the 3PL industry must find an appropriate design for their transportation network which can enable these transports. This pressure is felt by Company X, which is the Swedish division of one of the largest freight forwarders of road transports in Europe. The network is operated by hauliers and contains of 25 terminals where some of them also function as hubs, which consolidate goods in order to increase the utilization of transports. Company X are now facing problems in meeting the scheduled delivery time for deliveries to northern Sweden. Since Company X strives for meeting its customers' expectations it is wishful to develop a model based on a set of factors, which can evaluate the localisation of a hub and be a support for future decisions. Moreover, there has not been an evaluation of the main hub and its connected lines in the transportation network for many years. An analysis of the current network according to the model will therefore be conducted to identify the optimal hub localisation.

Purpose: The purpose of this master thesis consists of two parts; first, to develop a model, which can evaluate the localisation of a hub, and second, to perform an analysis of the current hub location to find an optimal one according to the model.

Research questions: The master thesis will answer the following questions to achieve the purpose:

- Which factors have to be taken into consideration by Company X when deciding where to locate a hub?
- How should the alternative hub localisations be identified and evaluated to arrive at a decision support for an optimal hub

localisation?

- What is the optimal hub localisation for the chosen lines according to the developed model and how reliable is the result?

Method: The thesis is based on a systems approach since synergy effects are expected to arise between the factors in the constructed model. The development of the model is considered to be an exploratory and a normative study while the second part of the purpose will be an explanatory study. Both qualitative and quantitative data will be used in order to develop the model and to perform the analysis. The model is validated according to four steps to ensure the validity, reliability and objectivity. The validity of the analysis is investigated through performed sensitivity analyses.

Conclusions: A number of factors affecting facility localisation were found in the literature and these were analysed to identify factors affecting the hub localisation for Company X. The following 16 factors were finally recognised to be considered when deciding where to locate a hub for Company X; highway access, labour availability, delivery time to customers, driving and rest periods, environmental regulations, construction feasibility, railway access, congestion, living costs and family conditions, location costs, wages, weather, closeness to similar companies, cost of return goods flows from northern Sweden, and closeness to nearby terminal to support goods handling at hub.

A decision support model has been created consisting of four sub models. With a set of fixed data a Centre-of-Gravity analysis can be completed where a centre of gravity is achieved. A number of alternatives which fulfil the qualifiers, factors that the hub location needs to fulfil, are obtained. Next, the alternatives are evaluated according to a set of parameters, factors which are wishful to fulfil for the locations, and a parameter score is calculated. Moreover, the transportation cost for the alternatives is estimated. The output of the model is to be used as a decision support for hub localisation.

Based on the analysis of the chosen transport lines the optimal hub location could not be distinguished, according to the model. Uppsala was the best alternative according to the parameter score, however, Gävle got the lowest transportation costs. Since the difference between the alternatives' score and cost was marginal, it was not possible to identify the optimal hub localisation. In addition, there are aspects which are not included in this analysis that need to be considered before making a decision.

Keywords: Facility localisation, optimal hub location, decision support model

Sammanfattning

Titel: Modell för beslutsunderlag vid lokalisering av hubb – En studie på ett företag i 3PL-branschen

Författare: Sara Josefsson & Andreas Medin

Handledare: Stefan Jansson, Företag X

Fredrik Eng Larsson, Institutionen för Teknisk ekonomi och logistik, Lunds Tekniska Högskola

Bakgrund: Med dagens krav på kortare produktlivscykler och snabbare tid till marknad upplever producerande företag en ökad efterfrågan av snabba transporter i sina försörjningskedjor. Detta skapar press för speditörer att kunna erbjuda sina kunder en tillförlitlig transportservice till ett rimligt pris. En annan utmaning för speditörer i Sverige är att tillhandahålla sådana transporter till alla delar av landet. Därför måste företagen i 3PL-branschen hitta en lämplig design för deras transportnätverk som kan möjliggöra dessa transporter. Denna press upplevs av Företag X, som är den svenska delen av en av Europas största speditörer av vägtransporter. Deras transportnätverk opereras av åkerier och består av 25 terminaler där några av dem även fungerar som hubbar, vilka konsoliderar gods för att öka utnyttjandegrad av transporterna. Företag X har nu svårigheter att hålla den planerade leveranstiden till norra Sverige. Eftersom Företag X strävar efter att möta kundernas förväntningar, är det önskvärt att utveckla en modell, baserad på ett antal faktorer, som kan utvärdera lokaliseringen av en hubb och vara ett underlag för framtida beslut. Dessutom har en utvärdering av den största hubben och dess linjer i transportnätverket inte gjorts på många år. Det nuvarande nätverket kommer därför att analyseras enligt modellen för att identifiera den optimala hubblokaliseringen.

Syfte: Syftet med studien består av två delar; dels att utveckla en modell som kan utvärdera lokaliseringen av en hubb men även att analysera den nuvarande hubben för att hitta en optimal lokalisering enligt modellen.

Forskningsfrågor: Studien kommer att besvara följande frågor för att uppfylla syftet:

- Vilka faktorer måste Företag X ta hänsyn till vid beslut kring lokalisering av hubb?
- Hur borde de alternativa hubb-lokaliseringarna identifieras och utvärderas för att komma fram till ett beslutsunderlag för en optimal hubblokalisering?
- Vad är den optimala hubblokaliseringen för de valda linjerna

enligt den utvecklade modellen och hur tillförlitligt är resultatet?

Metod: Studien är baserad på ett systemsynsätt eftersom synergieffekter förväntas uppkomma mellan faktorerna i den utvecklade modellen. Utvecklandet av modellen anses vara en explorativ och normativ studie medan den andra delen av syftet är en förklarande studie. Både kvalitativ och kvantitativ data kommer att användas. Modellen är validerad utifrån fyra steg för att säkerställa validitet, tillförlitlighet och objektivitet. Analysens validitet är undersökt genom att utföra känslighetsanalyser.

Slutsatser: Ett antal faktorer som påverkar lokalisering av faciliteter hittades i litteraturen och dessa analyserades för att identifiera faktorer som påverkar hubblokalisering för Företag X. Det upptäcktes att följande 16 faktorerna bör Företag X ta hänsyn till vid beslut var man ska lokalisera en hubb; närhet till motorväg, tillgänglig arbetskraft, leveranstid till kunder, kör- och vilotider, miljömässiga lagar, möjlighet att bygga faciliteten, tillgång till järnväg, trafikstockning, levnadskostnader och familje-förhållanden, lokaliseringskostnader, löner, väder, närhet till liknande företag, kostnad för returlaster från norra Sverige och närhet till närliggande terminal för volymavlastning.

En beslutsunderlagsmodell har skapats bestående av fyra delmodeller. Med bestämd indata kan en tyngdpunktsanalys utföras där tyngdpunkten erhålls. Ett antal alternativ som uppfyller kvalificerarna (faktorer som hubblokaliseringen måste uppfylla) hittas. Därefter utvärderas alternativen enligt ett antal parametrar (faktorer som är önskvärda att uppfyllas för alternativen) och en parameterpoäng beräknas. Sedan uppskattas en transportkostnad för respektive alternativ. Modellens resultat ska användas som beslutsunderlag för hubblokalisering.

Baserat på analysen av de valda transportlinjerna kunde en optimal hubb-lokalisering inte särskiljas. Uppsala var det bästa alternativet enligt parameterpoängen medan Gävle fick den lägsta transportkostnaden. Eftersom skillnaden mellan alternativens poäng och kostnad var marginell var det inte möjligt att identifiera den optimala hubblokaliseringen. Dessutom finns det aspekter som inte är inkluderade i denna analys som man måste tas hänsyn till innan ett beslut kan fattas.

Nyckelord: Facility localisation, optimal hub location, decision support model

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1 Introduction

The introduction gives a background of what initiated this thesis. Subsequently, the issue that has triggered this study is presented. Next, the purpose is revealed followed by the research questions, which are answered to fulfil the purpose. Furthermore, the focus and delimitations of the thesis are described. Last, the disposition of the report is presented.

1.1 Background

1.1.1 New Requirements put on the 3PL-providers

With todays' requirement of shorter product life cycles and faster time-to-market, producing companies experience an increased demand for faster transports in the supply chain. This since short delivery times both internally, between an organisation's facilities, and externally, to its customers, gives competitive advantages. Naturally, if a customer has a choice of a number of equal products, it often prefers the one supplier, which can offer the shortest delivery time. Therefore, by reducing both internal and external transportation times companies can be more successful.

With these aspects in mind, pressure is put on freight forwarders to offer their customers a timely and reliable transport service at a reasonable price. As road transports is the most flexible transportation mode it is used for a majority of the transports in Sweden. The increase of road transports can be explained by the increased demand for fast and efficient transportation (Lumsden, 2007). To accomplish a high quality service, the freight forwarders must offer its customers punctual and short delivery times to all locations in the country. In addition, this service must be provided to the customers on a daily basis.

As a result, the actors in the 3PL industry must identify a suitable design for their transportation network to enable such transportations. However, this is not an easy task since changing the design, basically moving or building new facilities, requires huge investments and takes time to realise. The customers' shifting demand patterns together with the typicality of Sweden's geography and demography make it even more difficult to ensure a well-planned network design. As the country is large and the majority of populated towns are located in the south and along the coast in the north it becomes difficult and costly to transport goods quickly from point A to B all over the country. This since the distances between sender and receiver can be large, but also since the demand of transportation services vary a lot across Sweden. Obviously, the demand is higher in greater cities where more companies are located compared to the sparsely populated countryside in the inland of northern Sweden. To sum up, the actors in the industry need a supporting structure of the transportation network to be able to offer the service which the customers demand.

An important part of the development of the network design is to locate hubs which can support the existing terminals in the network. Using one or several hubs can give numerous advantages, for example, it can enable daily deliveries to an area with low demand for goods. Instead of each terminal transporting small goods volumes on trucks with a low fill rate, these terminals can consolidate their goods at a hub which enables transports with a high fill rate to the specific area. Accordingly, a high service can be achieved in a cost efficient way to areas with lower demand.

1.1.2 Company X's Quality of Service Issue

The issue of offering a high quality service at a reasonable price is also experienced by the focus company of this study, Company X. During the last years it has been more focused than earlier on increasing the quality of service to its customers in a cost efficient manner. To clarify, Company X is the Swedish division of one of the largest freight forwarders in the European 3PL industry of road transports. The company's vision is to deliver beyond customer's expectations and as a result, it should be the first choice for customers demanding transportation services.

The company's transportation system in Sweden has the design of a network[1] and is operated by hauliers who provide customer transports in a wide range of services such as delivery of parcels, part loads and general cargo[2]. The network contains of 25 terminals[3] from Malmö in south to Luleå in north, which each has a site manager. The terminals are used to enable a consolidation of picked up goods from the local area which can be sent on trucks with a high fill rate to a terminal located close to the final destination were it first are sorted and then distributed. The transports from the terminal to customers in the surrounding area are referred to as pick-up and delivery transports by Company X. Some of the terminals also function as hubs, which support the network with consolidation of less-than-truck loads for transports between terminals, these are called linehaul transports. A hub is by Company X defined as a terminal which, in addition to the terminal activities, consolidate and reload goods with the same final destination between the sending and the receiving terminals.

With the recent change in the site managers' area of responsibility, Company X has made them in charge of the end-to-end service to customers. This means that each site manager is accountable for delivering goods in time, from the pickup in the local area to the delivery at the customer. Even if the goods are transported via a hub, the site manager at the sending terminal is responsible for delivering the goods in time to the end-customer. The site manager at the hub is subsequently not responsible for goods passing through their terminal. Earlier, the site managers' responsibility ended when the goods left their own terminal. As a consequence, the site managers now have an incentive to ensure the quality of service to its customers.

With the recent change in the site managers' area of responsibility, the company has discovered that many of the deliveries to customers in northern Sweden are not in time. Goods that are transported to a number of terminals in this region via the main hub fail to meet the promised delivery time to the customers. This issue can of course be caused by one of many reasons. Some reasons for this can be that goods should not be transported via the hub but rather directly, that the planning of the linehaul routes is

[1] A transportation system where the nodes are directly or indirectly connected to each other with links
[2] Parcels include packages with a maximum weight of 150 kg/shipment. General cargo is goods with a maximum weight of 2500 kg/shipment. Part loads are goods with a weight between 1000 kg and 37000 kg and is mostly transported directly between customers.
[3] 25 terminals include also the supporting locations but are excluding one recently closed terminal.

inappropriate, that the handling of goods at the hub is inefficient, or that the localisation of the hub is not optimal.

This problem has visualised the fact that the company today lacks an evidence-based decision-making tool concerning the design of the hub network. Due to an insufficient strategy regarding the design of the transportation network it is not clear how the main hub got the responsibility of handling these large goods volumes. In addition, there has not been an evaluation of the transportation network and its design for many years. With the issue of inadequate service quality, the Company doubts the location of the main hub. Consequently, an analysis of the current hub network is performed in this thesis.

Since Company X strives for meeting its customers' expectations and being a high quality brand it is wishful to live up to its expectations. Not managing to deliver goods in time to its customers is not good for business, therefore, the quality of service to the customers need to be improved. It is believed by the initiator of this thesis that by investigating the design of the hub network, and especially the localisation of the hub, the company can be one step closer to the solution of the problem. By developing an policy for how decisions should be made concerning the design of the transportation network, future decisions will no longer be made on managers' gut feeling.

According to Jonsson & Mattsson (2005) the transportation network should be designed to provide conditions for good customer service. Moreover, frequent and reliable transports within the area as well as high vehicle fill rate have to be fulfilled. The localisation of the hub is therefore questionable since the experienced problems concern transports through this hub. Therefore, the strategic planning of the transportation network needs to be investigated. Accordingly, a model based on a set of factors, which can evaluate the localization of a hub, should be developed to facilitate future decisions concerning the design of the hub network. Company X wants to enable a development of the transportation network design in order to streamline the business and to remain a strong player in the industry.

1.2 Purpose

The purpose of this master thesis is twofold; first, to develop a decision model, which should be used to evaluate where to locate a hub, and second, to perform an analysis of the current hub localisation.

The first part of the purpose is to develop a normative model. The model will include the qualitative and quantitative factors affecting the localisation of a hub. These factors will be evaluated in order to find an optimal location for a hub, supporting the transportation network. The result will be a decision support to be used for hub localisation.

The second part of the purpose is to find an optimal localisation of the main hub by analysing the lines which today transport goods to the main hub. The objective of the analysis is also to illustrate how the model can be used in practice.

1.3 Research Questions

The master thesis will answer the following questions to achieve the purpose:

- Which factors have to be taken into consideration by Company X when deciding where to locate a hub?
- How should the alternative hub localisations be identified and evaluated to arrive at a decision support for an optimal hub localisation?
- What is the optimal hub localisation for the chosen lines according to the developed model and how reliable is the result?

1.4 Focus and Delimitations

The model will only evaluate the location of the hub, not the handling of goods nor the planning of the transport routes. Moreover, the alternative to transporting goods via a hub, in other words transporting goods directly from sending to receiving terminal, will not be considered. This is decided together with the supervisor at Company X. The reason for this is that the hub localisation is prioritized and because of limitations of the model. These delimitations could affect the result since there are many parameters in the system that affects each other. As all effects could not be investigated in this thesis due to the time constraint they need to be considered before making a final decision about the hub localisation.

Additionally, the capacity of the current terminals will not be analysed and therefore, the investment cost of a new hub will neither be estimated. Neither the effects of pick-up and delivery transports nor the changes in the timetable due to a new hub will be considered. Only the hub activities will be considered in this study. Synergy effects could arise if a hub also functions as a terminal, however, with the limited amount of time for this thesis such a complex analysis will not be performed. But obviously this could affect the final result and need to be estimated before making a decision.

Furthermore, the transportation network is in the analysis delimited to the transportation flows in Sweden, which is decided by the supervisor at Company X. There are incentives to improve this part of the transportation network since his department is responsible for the transports within Sweden. This delimitation is not considered to affect the result since the supervisor's department is evaluated on key performance indicators of the Swedish transportation network. Moreover, the analysis will only include transportation lines, which today transport goods via the same hub. It is assumed that they will transport goods via the same hub in the future, even if the hub localisation is changed. Since the current hub network is analysed, this is not considered to affect the result.

Also, the analysis will include data of booked capacity from hauliers, put simply, transportation volumes. In these volumes parcels and general cargo are transported, and to increase the fill rate part loads are sometimes also loaded on to the trucks. In contrast, the analysis will not consider optional services that can be bought additionally to the standard products. This delimitation is not considered to affect the result since the optional services have a marginal share of the sold services compared to the parcels, general cargo and part loads.

The analysis is delimited to include towns which are municipal capitals near the centre of gravity. This is to simplify the analysis since information needs to be gathered for each location. Of course, there could be villages possible to locate a hub that are not investigated but since it is most likely that Company X will locate a hub in a city this delimitation does not affect the result to a great extent.

1.5 Disposition

In order to ease the understanding for the reader, it is described how the chapters are linked together and their respective content. Chapter 2 and 3, which presents the methodology and the frame of reference, could be omitted for readers who want to focus less on the parts of academic nature. Though, it is recommended to read section 2.3 to get an understanding of the work procedure and the data collection before reading chapter 5 and 6. Moreover, chapter 4 could be skipped for readers with knowledge about Company X and its transportation network.

Chapter 1 – Introduction: The background of the problem is described to introduce the reader to the subject. This is followed by a presentation of the purpose of the master thesis and its corresponding research questions. The focus and delimitations of the study are also defined.

Chapter 2 – Methodology: The methodology, that is the basis for the thesis, is presented in this chapter. First, the importance of methodology is discussed which is followed by a presentation of the existing scientific approaches together with a motivation of the one chosen in this thesis. Furthermore, the work procedure of the study is explained in detail, where the system is defined, the data collection is presented, the model construction is clarified, the analysis is made clear, and last the validation of the model and the analysis is discussed.

Chapter 3 – Frame of reference: This chapter presents three different topics; transportation systems, facility localisation and decision-making. In addition, the authors' framework for model construction and analysis is also presented.

Chapter 4 – Company X and its transportation network: A description of the company is presented. Moreover, the transportation network is described to give the reader an insight of the processes at Company X.

Chapter 5 – Model Construction: The qualifiers and parameters are identified from the factors found in the literature review. Also, the developed model is explained in detail.

Chapter 6 – Analysis of current hub location: The alternatives for hub location are identified and evaluated for the chosen lines. A sensitivity analysis is also performed.

Chapter 7 – Conclusion: This chapter connects the result from chapter 5 and 6 with the purpose and the research questions. Recommendations for Company X and suggestions for future research are also presented.

2 Methodology

The aim of this chapter is to explain the methodology that is the basis for this thesis. The importance of methodology is explained and existing scientific approaches together with a motivation of the chosen one are described and presented. The work procedure including problem and system definition, data collection, model construction, analysis of the current hub location and validation are explained and how they will be conducted.

2.1 Importance of Methodology

To be able to investigate, explain and understand the reality, some assumptions about the reality must be made. These assumptions are then the basis for the scientific approach and will guide the researcher to make decisions through the project. It is because of these assumptions that problems can be studied out of different angles. Collected data will also be based on these assumptions. Every human has some fundamental notions about her environment and her part of the environment. These notions are based on paradigms and affect how we look at problems. Consequently, self-reflection and awareness are necessary to understand the investigations and the knowledge that is produced (Arbnor & Bjerke, 1994). Figure 2.1 shows how the fundamental notions affect the scientific approach and how this in turn affects the area of study.

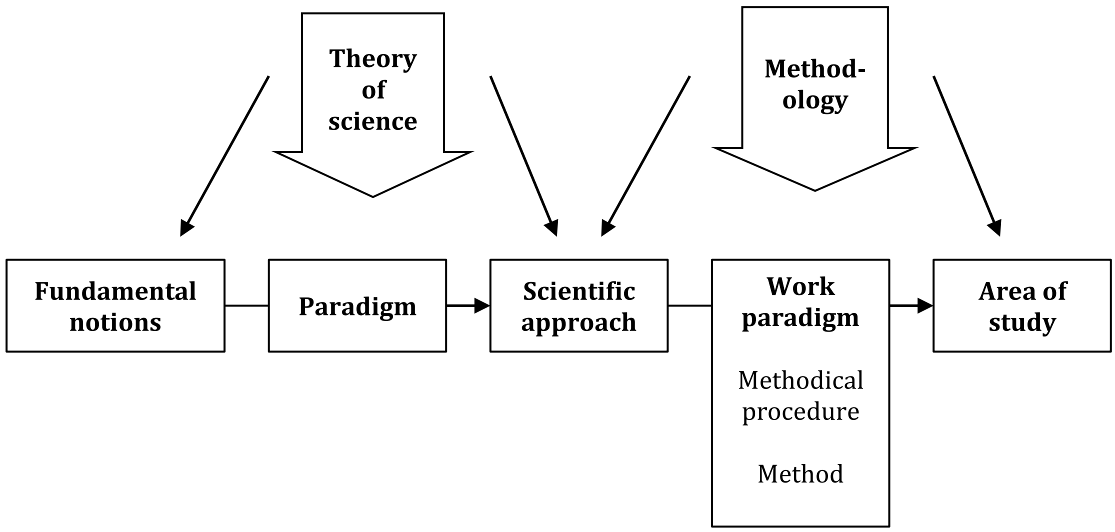

Figure 2.1: The effects of fundamental notions on the area of study (Arbnor & Bjerke, 1994, p. 31)

According to Arbnor & Bjerke (1994), the definition of a paradigm is fundamental philosophical notions where the development has a low rate of change. Furthermore, a scientific approach is based on humans' fundamental notions and is the basis for the project work procedure, which is called work paradigm. The work paradigm has a higher rate of change and contains two elements; methodical procedure and methodology. The methodical procedure is the way the researcher develops a technique within a scientific approach. This technique will be called a method when it is developed with a methodical procedure. The work paradigm is the bridge between scientific approaches and the actual area of study. Scientific approaches and the area of study cannot be described separately but need to be studied in a holistic view. This explains the importance of methodical procedure connected to the scientific approach and the area of study in a project. Accordingly, the methodology needs to match the scientific approach, the used methods and the area of study, which can be seen in Figure 2.1 (Arbnor & Bjerke, 1994).

2.2 Scientific Approach

Arbnor and Bjerke (1994) have formulated three scientific approaches to business studies. It is suggested that the choice of research methods should not only be influenced by the nature of the research question but also by the researcher's view of reality. The three approaches are:

- The analytical approach, which is closely related to the positivistic research tradition
- The systems approach, which is based on systems theory and is equivalent to the holistic approach often used in the logistics discipline as an approach to solve logistics problems
- The actors approach, which is based on sociological meta-theories

According to Gammelgaard (2004) these approaches are based on different paradigms, meaning that they for example differ in the researcher's view of reality, view of knowledge and the researcher's role.

2.2.1 Analytical Approach

According to Arbnor & Bjerke (1994), this approach assumes that there is an objective reality in which the whole is the sum of its parts. This means that once you know the parts, these parts can be summarized to the whole. The knowledge created should be independent of the individual and explained based on verified judgments. As a result, the researcher should position himself outside the research object and not influencing it. An example of a research method, which is typical for this approach, is quantitative data analysis based on statistical procedures (Arbnor & Bjerke, 1994).

2.2.2 Systems Approach

The systems approach, in contrast to the analytical approach, assumes that the reality is arranged in such a way that the whole is not the same as the sum of its parts. This is because the relationships between the parts give rise to synergy effects. Like the analytical approach an objective reality is assumed. The created knowledge is system dependent, meaning the parts are explained with the characteristics of the system. Consequently, the systems approach understands the parts from the features of the whole. The researcher should position himself outside the research object but influence it when implementing system changes. A case study with both quantitative and qualitative elements is an example of research method used when taking a systems approach (Arbnor & Bjerke, 1994).

Persson (1982) argues that many see the systems approach as a suitable starting-point when analysing the complex properties and relationships associated with a company's logistics system.

2.2.3 Actors Approach

The actors approach assumes that reality is a social construction since it is based on mapping of the meaning and significance that different actors lay in their actions and the surrounding environment. Therefore, the whole is explained based on the characteristics of the parts. The knowledge created is dependent on the individual, since the whole is understood based on the view of the actors. The researcher position himself inside the research object as part of the process. Qualitative studies are commonly used as a research method when taking an actors approach (Arbnor & Bjerke, 1994).

2.2.4 The Scientific Approach in this Thesis

The first part of the purpose of this thesis is to develop a decision model that should be used to evaluate where to locate a hub. This is not an easy task since there are a lot of factors influencing this. Both external and internal factors must been taken into consideration as well as soft factors, such as competitive strategy, and hard factors, such as goods volumes. In order to select a set of parameters for this model one must take all these factors into account. Moreover, how these factors influence each other is also needed to take into consideration. Synergy effects between these factors are expected to arise.

The second part of the purpose is to perform an analysis of the current hub localisation. Using the developed model, an analysis of the current situation will be made. In the analysis the parts of the whole cannot be investigated one at a time. This would mean that one parameter at a time would be analysed and then conclusions for this specific parameter would be drawn. Rather, the whole system of parameters is needed to be analysed in order to catch the synergies between the parameters. The synergy effects arise due to that parameter weights based on importance for hub localisation are combined with weights for how well each alternative fulfil each parameter. If a parameter is important for Company X and the alternative performs well concerning the parameter, this gives a stronger result than investigating them separately. It is neither possible to get the optimal hub location using the model since the output is a decision support containing a parameter score and a transportation cost. The whole system need to be considered before making a decision regarding the hub localisation.

With this in mind a systems approach is chosen.

2.3 Work procedure

2.3.1 Introduction

Depending on the understanding and the existing knowledge within the area of study, different research types can be used. This thesis has exploratory, normative and explanatory purposes. To achieve the purpose in this thesis, a modelling study is chosen to represent the work procedure. As Holme & Solvang (1997) explains it, a model is a tool for creating a simplification of reality to be used in scientific research. A selection of essential characteristics for the model is made based on experience or theoretical conditions. The model needs to include all relevant parameters to be able to represent the problem situation but at the same time be simple and clear to keep the overview. Moreover, according to Koole (2010), the definition of a model is "a description of a part of a system or process and its interaction with its environment that allows an analysis of certain aspects of that system or process". Here, the system is the object of the study and the process is a group of activities with a common goal. Moreover, modelling is defined as the process of developing the model and the whole method of solving problems using the model. By basing the research in this thesis of a modelling study, the two parts of the purpose will be fulfilled.

The modelling process in this thesis; its phases and the output of each phase is illustrated in Figure 2.2. In the figure, each arrow represents the input and output of each phase and each box represents the each phase.

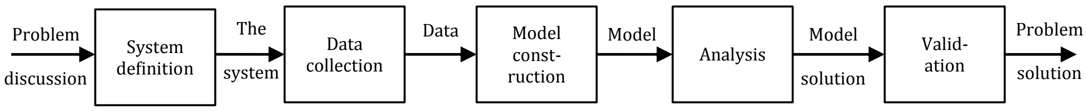

Figure 2.2: The modelling process in this thesis

In the first phase the system of study was defined. This was possible after discussions with the supervisor at Company X about the problem and the scope of the thesis. The system was defined by using the definition according to Churchman (1968).

In the second phase a data collection followed, which included interviews, data requests, a literature review, a questionnaire and a group discussion. The initial iSnterviews were of the exploratory type to get an understanding of Company X's processes and strategies in order to define the problem. According to Arbnor & Bjerke (1994) and Björklund & Paulsson (2003) *exploratory* studies can be used when the existing knowledge within the research area is insufficient. These types of studies often have the objective to hypothesise. The authors wanted to complement the existing knowledge within the area to enable a development of the model.

The third phase, the model development required a normative study since the objective of the model was to create support for future decisions. Arbnor & Bjerke (1994) and Björklund & Paulsson (2003) have defined a *normative* study as a study that strives for guidance and suggested actions. This research type requires some knowledge and understanding within the area. Since the authors started with exploratory interviews, the current situation was mapped and knowledge within the area studied was gained. This allowed a construction of the normative model with the aim to give the user a decision support concerning hub localisation. By using the model, an analysis was conducted.

The fourth phase, to analyse the current hub localisation by using the model, was of an explanatory type. The factors affecting the hub localisation were analysed and a suggested optimal location was presented. To be able to both describe and explain the analysis a deeper understanding and knowledge was required which is defined as an *explanatory* study according to Arbnor & Bjerke (1994) and Björklund & Paulsson (2003). This resulted in a model solution to the problem.

In the final phase a validation of the study could be performed. This contained of a model validation, investigating how reliable the model is, and an analysis validation, examining how reasonable the result is. By completing the validation phase a problem solution could be achieved.

Next, the phases of the modelling process are further described in detail.

2.3.2 System Definition

The problem situation of Company X was discussed with the supervisor at Company X in order to decide the purpose of the thesis. To start collect data, the system needed to be determined. By defining the system, the correct data could be gathered and literature within the area could be studied. Churchman (1968) defines a system as a set of parts coordinated to accomplish a set of goals. When discussing the system, five consideration must be kept in mind; the total system's objectives, the environment, the resources, the components and the management of the system.

Churchman (1968) says that the scientist's test of the objective of a system is the determination of whether the system knowingly sacrifices other goals in order to attain the objective. The objectives of the studied system are profit for linehaul transports and reliability of delivery to receiving terminal. The system is willing to compromise on other goals in order to get a high profit with reliable deliveries. The indirect objectives are to maximize sales and minimize costs which both are part of the profit. As well as maximizing profit, it is also important to deliver the goods in time, as promised, since quality is a competitive factor for Company X.

The resources of the system are the means that the system uses to do its jobs. They are the things that the system can change and use to its own advantage (Churchman, 1968). There are several resources identified that the system uses to operate; money, personnel, computers and business systems. These resources are considered mainly belonging to activities connected to the later described components. Money and personnel are input to the system and computers and business systems are considered as tools used by the staff.

The main components of the studied system are planning of movement of general cargo and parcels between terminals and planning of the network design, that is, the localisation of terminals. These activities require the above mentioned resources to achieve the objectives of the system. According to Churchman (1968) the components are the tasks that the system must perform.

Churchman (1968) defines the environment of the system as what lies outside of the system. From the system's point of view, the environment can be considered as things and people that are fixed or given. In order to determine the environment of the system, one must in each case ask, "Can I do anything about it?" and "Does it matter relatively to my objectives?" If the answer to the first question is "No" but the second is "Yes," then "it" is in the environment. There are several factors which influence the studied system on a daily basis, but as the system cannot affect. These are considered to be the environment and are important to include in the study; vehicles, weather, part load traffic, terminal workers, infrastructure, resources and costs. Possible problems with vehicles as well as the weather are risks of delays, which can have an impact on the objectives. Both the profit and the delivery time can be affected. The part load traffic is an important factor that has a great impact on transports of general cargo. As explained before, the trucks are filled up with part loads to increase the utilization of the vehicle, this way the amount of part loads on a line affects the planning of linehaul traffic. The terminal workers' ability to load general cargo and parcels on trucks is also a part of the environment. This since an inefficient loaded trailer could require a need for extra load metres[4] which results in an additional cost for the transports and thus reduces the profit. The infrastructure affects the planning of traffic, especially changes in infrastructure and road construction. The network design is affected by costs in the network as well as money invested in such strategic planning.

Churchman (1968) describes the responsibility of management of the system as the task to plan for all the above-mentioned basic considerations. Resources have to be allocated, the performance has to be controlled and the component goals have to be set to fulfil the objectives. The management of the system has also the responsibility of ensuring that the plans are being carried out according to the original ideas. The plans need to be evaluated and corrected if needed. Company X is considered to be the management of this system as it has the responsibility for the above mentioned components and resources with the purpose to fulfil the objectives.

2.3.3 Data Collection

There exists two types of data collection methods; qualitative and quantitative. This study contains both methods due to the purpose of the thesis. The normative model includes a number of factors and their impact on hub localisation, which can be measured from either numerical sources or qualitative references. By using both qualitative and quantitative data, the validity increases since several perspectives are used. It is also a common research type for the systems approach, according to Arbnor & Bjerke (1994). Studies that are *qualitative* are recommended when deeper understanding within an area is preferable. The objective of qualitative analysis is to identify and determine unknown phenomena, characteristics and meanings with respect to variations, structures and processes (Björklund & Paulsson, 2003; Starrin & Svensson, 1994). The exploratory interviews are aimed at gathering qualitative data to get an overview of the current situation at Company X. This type of data is also collected to the construction of the model as well as to the analysis of the optimal hub location. *Quantitative* studies contain information that is either measurable or valuable numerically. The objective of quantitative studies is to investigate how defined phenomena and its characteristics are allocated in a situation and to investigate relations between phenomena (Björklund & Paulsson, 2003; Starrin & Svensson, 1994). Quantitative data will be gathered from Company X's business system and will be input to both the model construction and the analysis. In addition, quantitative data was achieved from the questionnaire were the importance of factors was investigated.

Triangulation has been used by combining different methods for data collection and different sources of data. Denscombe (2010) argues that triangulation involves the practice of viewing things from more than one perspective. This way the researcher can

[4] Load metre is a measure of the area in the carrier that the goods claim. It is especially applicable for non-stackable goods which still use the entire loading area. Load metre is calculated as $\frac{Length\ (m) * Width\ (m)}{2,4}$ where 2.4 is the width of the carrier.

get a better understanding of the thing that is being investigated. By performing both a questionnaire and a group discussion to gather data regarding the importance of different factors for Company X, triangulation was used. Moreover, exploratory interviews were conducted with employees at different positions to compare and verify the answers regarding the hub localisation. The collected quantitative data files from Company X's database have also been compared in order to verify the data. This way of combining data sources is strengthened by the arguments of Denscombe (2010); working with different points of view gives a better understanding of the subject and an increased validation of the study.

Eight Steps of Data Collection

The data collection was conducted in eight steps, shown in Figure 2.3. First, the scope of the thesis was clarified through initial exploratory interviews. Second, a first quantitative data request was sent to get a feeling of the format of the data. Third, a literature review was conducted to increase the authors' knowledge in the area. Fourth, detailed interviews were held regarding what was found in the literature. Fifth, a second quantitative data request was sent which was more specific than the first one. Sixth, a questionnaire was performed to gather the employees' views on what was found in the literature. Seventh, a group discussion on the same topic was completed with the same employees as the questionnaire. Lastly, internal and external data needed to perform the analysis was collected.

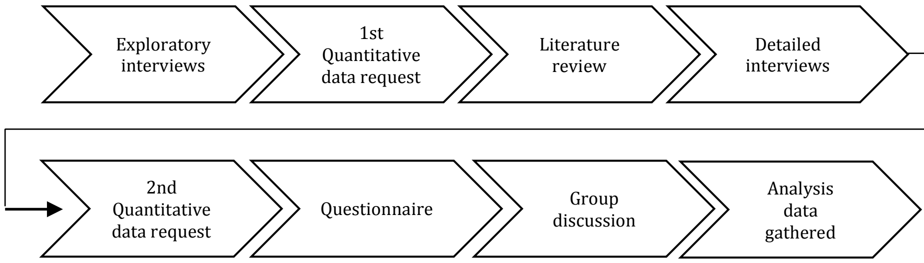

Figure 2.3: The eight steps of data collection in this thesis

Next, each step is described further in detail.

Exploratory interviews: In order to further clarify the scope of the thesis initial exploratory interviews were held with employees at Company X. The employees at Company X were chosen partly by the supervisor at Company X and partly by the authors of the thesis. This was to get the best possible insight in the company and its problem situation. The interviews were held with people with different areas of responsibility, such as terminals, quality performance, linehaul traffic and part load traffic. These interviews were prepared with an unstructured approach to get an overview of the problem and letting the interviewees talk freely about the subject. Asking several managers at different positions the same questions during the interviews ensured the reliability of the data collection. This was time consuming but increased the trustworthiness of the answers. This first phase of the data collection gave insight in Company X as well as a deeper understanding of the problem and the purpose of the thesis.

1st Quantitative data request: A first data request was sent to Company X to get a feeling of which data that was possible to receive and how long it would take to receive it. The data gathered in this step was secondary data from the business system at Company X.

Literature review: To create a theoretical frame of reference, different types of literature were studied. Literature within the area of logistics and specifically transportation were studied to get an overview of the subject. To create a theoretical frame with a broad base, general books within transportation systems were used. To further deepen the knowledge, books and articles regarding hub localisation were studied in detail. Four models within facility localisation were found and used as inspiration for the model in the thesis. Furthermore, theory within decision-making was also reviewed. This was performed to have a method for weighting the parameters according to their importance for Company X in the developed model.

Detailed interviews: Detailed interviews were conducted to collect information about the current strategies within the transportation network at Company X. Localisation strategies, flow of volumes and cost structures were mapped with this information and used as a basis for the empirical chapter. Employees at Company X with responsibility for terminals, linehaul traffic, network structure and performance monitoring were interviewed. These interviews were semi-structured in order to capture the wanted information but also to enable a flexible interview depending on the answers. These interviews were also used to evaluate the factors from the theoretical frameworks affecting hub localisation. To remove the parameters not affecting Company X, questions concerning the factors were asked. Factors were removed according to the interviewees' and the authors' opinion, see section 5.1. These interviews were conducted with managers responsible for terminals and linehaul traffic since these managers are most familiar with hub localisation questions.

2nd Quantitative data request: After the literature review and the detailed interviews, a second quantitative data request was sent to complement the first one. This since it was realised by the authors after phase three and four that additional data was needed. The method of gathering quantitative data for planning of a multi-terminal system is described by Tarkowski et al. (1995). The statistics to base the analysis on is historical data of the flow of goods from business systems. It should be cleaned from data noise and important changes in the market should be considered. The statistics should be adjusted to include future changes that can have an impact on the distribution system. The collected quantitative data were cleaned in order to be used in a proper and effective way.

Questionnaire: In order to evaluate the remaining factors affecting hub localisation from the detailed interviews, managers at different positions and at different levels of hierarchy at Company X were asked for their opinion. A questionnaire was designed with questions regarding the importance of each factor. According to Höst et al. (2006) it is recommended to test the questionnaire before using it for its purpose. This was done by letting two managers give their feedback on the questionnaire and it resulted in clearer instructions. As a result, it was possible to construct a model, which was influenced by the managers at Company X. The purpose of the questionnaire was to identify which factors that would be used as qualifiers and parameters respectively in the model. The employees chosen to be part of the questionnaire were three site managers, one manager responsible for all terminals in northern Sweden, one for process development, one for linehaul traffic, one for pick-up and delivery traffic, one for goods handling at a specific terminal and one for performance monitoring. They were chosen to get an appropriate mix of people at different positions and from different functions within Company X. This was to get a broad picture of the diverse opinions at Company X. Furthermore, the questionnaire consisted of 14 factors, which the managers would evaluate. Höst et al. (2006) argues that it is effective to use a measuring scale in a questionnaire to capture the participants' opinions. Therefore, a measurement scale from "not important" to "necessary" was used with seven steps, as presented in Appendix A. The factors were explained to make it clearer for the participants. The participants were also given the opportunity to add factors they thought were missing in the questionnaire. The result of the questionnaire is presented in Appendix F.

Group discussion: To get the parameters chosen in the questionnaire weighted, a group discussion was held with the same people answering the questionnaire, except one manager who was not able to participate. The discussion with the eight participants was held in one group since the number of people was considered small enough to enable a discussion where everybody could tell their opinion. The group discussed the parameters according to a spanning tree, see Appendix B. Nine parameters were chosen to be discussed during the group discussion, which required eight pairwise comparisons of the different factors and, consequently, eight separate discussions. The goal of the group discussion was to achieve consensus regarding the relative importance of the parameters. If the group would not agree, the authors had prepared an individual questionnaire where each person could state his or her opinion in each pairwise comparison of the factors, see Appendix C. The result from the questionnaires would have been analysed and used as a basis for the weighting of the parameters. In all discussions of the pairwise comparisons the group agreed so the questionnaire was not needed. The result of the group discussion is presented in Appendix D.

Analysis data gathered: The data needed to perform the analysis was collected by requesting internal data and searching for external data. This data was collected to evaluate how different locations satisfied the parameters. Internal data was requested from employees at Company X and external data was collected from public sources.

2.3.4 Model Construction

In order to perform the analysis the model needed to be constructed. The model should be a decision support and able to evaluate where to locate a hub. As Holme & Solvang (1997) describes, the model needs to include all relevant parameters to be able to represent the problem situation but at the same time be simple and clear to keep the overview. By reviewing the literature and discussing the model with the supervisor at Company X a model was constructed according to Company X's desires, to solve the problem. The model is based on the frame of reference but integrated with opinions from Company X since it includes factors from the literature combined with aspects found in the detailed interviews and the questionnaire. The output of this phase, in other words the complete decision support model, is presented in Figure 2.4.

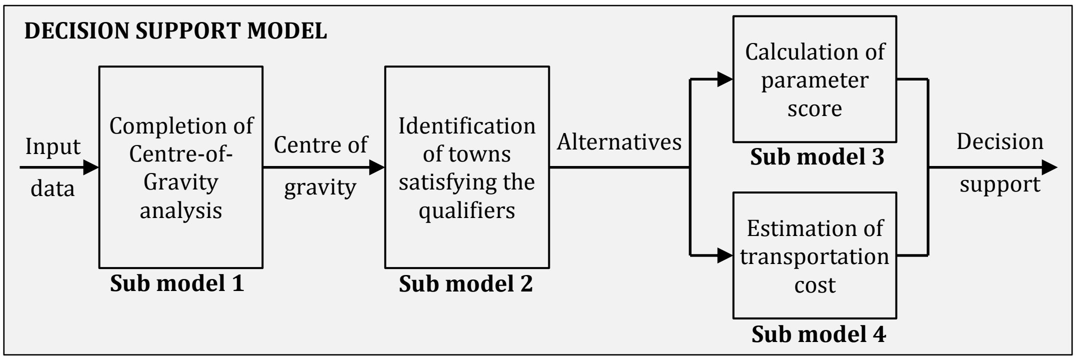

Figure 2.4: The outline of the decision support model

To be able to create a usable spread sheet model a number of sub models were needed to be built in the model construction phase:

1. Completion of Centre-of-Gravity analysis
2. Identification of towns satisfying the qualifiers
3. Calculation of parameter score
4. Estimation of transportation cost

In the first sub model a Centre-of-Gravity analysis can be completed. The input to the model is data such as coordinates for current terminals, goods volumes per line, and cost of goods volumes per line. This results in an output, which is the centre of gravity. In the second sub model towns in the proximity of the centre of gravity can be analysed in an iterative process according to the qualifiers. The iteration is stopped when the user have found the wished number of towns which fulfil the qualifiers. These towns are called alternatives for hub location, short alternatives, and are further evaluated in sub model 3 and 4. In the third sub model, the weight for each parameter first needs to be recognised. This is done by using the Analytical Hierarchy Process (AHP) where the parameters are pairwised compared to evaluate how important they are to consider when deciding of a hub localisation. Then, the parameter score for each alternative can be calculated. The alternatives are compared in the same way with the AHP to evaluate how well they satisfy each parameter. As a result, each alternative will receive a parameter score. Next, the transportation cost for each alternative hub location can be estimated based on the input data to sub model 1. Finally, the user obtains a decision support where he or she can compare the alternatives' parameter score and transportation cost in order to decide where to locate a hub.

2.3.5 Analysis of Optimal Hub Location

According to Koole (2010), one part of the modelling process is to solve the problem by using the model to analyse the problem situation. The analysis of the thesis was conducted by using the model constructed in the previous phase. Deciding the transport lines to analyse according to the delimitations and the system in the thesis was the first step in the analysis. One of the delimitations in section 1.4 was to only analyse lines going through the current main hub. By using the model, these lines and their respective terminals were used as input to sub model 1 and the centre of gravity was received as output. Next, the current hub location and a number of towns in the closeness of the centre of gravity were found which fulfilled all the qualifiers. Then, the parameter score was calculated and the transportation cost was estimated for these alternatives. Last, a decision support for an optimal hub location was acquired.

2.3.6 Validation

Validity is an investigation if the model is a correct and valid description of the phenomena. It needs to be investigated if the results are to be considered reasonable and it needs to be verified that the model has measured what it was expected to measure (Höst et. al. 2006). Moreover, it is common within the systems approach to get as many viewpoints as possible of the system to validate the results. Interviewing as many people as possible and gathering as much information as possible are ways to conduct this. An essential validity control is to examine the effects of applying the result indicatively (Arbnor & Bjerke, 1994). The validation of model is described below.

Model Validation

Landry et al. (1983) introduce the modelling-validating process, where the model building and the model validation are integrated into a single process. There are four activities in the process; problem situation, conceptual model, formal model, and solution. Different validation procedures are conducted between these activities, namely; conceptual validation, logical validation, experimental validation, operational validation, and data validation. The modelling-validating process is shown in Figure 2.5.

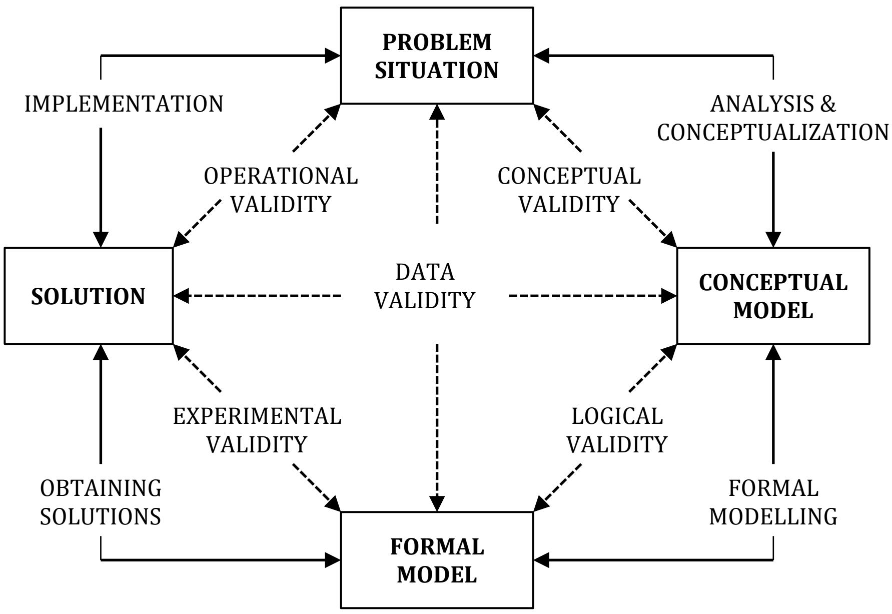

Figure 2.5: The modelling-validating process (Landry et al. 1983, p. 212)

Next the validation procedures are further described and how they have been performed in this study.

Conceptual validation: A conceptual model is a mental image, which shows how the problem is perceived, according to Landry et al. (1983). The objective of the conceptual validation is to validate that the perspective of the problem situation is right in order to get an appropriate solution. In the beginning of the thesis, many meetings were held with the supervisor at Company X to discuss the problem situation and the concept of the model. The discussions moved back and forth between the problem situation and the conceptual model. When the model was discussed, new questions regarding the problem situation and the scope of the project arose. This is natural according to Landry et al. (1983) who argue that it is an iterative process to identify a suitable conceptual model, where one moves back and forth between the problem situation and the conceptual model. He also states that different conceptual models can represent different perspectives of the problem situation and this validation is made to ensure that the right conceptual model is used.

A lot of different concepts were discussed between the authors and the supervisor, it varied much what to include in the model and what to not include. The definition of the problem situation was also discussed back and forth. After discussions, the authors compiled three different suggestions for the model to be made depending on the definition of the problem situation. After discussing these with the supervisor the one which best solved the problem situation was chosen. To make this model even better it was enhanced with regards to the problem situation after further discussion with the supervisor. In addition, it was believed by the supervisor and the authors that the conceptual model presented in Figure 2.4 best represented the perspective of the problem situation. Breaking down the elements of the model, i.e. looking at the earlier described steps of the model it is assumed that the perspective is correct in order to achieve an appropriate solution. Moreover, the frameworks regarding hub localisation from the frame of reference that are the basis for the conceptual model are considered to be relevant for the problem situation. These were discussed with the supervisor at Company X who confirmed the relevance. The theoretical models were adapted to Company X and the problem situation; parameters were added and removed to enable an appropriate model.

Logical validation: The formal model was developed as a spread sheet model, it was therefore relatively easy for the authors to translate the conceptual model to a formal model. This since the model itself does not contain many formulas and the ones, which occur, have easily been created with the software's built in functions. Landry et al. (1983) says that the process of ensuring that the conceptual model is correctly described in the formal model, so the problem situation is acceptably defined, is called logical validation. This validates that the parameters and the relationships are defined as in the problem situation and in the conceptual model. It also evaluates the language of the formal model to ensure that the conceptual model is correctly translated (Landry et al. 1983). It has always been checked that the correct cells are used in the formulas. The predefined sub models of the conceptual model were easy to implement, it was natural that each sub model was divided into one or two spread sheets.

Experimental validation: The quality of the solution is measured and tested with experimental validation. Changes in parameters and solution sensitivity are confirmed with this validation, argues Landry et al. (1983). Changes in the model's parameters will of course affect the solution. A sensitivity analysis was conducted with the input data used in the analysis and is presented in section 6.6. Depending on changes in Company X's environment or the external environment, the parameters in the model are needed to be updated if an analysis will be performed in the future. The reason for this is that the parameters have been adapted to suit the current situation of Company X.

Operational validation: The operational validation ensures the users of the formal model that the solution is applicable in the problem situation. This validation helps the decision-makers to enable implementations of the recommendations. The implementation often needs to be adapted to assumptions and conditions that were removed for simplicity in the conceptual model (Landry et al. 1983). In this study, the developed model is considered very straightforward and easy to use for Company X. In addition, it is clear that the model solution will solve the problem. This is because the model gives a support for making a decision concerning where to locate a hub. However, the estimated transportation cost will not be an exact cost. It should be seen as a parameter that enables a cost comparison between the alternatives. As said, the transportation cost is based on load metre and kilometre and is negotiated for each line in the network. If locating a hub at a new location, the cost for transports to this hub has to be negotiated. This means that the exact transportation cost cannot be calculated on beforehand.

The result of the model will give an indication of where the best location is for a hub with the current flows and transportation costs. There are aspects that are not included in the model but still affect a localisation decision. These aspects are not included in the model because of delimitations. The effects of pick-up and delivery traffic have not been considered in this thesis, neither costs due to damages at re-loading. The model does also need to be complemented with an analysis whether the current flows should be transported via the hub or directly to the receiving terminal. The changes of the timetable could also have implications on the network, which are not illustrated with this model. These need to be considered and weighted together with the advantages of a new hub location before making a decision.

Data validation: Evaluating the data sources is called data validation. Availability of data, accuracy, and appropriate data are necessary to develop a correct model and a solution to the problem (Landry et al. 1983). The data which was collected from the company's business system is considered valid. The reason is that all the used data was collected from the same time period. Furthermore, the requested data was available and easy to retrieve from the business system. The coordinates for the terminals have been checked with different sources to ensure that they are correct.

The input from the group discussion to the comparisons of the parameters is subjective since the group's opinion was used as input data to the model. The purpose of the model is to integrate theory from facility localisation with Company X's opinion so the subjectivity does not reduce the trustworthiness of the model.

As discussed above, the estimations of the total transportation cost will not give an exact cost since it is assumed that the costs per line for the alternative locations are the same as for the current hub location. This assumption was necessary to make calculations in the Centre-of-Gravity analysis and estimations of the total transportation cost.

By having a continuous contact with the supervisor at Company X, it was confirmed that the investigations and the planned interviews were of value for the final result. This iterative contact increased the validity and ensured that the authors were on the right track during the thesis and that the solution is appropriate for Company X.

Analysis Validation

Höst et al. (2006) means that the conclusions from the analysis need to be validated and it should be questioned if the result is reliable. To analyse the reliability of the analysis, the input and output of each step in the analysis need to be investigated. This can be conducted by interviewing experienced people with knowledge within the area. This validation is presented below for each sub model and also for the output of the model.

Sub model 1, Completion of Centre-of-Gravity analysis: The fixed input data, namely, the coordinates and the distances between the terminals are considered reliable. The flow of goods data, number of load metres per line and year, is gathered from one year, which takes possible seasonal variations in demand into consideration. So with the purpose of locating one hub for the total flow in the network, data from one year is considered to be enough. Moreover, the costs used as input in the Centre-of-Gravity analysis are costs per load metre and kilometre for each line. This is the existing cost independent of truck utilization since the cost is based on the ordinary booked capacity for all lines in the network. The Centre-of-Gravity analysis then minimizes the existing transportation cost in the network, which is the purpose.

The analysis is considered to be objective since the analysis method is based on theory and secondary data was gathered from the business system at Company X. The Centre-of-Gravity analysis has a high internal validity since it is a well-known method for locating facilities. Additionally, the reliability of the output of the model, the centre of gravity, is considered to be reliable after re-calculating the coordinates manually. In addition, the location of the centre of gravity is considered to be reasonable since the flow of goods in the network occur both south and north of these coordinates. The centre of gravity is also located relatively close to many other terminals.

Sub model 2, Identification of towns satisfying the qualifiers: Since it is decided by the user of the model how the qualifiers should be evaluated it is important to validate the result. The authors chose a definition for how each qualifier should be evaluated and then both internal and external sources where used to evaluate the towns. The internal sources where employees at the company, while external sources where from Ekonomifakta and SCB. These were all considered reliable.

The way the qualifiers where evaluated and the result of the three identified alternatives were considered to be reliable after discussions with the supervisor at Company X. His opinion about the reliability is considered valuable since he has experience from the industry.

Sub model 3, Calculation of parameter score: The reliability of the comparison values for the alternatives is based on how the parameter is evaluated. For example, the average number of days with snow per year has been the basis for the evaluation of weather for the different alternatives. It is possible that other ways of evaluating the alternatives according to the parameters could be found. However, it is currently considered to be the best way according to the authors and the supervisor. The input to the evaluation of the alternatives according to the parameter is both internal and external data. Internal data have been gathered from Company X's business system and from interviews with employees. The interviews have been held with people at different positions to validate the answers. The external data are mostly electronic sources, which are considered to be reliable according to the authors. The reliability of the sources has been judged according to the trustworthiness of the websites' originator and the ability of finding the same information from different sources.

The objectivity of the analysis of the alternatives according to the parameters can be discussed. Some of the comparison values are based on the authors' opinion and it is difficult not to be subjective in this type of analysis. Though, the authors are aware of the subjectivity and it has been discussed with the supervisor. Since the model is based on subjective estimations and assumptions, the subjectivity is a part of the result. In addition, to ensure the reliability of the alternatives' parameter score, the weights for each alternative have been discussed respectively to confirm that the weights reflect the opinion regarding the fulfilment of the parameters. Though, the result is subjective since the analysis has been conducted with the authors' opinion but it is unavoidable because it is the purpose of the model.

Sub model 4, Estimation of transportation cost: As discussed in the validation of sub model 1, using data from one year and from the same time period increases the validity and the reliability. There are seasonalities in the goods flows but the result is not affected by these.

Since it is an assumption that the total costs per transport from the business system at Company X can be recalculated into costs per load metre and km, the total costs presented in the result could differ from the real cost. It is also assumed that the costs for the alternative locations are the same per load metre and km as for the current hub location. This is of course not true since new cost needs to be negotiated with hauliers for each line servicing the new hub location. This assumption can affect the result of the transportation cost which needs to be recalculated for a more accurate cost. Though, it is considered to be reasonable and a good indication of the difference between the costs for the alternative locations. The purpose of the transportation cost analysis is rather to illustrate the difference between the alternatives than to present an exact total cost.

Output, Decision support: The final result, i.e. the decision support, is considered to be feasible after discussion with the supervisor at Company X. This opinion is based on a review of the analysis. The result should be seen as an indication of where the hub should be located. As discussed, the transportation costs are not exact because of the assumption made about the costs for the new lines to the alternative locations. Parameters that are not included in this model can affect the result. They are delimited in this thesis due to the complexity and time limitations but can still have an impact on the result of the best hub location. The analysis made is subjective, the alternatives are evaluated according to the qualifiers and the parameters based on the authors' opinion. However, since it has been discussed with the supervisor at Company X, it is considered to be reasonable.

3 Frame of Reference

This chapter is aimed to present theory to be the basis for the problem and system definition, model construction and the analysis. First it is discussed how the frame of reference supports the work process of the study. Second, the terminology of transportation systems and the functions of the elements in a transportation network are explained. Third, four frameworks for facility location planning are presented and fourth, decision-making and the Analytical Hierarchy Process are explained to be used in the model construction and in the analysis. Lastly, the authors' framework for model construction and analysis is presented.

3.1 Introduction

This chapter is aimed to give a theoretical frame of reference to support the work procedure, described in section 2.3. The chapter is divided into three parts; terminology and design of transportation systems, frameworks and methods for facility localisation and a method for decision-making. Figure 3.1 shows how the three parts in the frame of reference will support the work process of the thesis.

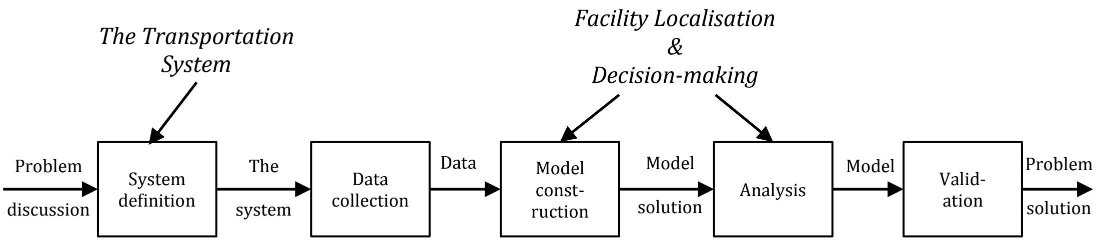

Figure 3.1: The support of the frame of reference of the different phases in the modelling process

The first part, the transportation system, gives the reader terminology and a basic understanding of elements in transportation systems. Nodes and links are defined to get a structured view of a transportation system. Different types of design of transportation systems are presented to get a deeper understanding of Company X's design. Planning of the system is described to understand the theory behind Company X's planning as well as the level of planning which the purpose of this thesis deals with. This first part of the chapter is described in order to enable an investigation of Company X's transportation system to get a platform for understanding. The second part, facility localisation, presents four frameworks from different authors regarding facility localisation. These frameworks describe factors to consider when locating a facility, methodology for the facility location process and mathematical models for finding optimal location. In addition, the factors affecting facility location will be compiled to get an overview. This part will be a basis for the model construction as well as the analysis by evaluating which factors affecting hub localisation at Company X. The third part, decision-making, explains the Analytical Hierarchy Process, which is a method for weighting opinions regarding different options used when making decisions. This method will be used to construct the model as well as in the analysis.

3.2 The Transportation System

3.2.1 Introduction

This subchapter introduces the authors to the terminology of the area of study. In order to understand the current situation of the transportation network at Company X, theory has been compiled concerning functions of a nodes and links, network design and planning of a network. With this theoretical background, it will be possible to map the situation and thereby enable a development of a model, adapted to Company X.

3.2.2 Definition of a Transportation System

According to Lumsden (2007) the transportation system is divided into three parts; the material flow, the transport flow and the infrastructural system. The material flow refers to the processes where the products go within and in between organisations. The transport flow is the flow of vehicles and equipment between and in-between organisations. The infrastructural system is built out of assets that make the transportation flow possible. These assets can be parts of for example road network and facilities.

The perspective of the system in this study is the transport flow in the transportation system. Company X's objective is to provide the best quality of service to the lowest transportation cost which also is the aim when considering the transport flow. The decision model and the analysis performed in this thesis reflect the processes between Company X and its customers as well as the transports within the organisation. This point of view mirrors the purpose of the study and therefore also the following chapters.

3.2.3 Nodes and Links in a Transportation System

A generalized network structure consists of nodes and links. A node is defined as a stop in the flow or a point where the flow can be stopped. Terminals, stock keeping and similar activities are examples of nodes. The flow between the nodes is represented by links, which are all transports of goods with different time durations. The transports have to converge in certain nodes at certain times. To ensure the functionality and the efficiency of the network, each link is given a specified cycle time to operate within (Lumsden, 2007).

Split and Co-loading Points

A distribution network can increase its frequency and reduce its costs by introducing split or co-loading points, these are illustrated in Figure 3.2. A split point is where goods arrive from one terminal to another and from there are distributed to customers in the area. A co-loading point is the reverse of a split point. Goods arrive from different locations within an area and are consolidated and transported together in one direction (Lumsden, 2007). A fundamental principle for all transportation systems is to strive for as high utilization as possible by consolidating smaller shipments into full truckloads to increase the efficiency of the system. To enable consolidation of smaller shipments, transportation systems are built up by a number of terminals, where goods are sorted and reloaded, and linehaul traffic with full truckloads in-between the terminals (Jonsson & Mattson, 2011).

Figure 3.2: Split point and co-loading point (Lumsden, 2007, pp. 509-510)

There are a number of conditions that have to be satisfied in order to success with such structure; weight and volume, unit loads, original and final destination points and frequency in the system. Weight and volume refers to the possibility of loading different types of goods together in one transport. Restrictions in loading goods together are often weight or volume. Unit loads means that it facilitates the handling of goods if it is loaded uniformly and the possibility of using full truck loads increases. The third condition concerning regions is that the distributed goods should come from the same region and that the destination should be within the same region. Each split point is responsible for a specific area; therefore, the distribution should be concentrated there. To get a higher frequency in transports without increased costs, split points are usually recommended (Lumsden, 2007).

Terminals

Direct transports between sender and receiver would be the ideal but the reality with general cargo with different weight and size often requires consolidation of goods. Networks with direct transports often result in a large number of transportation relations. If volumes are low, the utilization becomes poor as well as the frequency in transports. This results in poor delivery time due to too low frequency in transports and difficulty to meet customer demand. This is a trade-off for freight forwarders, to keep a high fill rate but at the same time have frequent transports in order to achieve short lead-times. The business environment today requires short lead-times and it is difficult for the transport companies to keep profitable (Lumsden, 2007).

To reduce the number of direct relations, an introduction of terminals in the system could be a solution. One or more terminals are positioned in the network to increase the utilization of the vehicles. Goods are collected from the local area near the terminals and are then possibly unified and consolidated to a larger transport. The goods are transported to a second terminal from where it is delivered to customers nearby (Lumsden, 2007). This design is shown in Figure 3.3.

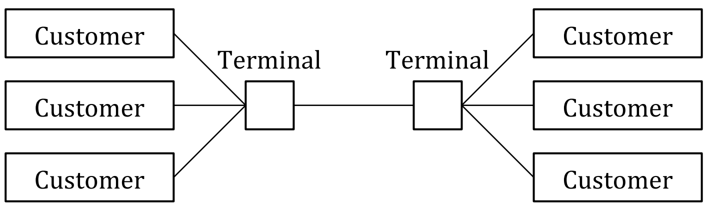

Figure 3.3: Transports between customers via two terminals (Lumsden, 2007, p. 449)

Time restrictions exist for this type of system and many transports are connected to each other. The outgoing transports from one terminal are independent but connected in time with incoming transports. Incoming transports must have arrived before the outgoing can departure. This is true for each terminal. This could be controlled with a timetable so that the arrival and departure times are synchronized. The capacity of the vehicles could also be coordinated to get a smooth flow of goods (Lumsden, 2007).

Tarkowski et al. (1995), means that a terminal in a transportation system mainly has three functions:

- Create conditions to maximize the utilization of the transport system. This is conducted with transhipment and sorting in the terminal
- Create conditions to achieve the wanted customer service to senders and receivers within the traffic area
- Function as a node with refining possibilities of goods as repacking and labelling

3.2.4 Design of the Transportation System

According to Jonsson & Mattson (2011), the geographical area, which the terminal covers, affects the physical design of the transportation system; how it is divided into traffic areas, and how the terminals are organized and used in the system. The system is designed to facilitate a good transportation service, which are frequent and reliable transports with high utilization within the geographical area.

A national transportation system consists of both long and short distance transports. The long distance transports take place in-between traffic areas all over the transportation system, while short distance transports occur in each traffic area. Figure 3.4 illustrates the principles of a transportation system with traffic areas (Jonsson & Mattson, 2011).

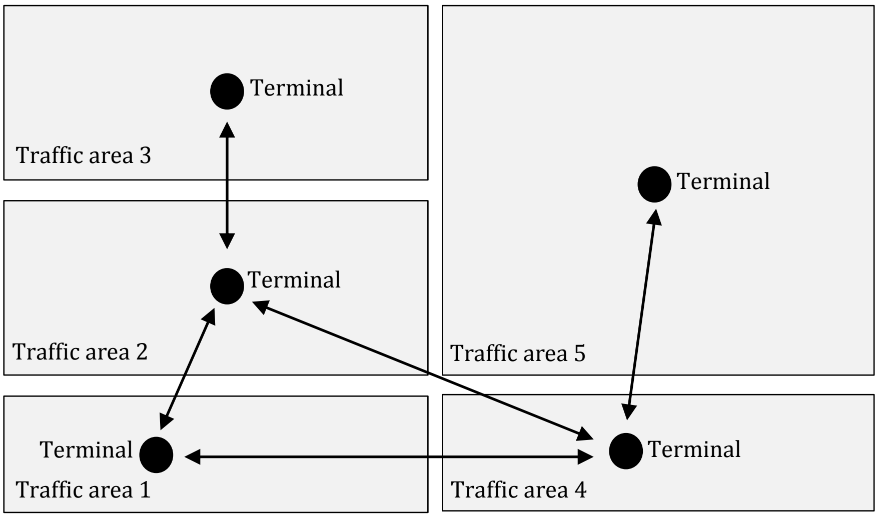

Figure 3.4: Linehaul traffic in different traffic areas (Jonsson & Mattson, 2011, p. 381)

Types of Transportation Systems

The movement of goods between nodes in a system can be illustrated with different network models. Figure 3.5 shows three different models where the circles are nodes and represents terminals and the lines represent the links between the terminals (Tarkowski et al. 1995).

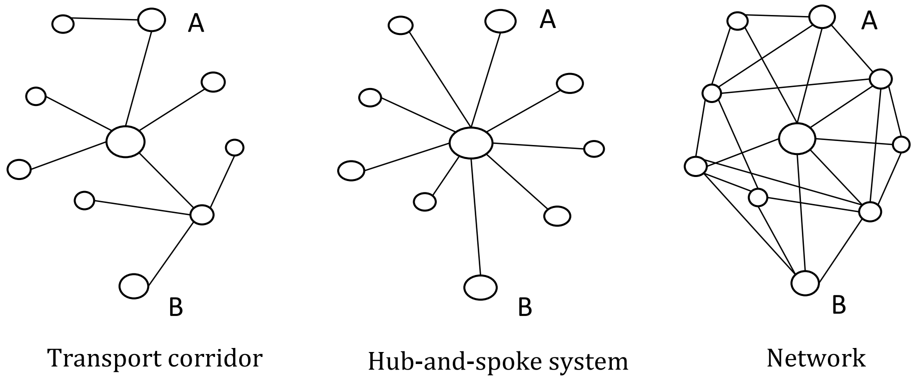

Figure 3.5: Types of transportation systems (Tarkowski et al. 1995, p. 204)

The *transport corridor* is defined as a link between two nodes that physically connects the two terminals in a transport system. A *hub-and-spoke system* has the structure of consolidation at the central hub. The links, called spokes, are directly connected to the hub so the goods can be consolidated at the hub and then directly be sent to the receiver via the spokes. In a *network*, the nodes are physically connected to each other with links. Some terminals are directly connected and others are indirectly connected to each other (Tarkowski et al. 1995).

Milk runs

Milk runs are transport routes through several customers to load and unload goods. The vehicle is filled through several stops on the route to later unload the goods at a terminal in a certain traffic area. Milk runs are illustrated in Figure 3.6. The purpose is to increase the transport frequency and consolidation to increase utilization (Jonsson & Mattsson, 2011).

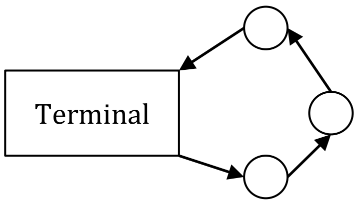

Figure 3.6: Illustration of a milk run (Jonsson & Mattsson, 2011, p. 385)

The routes for loading and unloading goods could either be separated in two routes or be coordinated to load and unload at the same time at the customers on the way (Jonsson & Mattsson, 2011).

Single-terminal System

In a single-terminal system, there is a central terminal responsible for sorting and consolidation of goods from local terminals located in each traffic area. The local terminals gather and distribute goods from each area by reloading goods from pick-up-and-delivery transports to linehaul transports. This gives a concentrated flow of goods and few relations in the network. The goods are handled three times, first at the local sender terminal, then at the central terminal and last at the local receiver terminal. The transportation costs are rather high due to the large distances between the terminals but the utilization of the vehicles is high. The single-terminal system is appropriate for a large area with small flows. The system provides a homogeneous transport service with high utilization through the entire system, which enables a high transport quality (Tarkowski et al. 1995).

Multi-terminal System

A common system within transports of general cargo is a network called multi-terminal system. The system consists of several terminals at the same terminal level, which is preferable in a system with a large number of small consignments. Each terminal has a specific area of gathering and distribution of goods which functions as a co-loading point. The terminal is responsible for sorting and transhipment and is a node in the system connected to all other terminals for transportation between the allocated areas. The transports between the terminals are often linehaul traffic on a regular basis (Tarkowski et al. 1995). The difference compared to the single-terminal system is that all terminals perform sorting and consolidation of goods. Direct transports are conducted at the distances where the volume is high enough to achieve a high utilization of the vehicles. Most of the goods are sent via two terminals but transportations via three or more terminals do also exist (Jonsson & Mattson, 2011).

The design of a specific area for each terminal originates from the former importance of local distribution and proximity to customers. This has resulted in a large number of terminals for many forwarding companies. It is not possible to create relations between all the terminals since the number of relations would be too large and the utilization of vehicles would be too low. Therefore, not all terminals have direct transports but transhipment via another terminal, as a result, the system consists of both direct and indirect transports (Tarkowski et al. 1995).

3.2.5 Planning of the Transportation System

Planning at Three Levels

Jonsson & Mattson (2011) says that the transportation of goods between supplier and customer, and in-between companies influences in different ways the efficiency of the logistics system. Naturally, transport activities result in costs. The choice of transportation mode impacts the frequency and quantity of the delivered goods. Accordingly, the tied-up capital and delivery service are affected. Transportation patterns also matters to which extent different flows of material needs to be coordinated between two parties, both in terms of delivery and production. Clearly, transports have an environmental impact as well. Therefore, the required resources to achieve these transport activities and patterns need to be planned. Transportation planning is performed at different levels. Strategic planning includes decisions regarding the design of the transportation network and how it should be served. For instance, which type of cargo that should be transported in the system and where terminals should be located. At the tactical and operational level focus is on planning full truckloads, consolidate shipments, linehaul between distribution areas, routes in the distribution areas, and follow up and track goods in delivery.

Planning of Transports between Terminals

When having a multi-terminal system, transports are performed between terminals and within the traffic area, which the terminal is responsible for. Hence, planning is needed for both transports between terminals and within each terminal’s traffic area (Jonsson & Mattson, 2011).

Jonsson & Mattson (2011) means that the transportation flows between the terminals are normally based on a timetable for the linehaul traffic. The average daily flow of goods forms the base of how the capacity and frequency of the transports are dimensioned between different traffic areas. When planning the linehaul traffic, restrictions in capacity need to be considered since the vehicle has a limited cargo carrying capacity. In addition, time restrictions caused by the actual transportation time must be accounted for. As consequence of these two restrictions, if the customers demand short delivery time, it can be difficult to achieve a high utilization of the cargo area on the vehicle.

Planning of the linehaul traffic includes deciding which incoming and outgoing long haul routes should exist, when goods should be delivered and shipped out, and what capacity is needed in terms of number and size of the trucks. As a result, this forms the basis of the timetable, which the linehaul traffic should follow (Jonsson & Mattson, 2011).

However, according to Jonsson & Mattson (2011), for linehaul traffic scheduled by a timetable to be efficient, the demand for transports is needed to be steady over time. If the demand is not steady in some aspect, one of the following methods can be used. The capacity of the linehaul traffic can be dimensioned according to the peaks in demand. Consequently, the degree of utilization will decrease during periods when demand is low. If there is seasonality in demand, one can create timetables for time periods with different demand. Though, if demand fluctuates in between weeks or even days it is not possible to adjust the capacity with different timetables. Instead, the linehaul traffic can be adjusted to the time periods with the lowest demand, which is defined as the basis of capacity. The peaks in demand are then handled by excess capacity, meaning trucks, which are not designated to a specific route. The principle when planning with normal and excess capacity is made clear in Figure 3.7.

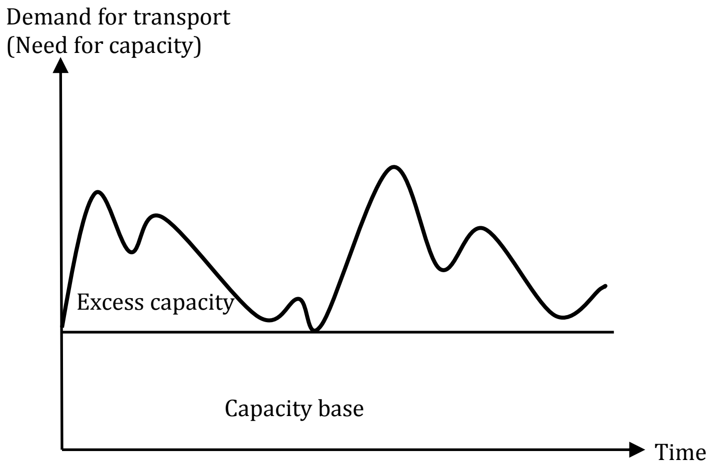

Figure 3.7: Transport planning with excess capacity (Jonsson & Mattson, 2011, p. 387)

At large short-term fluctuations in demand, a low capacity base is created together with a high excess capacity. However, small short-term fluctuations enable a higher capacity base and a lower excess capacity (Jonsson & Mattson, 2011).

3.3 Facility Localisation

3.3.1 Introduction

This subchapter presents four frameworks regarding facility localisation. It aims to give the authors different perspectives of the area in order to develop a model with factors affecting facility localisation summarised from the theory. Theory about the aspects of driving and rest periods is also presented. The factors affecting facility localisation from the frameworks are later summarised to be used as a part of the model construction. Finally, the Centre-of-Gravity method will be explained.

3.3.2 Site Selection by Waller (1999)

Waller (1999) describes that the change of facility location could either be on a new place or a facility modification at an existing place. The decision of changing the facility location is often based on operating costs of the new facility or the revenue generated through the change. The decision of a new site location is both strategic and operational. It is a long-term decision, which is made by top management and often includes large investments. Thus, it also affects the operational work at a company since the operations management will be responsible for the work at the facility. In addition, they often have detailed competence concerning labour, power consumption and the overall costs of running a site.

Factors Influencing Site Selection

There are numerous factors that need to be considered when changing the site location. The following factors; markets, staffing, local conditions, construction feasibility, financial factors, proximity of suppliers, availability of energy and raw materials are described below (Waller, 1999).

Markets: all firms and companies have the objective to sell their product or service. Therefore, the reliability and the *closeness to market* are of importance. The *market risks* also need to be considered. To evaluate the market, the growth of demand, competitors and barriers for entrants need to be reflected (Waller 1999).

Staffing: direct and indirect personnel running the facility, including management, means costs and other factors affecting the localisation of a facility. The most important factor is the direct *wages* of staff at the facility, which is essential when deciding the location. Social laws, controlling labour flexibility, are also a strong factor. The *availability of labour* is different in different regions and must be considered. Finding *competent staff* that is appropriate for the work tasks is something to consider as well as productivity among the workers, which is direct related to costs. Thus, the educational level and possibility of training in the area is important (Waller, 1999).

Local conditions: having good conditions for workers employed by the company, as well as for their families, is an important factor. The *climate* tends to affect the location of labour since people prefer to live in regions with good weather. It is easier to attract workers to facilities located in such areas and operating energy costs can also be reduced. Locating facilities in regions with different *cultures* compared to where the head office is situated can be costly for the company because of premium salaries to expatriates. It could also be difficult for expatriates to adapt to the new culture and there is a risk of a high turnover of employees. *Language* could also be a barrier for a company employing workers to a facility located in another country (Waller, 1999).

Infrastructure: several conditions regarding infrastructure have to be considered before a localisation decision. *Family services* in the region is one part of infrastructure that has to be taken into consideration; having medical services, schools and shops available for the staff working at the site. The *living costs* in the area can also have an impact on the ability to attract workers. Likewise, c*ommunication* is of importance; having the possibility of using telephone, computer networks and fax lines. Furthermore, potential strict *environmental regulations* concerning air, water and noise pollution could be costly for a company locating a facility. Potential laws need to be considered since they can vary significantly between countries. The *rental costs* of the facility are also something to consider, which can differ between large cities and adjacent towns (Waller, 1999).

What most people associate with infrastructure are the possibilities of *transportation*. The facilities and the transportation network are required conditions for freight forwarders. *Transportation costs* can be a significantly large part of the total cost of a product and the *closeness to customers* or other functions could also be essential. An unreliable transportation network can result in high inventory buffers and tied-up capital. Road bottlenecks can be a reason for changing the facility location (Waller, 1999).

Construction feasibility: when building a new site, there are considerations concerning construction that have to be made. The *cost of land*, including taxes, differs between regions and is often high where land is limited. The availability of construction labour as well as the need of land preparation before construction are factors that affect the possibility of building a new facility. Expansion possibilities are also important to investigate before deciding of location (Waller, 1999).

Financial factors: fluctuating *exchange rates* can be essential when locating a site. The stability of a currency is important and reduces the financial risks and can affect the revenue of a company. An indicator of country stability is a strong currency, which could be the difference between profit and loss for a company. *Taxes* for companies are also something to consider because there are large variations between countries. *Financial aid* from governments can be vital when locating a facility. Tax incentives or direct cash grants are examples of financial aid when building a facility (Waller, 1999).

Proximity of resources: when making decisions about building a new facility, the closeness to raw materials and suppliers need to be considered. Naturally, these factors are more important to some businesses, which refine resources, but the impact is still important to evaluate. To increase the reliability of *suppliers* in the supply chain, they can advantageously be located close to the operating facility. This reduces risks of interruptions in the supply chain and transportation costs (Waller, 1999).

Quantitative Approaches to Site Selection

Waller suggests three different approaches of mathematical type that can be used as a basis for site selection when having the possibility of using quantitative parameters.

Weighting the selection criteria applies weights to factors where the factor with the highest value is recommended to be the best location. The procedure starts with weighting of the factors, F, where the most important factor gets the highest weight. Then, evaluating each possible location by giving them a numerical score, S, for each factor. Next, multiplying F with S for each location and each criterion and then summarizing these terms. The obtained value is an indicator of how suitable each location is for the site selection. The higher the value is for a location the more suitable it is. In Table 3.1, an example is presented where five possible locations are evaluated and scored to illustrate the method. Each criterion is also weighted with a factor based on importance for site location (Waller, 1999).

Table 3.1: Example of weighting the selection criteria-method (Waller, 1999, p. 69)

Site criteria	Weighting factor	1. Bari	2. Lille	3. Munich	4. Valence	5. Watford
Productivity	2.75	25	65	90	60	75
Construction cost	1.35	60	50	30	70	40
Labour cost	2.50	70	30	25	35	50
Proximity to clients	1.25	40	75	85	60	55
Proximity to suppliers	1.15	30	65	65	35	45
Weather/ quality of living	1.00	85	25	25	90	35
Total	10.00	494.25	514.75	545.00	**552.25**	540.75

According to this example, one can conclude that Valence gets the highest score of 552.25 and is therefore the best location.

Centre of gravity-method is a common method used to decide the best location of a facility. The best location is the position that is nearest all secondary distribution centres (Waller, 1999). A more detailed description can be read in section 3.3.8.

3.3.3 Logistics Network Design by Langley et al. (2008)

Facility location needs to be considered a variable in the long-term perspective. A location decision does affect costs for logistics as well as for manufacturing, marketing and finance. However, the current conditions as well as being flexible to future changes must be considered. Since the environment and the market change, all networks need to be re-evaluated after a number of years. This could imply reduction of costs or improvement of service. Since the process of redesigning the network is complex, six steps are identified to follow. These are illustrated in Figure 3.8.

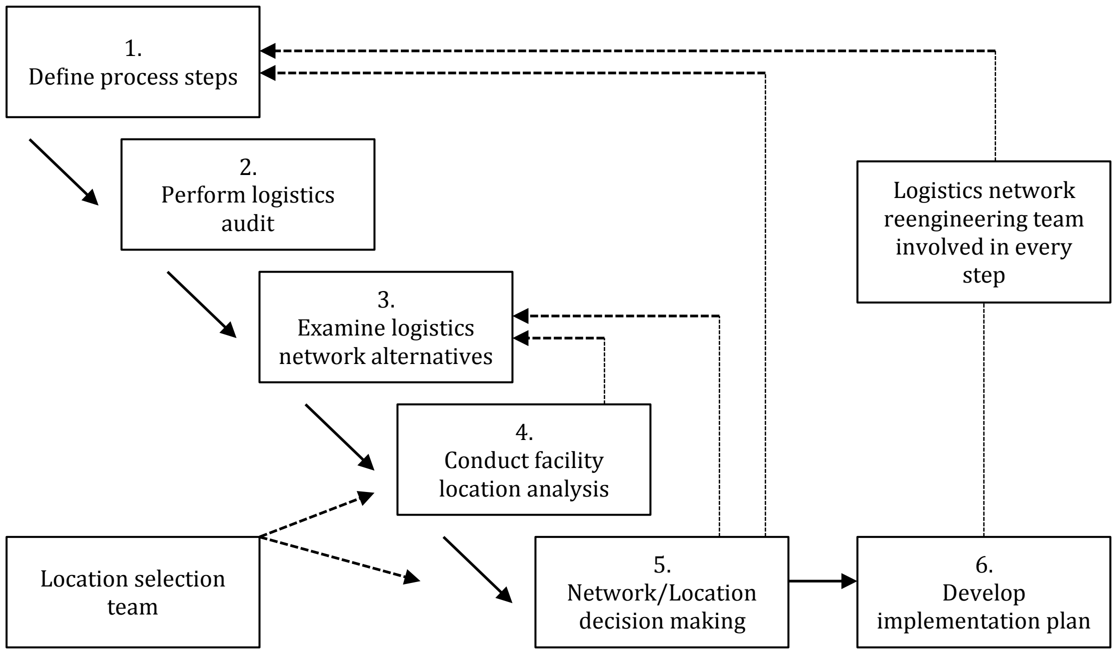

Figure 3.8: Key steps in the logistics network design process (Langley et al. 2008, p. 473)

Step 1: Design the Logistics Network Design Process

The first step is to identify the business strategies and the needs of the supply chain to ensure a profitable redesign. Objectives of the logistics network design also need to be established. By having communicated expectations, the efficiency of the process increases and it is easier to identify the needed resources.

Step 2: Perform a Logistics Audit

The audit is a step in the process when to gather information about the logistics activities. This enables the members of the redesigning process to collect information facilitating the further process. Steps in the audit are illustrated in Figure 3.9.

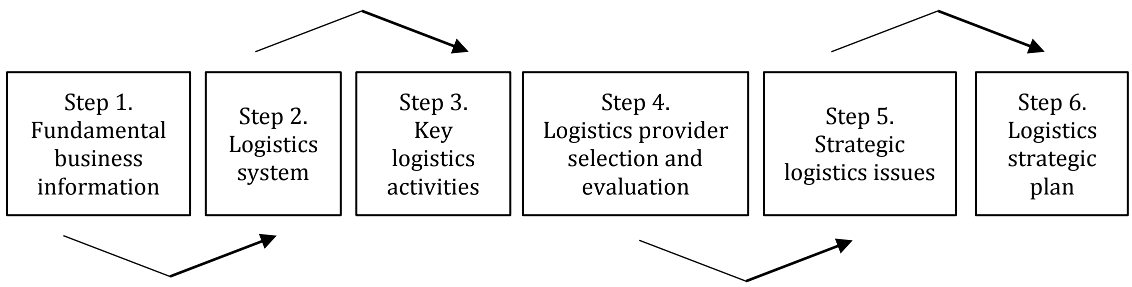

Figure 3.9: Key steps in logistics audit (Langley et al. 2008, p. 474)

The information gathered in the different steps could result in:

- Customer requirements and environmental aspects
- Logistics objectives
- Supply chain profile and position in the supply chain
- Key performance indicators and benchmark
- Improvement areas

Step 3: Examine the Logistics Network Alternatives

Step 3 includes an analysis of the alternatives in the current logistics network. This could be performed by applying different mathematical models evaluating the current network as well as alternatives. These models can measure costs and service to find substitutes to the current design. The quantitative models can be optimization, simulation or heuristic. Optimization is a method for finding the optimal solution, simulation strives for modelling the real network and heuristics solves broad problem definitions but does not necessarily find the optimal solution. A common heuristic is the centre-of-gravity method that minimizes the transportation cost by finding a centre position for the facility according to other resources. The chosen model should identify an alternative to the current network according to the strategies found in the audit. The result of this step is recommendations of locations that fulfil the objectives.

Step 4: Conduct a Facility Location Analysis

After finding a number of alternative locations, they have to be analysed according to different attributes. The aspects should be identified as well as how the alternatives fulfil the aspects. Both quantitative and qualitative aspects will be included, even though some of the quantitative attributes were included in step 3.

Step 5: Make Decisions Regarding Network and Facility Location

The alternatives should then be evaluated according to the strategies identified in step 1. This confirms the choice of locations and their appropriateness.

Step 6: Develop an Implementation Plan

After deciding the redesign it is critical to develop an implementation plan. The plan should function as a road map for the progress of changing the current network to the new design.

Major Locational Determinants

The attributes identified in step 4 can be categorized in regional determinants and site-specific determinants. The importance of the determinants differs depending on industry and among individual companies within an industry. The site-specific determinants are transportation access, availability of workforce, land costs, taxes and utilities. The regional determinants are explained below.

Labour Climate: The labour climate is of importance when locating a facility. *Labour availability*, *labour cost*, *skill level*, work ethic, productivity and enthusiasm have to be considered. The rate of unemployment affects the wages and the attractiveness of the area. To evaluate these parameters, the region has to be visited by the company considering locating a facility there.

Availability of Transportation: Having high quality of transportation is of importance for facility location. This includes *highway access*, *railway services*, airport and ocean port facilities.

Proximity to Markets and Customers: The *closeness to market* is to be considered to have as short lead-time as possible. However, with an increasing complexity of the network, the transportation costs increases.

Quality of Life: The quality of life for the employees affects the productivity but it is difficult to quantify. This is a factor important for companies having a mobile workforce, as in high-tech business. The attribute includes *climate*, *living costs*, *possibilities of education, health care and transportation.*

Taxes and Industrial Development Incentives: Different types of taxes will affect the business and the attractiveness of the region. *Tax incentives* exist in some areas to attract companies to locate there. This could have an impact of the total costs of localisation in the area.

Supplier networks: The *closeness to resources* reduces the transportation costs and increases the availability of resources. This is of significance when deciding of facility location.

Land Costs and Utilities: Depending on the type of facility, *availability and costs of land* are of importance. Availability of utilities during and after construction does also need to be considered.

Company Preference: A company or a top manager could prefer a specific area or location, which matters in a location decision. This is defined as an agglomeration and refers to companies locating all their facilities in the same area.

3.3.4 Facilities Location Decisions by Soltani (2009)

Soltani (2009) argues that decisions concerning facility locations are important due to the large investments and the difficulty to redo such a decision. The location of the facility, the size, what goods and services that should be produced and what markets that should be served, are parts of the decision. For profit-oriented companies, the objective of the facility location is to generate more profit and for non-profit-oriented companies, the objective could be to balance the costs and the level of service. It is therefore needed to identify the factors affecting this decision depending on the organization. The aim in the end is to choose the alternative with the best net gains for the organization (Soltani, 2009).

According to Soltani (2009), there are three issues that need to be balanced in order to achieve the above-mentioned objective. First, the variable operating costs or the costs connected to the change of the location, second, the provided service to the customers, and third, the potential revenue of the firm. The last two factors are more related to profit-oriented organizations since a better service generate growth in demand and increase the total revenue. For non-profit-oriented organizations, the revenue issue is not as important (Soltani, 2009).

There are a number of factors that influence a decision regarding facility location, such as labour, financial risks, location costs, culture of government toward location decisions and proximity to markets, suppliers and competitors. The considerations regarding labour are usually *wages* and *availability of workers*. Productivity, *culture* and attitudes among employees are also influencing factors. When deciding of location, *currencies and exchange rates* are also to be considered. Calculations of tangible and intangible *location costs* are as important. The *closeness to markets*, *suppliers* and raw material are important for many firms. This could reduce the transportation costs. The *location near competitors can* sometimes be preferable when a major resource is located in the area. Clustering can also be advantageous concerning customers (Soltani, 2009).

To find the optimal location for the facility, cost benefits and availability are often considered first. Methods to use for choosing the best alternative, according to Soltani (2009), are weighted-factor method, centre of gravity method, location break-even analysis and transportation model. In the weighted-factor method, criteria, also called success factors, are chosen to evaluate the optimal location. Location break-even analysis compares cost and volume in an analysis of alternatives. A common mathematical technique is the Centre-of-Gravity method that minimizes the distribution costs to find the location (Soltani, 2009).

3.3.5 A Framework for Network Design Decisions by Chopra & Meindl (2010)

The Role of Network Design in the Supply Chain

Facility location decisions have a long-term impact on a supply chain's performance because it is very expensive to shut down or move a facility. A good location decision can help a supply chain to be responsive while keeping its costs low. A poorly located facility makes it very difficult for a supply chain to perform close to the efficient frontier. Capacity allocation decisions can also have a significant impact on supply chain performance. Allocating too much capacity to a location can result in poor utilization and thus higher costs. Allocating too little capacity can result in poor responsiveness if demand is not satisfied or high cost if demand is filled from a distant facility. A company has to focus on network design decisions as its demand grows and as its current configuration becomes too expensive or provides poor responsiveness (Chopra & Meindl, 2010).

Factors Influencing Network Design Decisions

Strategic, technological, macroeconomic, infrastructure, competitive and operational factors influence network design decisions in supply chains (Chopra & Meindl, 2010).

Strategic factors: firms focusing on *cost leadership* tend to find the lowest cost location even though it is far from the markets they serve. Firms focusing on responsiveness tend to locate facilities closer to the market and may select a high-cost location if it is needed (Chopra & Meindl, 2010).

Technological factors: if production technology displays significant *economies of scale* it is more effective to have a few high-capacity locations. On the other hand, if facilities have low fixed costs, it is preferred to have many facilities because this helps to lower transportation costs (Chopra & Meindl, 2010).

Macroeconomic factors: include taxes, tariffs, exchange rates and other economic factors that are not internal to an individual firm. As global trade has increased, macroeconomic factors have had a significant influence on the success or failure of supply chain networks (Chopra & Meindl, 2010).

Political factors: the *political stability* of the considered country plays a significant role in location choice. Politically stable countries are preferred when companies locate facilities because the rules of commerce and ownership there are often well defined (Chopra & Meindl, 2010).

Infrastructure factors: the availability of good infrastructure is an important prerequisite to locating a facility in a given area. Key elements to consider when designing a network include availability of sites, *labour availability*, *rail services, highway access, congestion*, and *local utilities* (Chopra & Meindl, 2010).

Competitive factors: competitor's strategy, size and location must be considered. It has to be decided whether to *locate close or far from competitors*. How the firms compete and whether external factors such as raw material or labour availability force them to locate close or far away influence this decision. A cluster where all located companies benefits from the location is called positive externalities. This leads to competitors locating near each other because of advantages in for example increased demand. Having several companies positioned in the same area makes it more convenient for the customer. Another example is development of infrastructure in developing countries because of cluster of companies demanding appropriate infrastructure. When no positive externalities exist, competitors locate far from each other to be able to capture as large market share as possible. Price competition decreases with this kind of location and profits can be maximized (Chopra & Meindl, 2010).

Customer response time and local presence: firms that target *customers* who value a short response time must locate close to them. Accordingly, more facilities are needed to satisfy the customers demand for a short response time. If a firm is delivering its product to customers, the use of a rapid means of transportation allows the firm to build fewer facilities and still provide a short response time. However, this option increases transportation costs (Chopra & Meindl, 2010).

Logistics and facility costs: these costs occur within a supply chain as the number of facilities, their location, and capacity allocation are changed. Companies must consider inventory, *transportation*, and *facility costs* when designing their supply chain networks. Inventory and facility costs increase as the number of facilities increase, while transportation costs decrease. The total logistics costs are a sum of the inventory, transportation, and facility costs. The facilities in a supply chain network should at least equal the number that minimizes total logistics cost. A company may increase the number of facilities beyond this point to improve response time to its customers. This decision is justified if the increased revenue from improved response outweighs the increased cost from additional facilities (Chopra & Meindl, 2010).

A Framework for Network Design Decisions

The goal when designing a supply chain network is to maximize the firm's profits while satisfying customer needs in terms of demand and responsiveness. To design an effective network a manager must consider the factors described above. Global network design decisions are made in four phases as shown in Figure 3.10 (Chopra & Meindl, 2010).

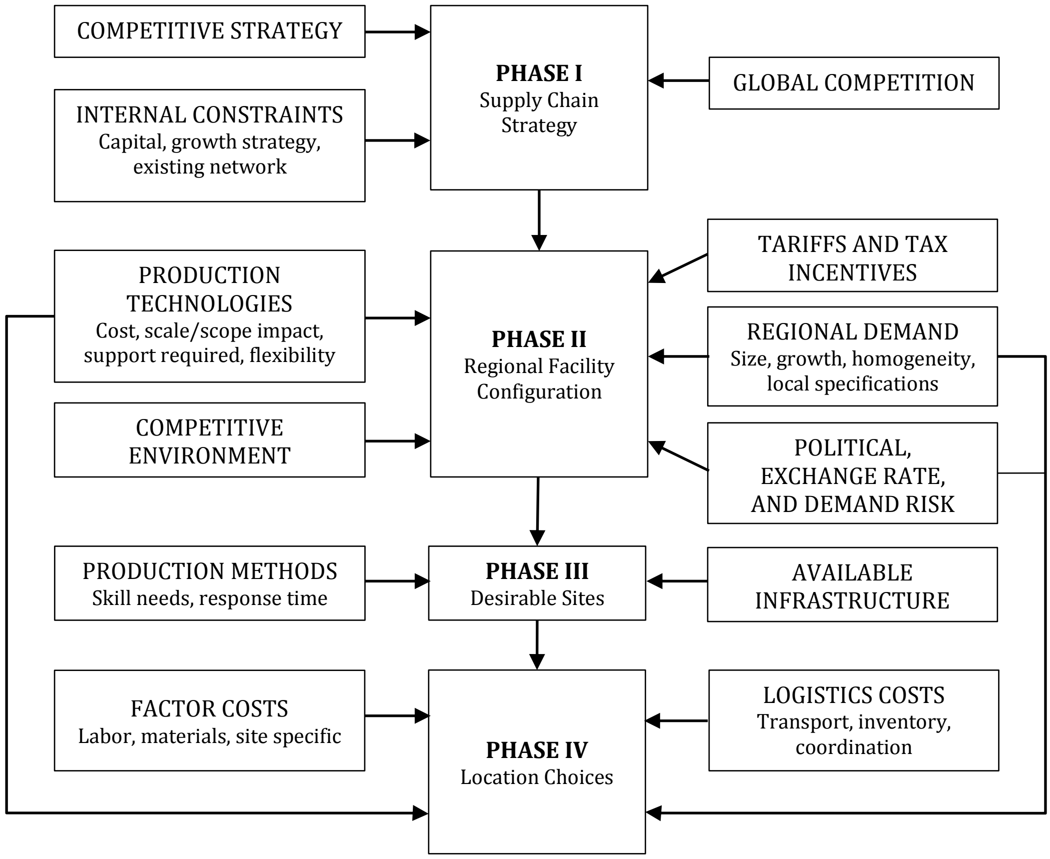

Figure 3.10: A framework for network design decisions (Chopra & Meindl, 2010, p. 132)

Phase I: Define a supply chain strategy/design: The objective of the first phase is to define a firm's broad supply chain design. The stages in the supply chain are determined, and whether each supply chain function will be performed in-house or outsourced. Based on the competitive strategy of the firm, its resulting supply chain strategy, an analysis of the competition, any economics of scale or scope and any constraints, managers must determine the supply chain design for the firm (Chopra & Meindl, 2010).

Phase II: Define the regional facility configuration: The objective of the second phase is to identify regions where facilities will be located, their potential roles, and their approximate capacity. Based on forecast of regional demand, the impact of economics of scale or scope, macroeconomic factors, competitive environment and logistics costs, managers can identify the regional facility configuration for the supply chain network. As a tool, network design models discussed in the next section, can be used. The regional configuration defines the approximate number of facilities in the network, in which regions facilities will be set up, and whether a facility will produce all products for a given market or a few products for all markets in the network (Chopra & Meindl, 2010).

Phase III: Select a set of desirable potential sites: The objective of the third phase is to select a set of desirable potential sites within each region where facilities are to be located. Sites should be selected based on an analysis of infrastructure availability to support the desired production methodologies (Chopra & Meindl, 2010).

Phase IV: Location choices: The objective of the fourth phase is to select a precise location and capacity allocation for each facility. Attention is restricted to the desirable potential sites in Phase III. The network is designed to maximize total profits taking into account the expected margin and demand in each market, various logistics and facility costs, and taxes and tariffs at each location (Chopra & Meindl, 2010).

Models for Facility Location and Capacity Allocation

The goal is to maximize profit while providing customers with the appropriate responsiveness. The following information must be available before the design decision can be made (Chopra & Meindl, 2010):

- Location of supply sources and markets
- Location of potential facility sites
- Demand forecast by market
- Facility, labour and material costs by site
- Transportation costs between each pair of sites
- Inventory costs by site as well as a function quantity
- Sales price of product in different regions
- Taxes and tariffs as product is moved between locations
- Desired response time and other service factors

Given this information, either gravity models or network optimization models may be used to design the network. The models are organized according to the phase of the network design framework at which each model is likely to be useful (Chopra & Meindl, 2010).

Making Network Design Decisions in Practice

When managers make decisions regarding network design for a supply chain the following issues should be kept in mind (Chopra & Meindl, 2010).

Do not underestimate the life span of facilities. Think about long-term consequences. Managers must not only consider future demand and costs but also scenarios where technology may change (Chopra & Meindl, 2010).

Do not gloss over the cultural implications. Network design decisions regarding facility location have a significant impact on the culture of each facility and the firm. The culture of a facility will be influenced by the culture of another close facility. The communication will be different depending on having facilities close or far from each other (Chopra & Meindl, 2010).

Do not ignore quality-of-life issues. The quality of life at selected facility locations has a significant impact on performance because it influences the workforce available and its morale. In many cases, it may be better for a company to select a higher-cost location if it provides a much better quality of life. Failure to do so can lead to staff refusing to relocate to the new area (Chopra & Meindl, 2010).

Focus on tariffs and tax incentives when locating facilities. This should be considered for companies, which are considering international locations (Chopra & Meindl, 2010).

3.3.6 Driving and Rest Periods

There are rules for driving and rest periods in the European Union for vehicles heavier than 3.5 tonne to ensure road safety, to give drivers a feasible work environment and to ensure a proper competition between actors in the transportation industry. The driving period includes driving time reported in the tachygraphy. The driving period allows a maximum period of time of 9 hours. Though, it is allowed to drive 10 hours twice a week (Transportstyrelsen, 2011).

After a consecutive driving period of 4.5 hours, a break of 45 minutes is necessary. The break can also be divided in two parts with the first part of at least 15 minutes and the last part of at least 30 minutes. During the break, the driver is not allowed to drive or do any kind of work (Transportstyrelsen, 2011).

There are also restrictions concerning the daily rest. The daily rest has to consist of at least 11 consecutive hours or alternatively 12 hours divided in two periods with the first period of at least 3 hours and the last period of at least 9 hours at the end of the shift. During two weeks, it is allowed to have maximum thee reduced daily rests consisting of at least 9 hours each (Transportstyrelsen, 2011).

3.3.7 Compilation of Factors Affecting Facility Localisation

The factors, which affect facility localisation, have been compiled in Table 3.2 into different categories in order to get a better overview of what the frameworks have discussed. These factors are either described in at least one of the presented frameworks or described in section 3.3.6. The pattern of occurrence can also be seen in the table.

Table 3.2: Factors affecting facility localisation

	No.	Factor	Waller (1999)	Langley et al. (2008)	Soltani (2009)	Chopra & Meindl (2010)	Other
Infrastructure	1	Highway access		X		X	
	2	Railway access		X		X	
	3	Congestion				X	
	4	Living costs & family conditions	X	X			
	5	Communication	X				
	6	Utilities		X		X	
Macro-economy	7	Taxes, tariffs, exchange rates	X	X	X	X	
	8	Financial aid	X				
Costs	9	Location costs	X	X	X	X	
	10	Transportation costs	X		X	X	
	11	Wages	X	X	X		
Labour	12	Labour availability	X	X	X	X	
	13	Competent staff	X	X			
Environment	14	Political stability				X	
	15	Regional culture	X		X		
	16	Environmental regulations	X				
	17	Climate	X				
	18	Language	X				
	19	Construction feasibility	X	X			
Market	20	Closeness to competitors			X	X	
	21	Closeness to customers	X	X	X	X	
	22	Resource proximity	X	X			
	23	Market risks	X				
Strategy	24	Cost leadership				X	
	25	Economies of scale/scope				X	
Other	26	Driving and rest periods					X

Table 3.2 shows that the frameworks are complementing each other. A complete theoretical model in this thesis is therefore a mix of factors from all four frameworks. The factors' appropriateness for the specific problem situation at Company X is discussed in section 5.1.

3.3.8 The Centre-of-Gravity Model

There are several elements to consider when locating a terminal. There are qualitative parameters that are beyond the control of a company and it is therefore appropriate to also make a quantitative judgement about the location. If there are several qualititative parameters to consider, a quantitative method does not deliver the true answer. Though, it could be a guideline, according to Lumsden (2007).

When transporting different volumes in the network, different vehicles are often used for different lines in order to maximize the utilization and to lower the costs. The Centre-of-Gravity method minimizes the total transportation cost to find the optimal location for a facility. Several suppliers, one central facility and several customers are assumed in the network. A plane is considered and all suppliers and customers are located as grid points on the plane. The model is illustrated in Figure 3.11 where the squares represent suppliers, the circles represent customers and the triangle is the central facility to locate (Lumsden, 2007).

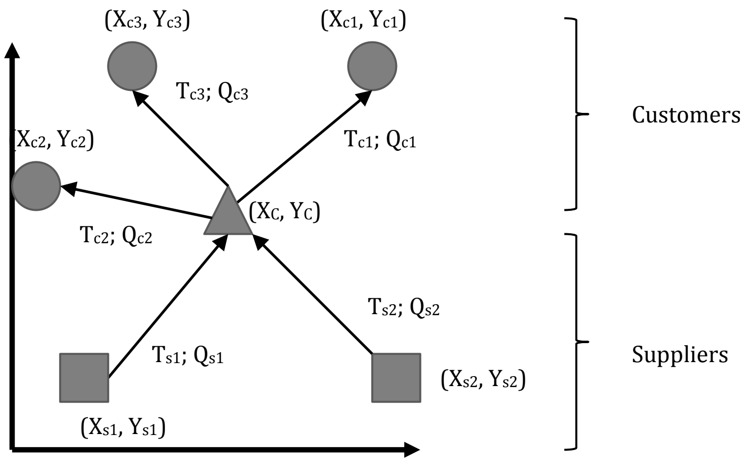

Figure 3.11: The centre-of-gravity model. Based on (Lumsden, 2007, p. 485)

The following are defined in the model:

- X_C and Y_C are the coordinates for the centre position.
- X_{sj} and Y_{sj} are the coordinates for each supplier site at the grid.
- X_{ci} and Y_{ci} are the coordinates for each customer site at the grid.
- Q_j is the delivered quantity from the supplier site *j* to the central facility.
- Q_i is the delivered quantity from the central facility to the customer site *i*.
- T_j is the price per volume km from the supplier site *j* to the central facility.
- T_i is the price per volume km from the central facility to the customer site *i*.

The coordinates for the centre location is calculated by:

$X_C = \frac{\sum X_{sj} Q_j T_j + \sum X_{ci} Q_i T_i}{\sum Q_j T_j + \sum Q_i T_i}$ and $Y_C = \frac{\sum Y_{sj} Q_j T_j + \sum Y_{ci} Q_i T_i}{\sum Q_j T_j + \sum Q_i T_i}$ (Lumsden, 2007)

To calculate the total transportation cost for the central facility location, the road distance between the coordinates d_i, the transportation cost per unit and unit distance from each terminal T_i and the quantity shipped Q_i need to be defined for n facilities in the network. The total transportation cost is $TC = \sum_{i=1}^{n} d_i T_i Q_i$ (Chopra & Meindl, 2010).

3.4 Decision-making

3.4.1 Introduction

This subchapter aims to present the Analytical Hierarchy Process that is a method for quantifying the importance of qualitative factors when making a decision. The method will be used for weighting parameters importance when making a hub localisation decision as well as for the analysis when evaluating how well the alternative hub locations fulfil the parameters.

3.4.2 The Analytic Hierarchy Process

The Analytic Hierarchy Process (AHP) was developed by Thomas Saaty in 1980. It is a multi-criteria decision making approach in which factors are arranged in a hierarchic structure. When making a decision, a difficult task is to choose the factors that are important for that decision. In the Analytic Hierarchy Process these factors, once selected, are arranged in a hierarchic structure descending from an overall goal to criteria, sub-criteria and alternatives in successive levels (Saaty 1990).

Arranging the goals, attributes, issues, and stakeholders in a hierarchy serves two purposes. It provides an overall view of the complex relationships underlying the situation; and helps the decision maker assess whether the issues in each level are of the same order of magnitude, so these homogenous elements can be compared accurately (Saaty 1990).

The Process

The procedure for using the AHP can be summarized as (Saaty, 1999):

1. Model the problem as a hierarchy, which contains the decision goal, the alternatives for reaching it, and the criteria for evaluating the alternatives.
2. Establish priorities among the elements of the hierarchy by making a series of judgments based on pairwise comparisons of the elements. For instance, when comparing potential real estate purchases, the investors might say they prefer location to price and price over timing.
3. Synthesize these judgments to yield a set of overall priorities for the hierarchy. This would combine the investors' judgments about location, price and timing for properties A, B and C into overall priorities for each property.
4. Come to a final decision based on the results of this process.

Pairwise Comparisons

The pairwise comparisons in step 2 can be conducted by asking a group of a minimum number of judgements. The judgements need to connect in a way so all elements of one level in the hierarchy are compared, directly or indirectly. For example, if A = 7B and A = 5C, this implies that 7B = 5C or B = 7/5C. This can be conducted with a spanning tree, illustrated in Figure 3.12. If nine elements are to be compared, the minimum number of judgements is eight (Saaty, 1999).

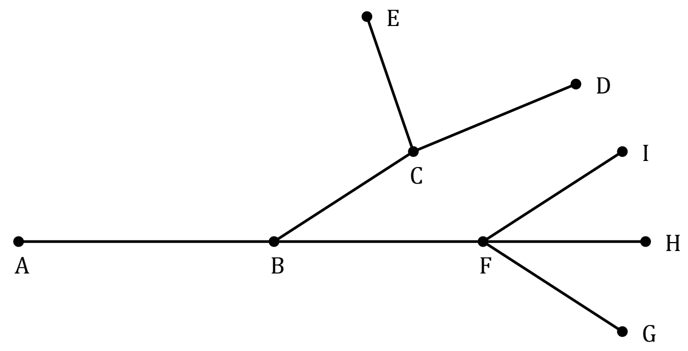

Figure 3.12: Example of spanning tree (Saaty, 1999, p. 269)

If putting these comparisons in a matrix, the matrix will automatically be consistent since it is derived from a minimal number of judgements (Saaty, 1999). If not assuming consistency, all elements need to be compared with each other. This implies $\frac{n(n-1)}{2}$ comparisons for n parameters. Next, an example of AHP can be used is explained below.

A Worked Example

A firm wishes to buy one new piece of equipment of a certain type and has four aspects in mind, which will govern its purchasing choice: expense, operability, reliability, and flexibility. Competing manufacturers of that equipment have offered one option each: X, Y and Z. The firm's engineers have looked at these options and decided that X is cheap and easy to operate but is not very reliable and could not easily be adapted to other uses. Y is somewhat more expensive, reasonably easy to operate, very reliable but not very adaptable. Finally, Z is very expensive, not easy to operate, a little less reliable than Y but is claimed by the manufacturer to have a wide range of alternative uses. Each of X, Y and Z will satisfy the firm's requirements to differing extents so which, overall, best meets this firm's needs (Coyle 2003)?

The first step of the process is to determine the AHP hierarchy for the decision, this is shown in Figure 3.13 below.

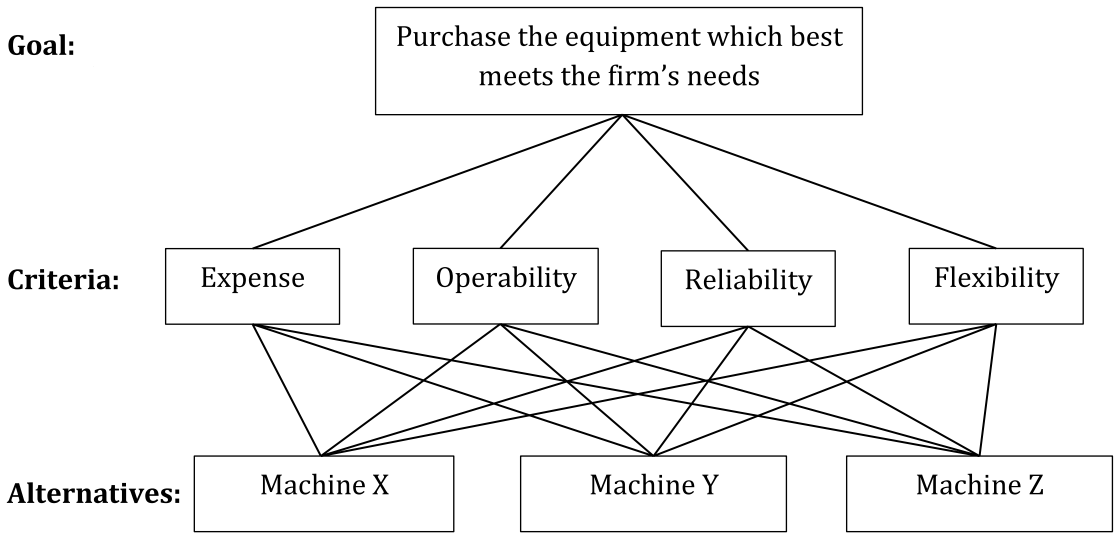

Figure 3.13: The AHP hierarchy in three layers

As the decision makers continue with the AHP, they will determine priorities for the machines with respect to each of the decision criteria, and priorities for each of the criteria with respect to their importance in reaching the goal. The priorities will then be combined throughout the hierarchy to give an overall priority for each machine. The machine with the highest priority will be the most suitable alternative, and the ratios of the machines' priorities will indicate their relative strengths with respect to the goal.

The second step is establishing the priorities of elements in order to make pairwise comparisons, meaning to compare the elements in pairs against a given criterion. To perform these comparisons it is preferred to use a matrix. In order to fill in the matrix, numbers are used to represent the relative importance of one element over another with respect to the property. Table 3.3 contains the Fundamental Scale of the AHP for pairwise comparisons (Saaty 1999).

Table 3.3: The fundamental scale. Based on (Saaty, 1990, p. 15)

Intensity of importance	Definition	Explanation
1	Equal importance	Two activities contribute equally to the objective
3	Moderate importance of one over another	Experience and judgment favour one activity over another
5	Essential or strong importance	Experience and judgment strongly favour one activity over another
7	Very strong importance	An activity is strongly favoured and its dominance demonstrated in practice
9	Extreme importance	The evidence favouring one activity over another is of the highest possible order of affirmation
2, 4, 6, 8	Intermediate values	When compromise is needed

An assumption is that if attribute A is extremely more important than attribute B and is rated at 9, then B must be absolutely less important than A and is valued at 1/9. These pairwise comparisons are carried out for all factors to be considered and the matrix is completed, see Table 3.4. This is called the Overall Preference Matrix (Coyle 2003).

Table 3.4: The Overall Preference Matrix

	Expense	Operability	Reliability	Flexibility
Expense	1	1/3	5	1
Operability	3	1	5	1
Reliability	1/5	1/5	1	1/5
Flexibility	1	1	5	1

Next, the eigenvector, which is called the Relative Value Vector (RVV), is calculated, see Table 3.5 (Coyle 2003).

Table 3.5: RVV for expense, operability, reliability and flexibility

	RVV
Expense	0.232
Operability	0.402
Reliability	0.061
Flexibility	0.305

These numbers correspond, in turn, to the relative values of expense, operability, reliability and flexibility, see Table 3.5. As operability has the highest value of 0.402 this factor is valued the most by the firm and reliability is least valued.

For the procedure of creating the Overall Preference Matrix and the calculations for the Relative Value Vector see Appendix E.

The third step is to synthesize these judgments to yield a set of overall priorities for the hierarchy, these are put together in Table 3.6, the Option Performance Matrix (OPM). The calculations can be observed in Appendix E (Coyle 2005).

Table 3.6: The Option Performance Matrix

	Expense	Operability	Reliability	Flexibility
Machine X	0.751	0.480	0.077	0.066
Machine Y	0.178	0.406	0.231	0.615
Machine Z	0.071	0.114	0.692	0.319

The Option Performance Matrix summarizes the respective capability of the three machines in terms of what the firm wants. It can be concluded that machine X is far better than Y and Z in terms of expense; a little better than Y with respect to operability; however, X is of limited value in terms of reliability and flexibility. These values are not, nevertheless, absolutes, they relate only to the set of criteria chosen by the firm (Coyle 2003).

The final step is to take into account the firm's judgments as to the relative importance of expense, operability, reliability and flexibility. This is the Relative Value Vector, which was calculated earlier. By post-multiplying the OPM with the RVV a vector for the respective abilities of these machines to meet the firm's needs is obtained. The resulting vector might be called Value For Money (VFM), or in words, performance*requirement = value for money (Coyle 2003).

$$VFM = OPM * RVV = \begin{bmatrix} 0.392 \\ 0.406 \\ 0.204 \end{bmatrix}$$

The first row represents machine X, the second row machine Y and the third row machine Z. The VFM is the final result of the AHP but what does it mean? First, it can be concluded that machine Y meets the firm's needs the best with a score at 0.406, slightly better than machine X at 0.392. Machine Z is well behind at 0.204 and would do rather badly at satisfying the firm's requirements in this case. Secondly, since machine X and Y have a very close score it might be sensible to choose machine X since this option have a higher priority in terms of expense, meaning it puts the least pressure on the cash flow. Thirdly, the vector of relative values of machine X, Y and Z follows insistently from judgments made by the firm as to its requirements and by their engineers as to the capabilities of the different machines. There is a strong audit trail from output back to input. Of course, anyone who understands the AHP procedure might be able to fiddle the judgments so as to guarantee a preferred outcome, but that is unavoidable (Coyle 2003).

3.5 The Framework for Model Construction and Analysis

How the frame of reference in the previous sections has influenced the model construction and analysis in this study is discussed here. In addition, it is clarified how the research questions are intended to be answered by the framework which is presented in Figure 3.14.

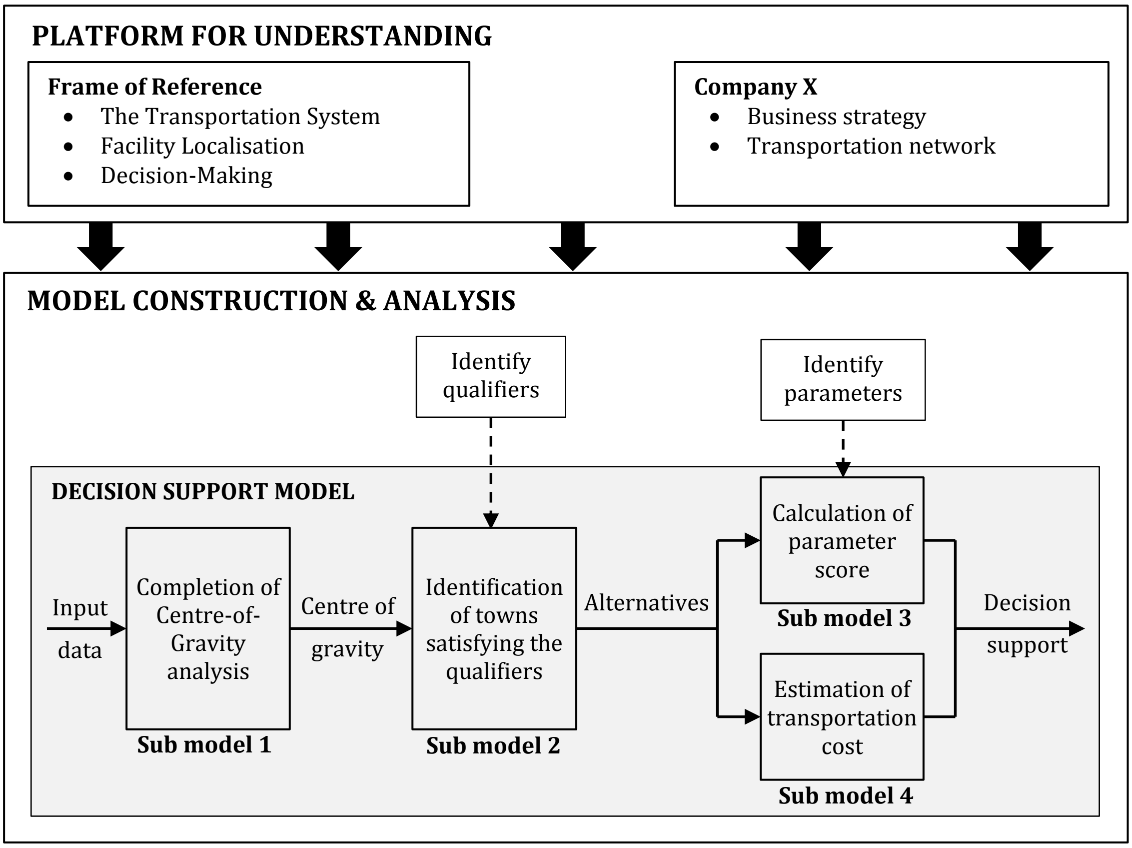

Figure 3.14: The framework for model construction and analysis

First, a platform for understanding is needed to for the authors to be able to construct a model and an analysis. The platform is based on the frame of reference and knowledge about Company X. The frame of reference chapter concerning transportation system gives an understanding of the basic terminology in the area. Moreover, the subject of facility localisation provides a deeper knowledge on the topic and gives inspiration for the model construction. In addition, the matter of decision-making enables an evidence-based approach on quantifying qualitative aspects. Furthermore, with understanding and knowledge of Company X's business strategy and transportation network the authors can construct a decision model which can correspond to Company X's need.

With the platform for understanding the authors were able to construct a decision model perform an analysis. The knowledge in transportation system enabled the authors to gain insight in a number of frameworks for facility localisation. The Centre-of-Gravity model was found to be a suitable method to use in the sub model 1 of the decision model for identifying an area in which a hub should be located. In addition, factors affecting facility localisation were put together from the frameworks to get an overview of what the literature suggests. With the managers' views at Company X a number of qualifiers could be recognised from these factors. These qualifiers became the basis of sub model 2 where a number of towns in the proximity of the centre point which satisfies the qualifiers are identified as alternatives for hub localisation. Moreover, a number of parameters were acknowledged from these factors and from the managers' opinions. Together with the knowledge in decision-making or rather the Analytic Hierarchy Process, sub model 3 was enabled to be constructed. Here, the alternatives obtain a parameter score based on how well each alternative fulfils each parameter compared to the other alternatives. Furthermore, sub model 4 was constructed as the supervisor at Company X had a desire to put a transportation cost on each alternative. With the data used in sub model 1, this was possible. As a result, the user acquires a decision support for which he or she can identify the best alternative according to the parameter score and transportation cost.

With the input data to sub model 1 and specific information regarding how well the alternatives fulfil the qualifiers and parameters an analysis of the optimal hub location for a number of lines can be performed with this decision model. Since the user defines how the qualifiers and parameters should be evaluated he or she also need to gather this information for the different alternatives.

4 Company X and its Transportation Network

This chapter aims to give an introduction to Company X as well as the empirical findings that have been made in this thesis. First, the company, its strategies and its products are described. Second, the transportation network and its processes are explained. The planning and the costs of the linehaul transports are clarified.

4.1 Company Description

4.1.1 An Introduction to Company X

Company X is the Swedish division of one of the largest freight forwarders in the European overland transportation business. Company X has had a turnover over the last few years of between 5 and 10 billion SEK. They employ approximately 2 500 people in Sweden. The organisation chart of the domestic function at Company X can be seen in Figure 4.1. This thesis has been written in cooperation with the Operations department, which have been marked in bold. A number of departments report to the Vice President of Domestic.

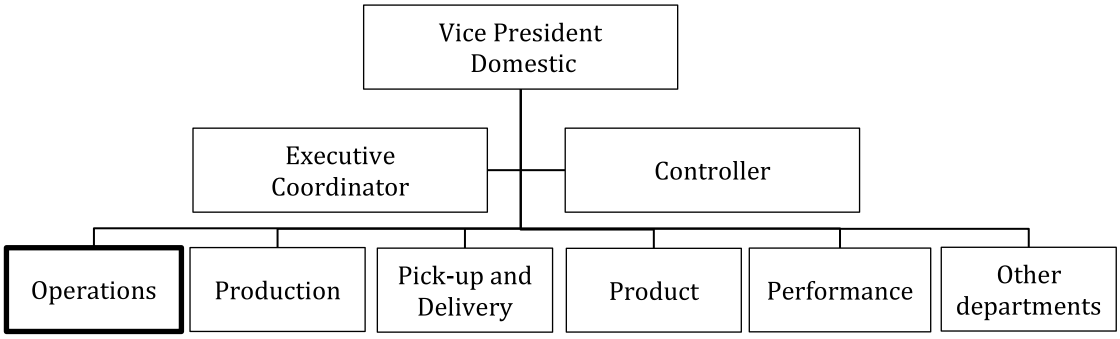

Figure 4.1: Organisation chart for the domestic function

The *Operations department*, handles the daily flow of goods at the terminals. Accordingly, the site managers for all the terminals and hubs are part of this department. The operations department have the overall responsibility of all the shipments, which are handled in the network. Next, the *Production department* is responsible for the traffic planning of the part loads in Sweden. Moreover, they are responsible for that the linehaul traffic between the terminals is planned according to the current timetable. Also, they plan these transports and buy excess capacity, meaning extra hauliers, when it is needed in the network. The *Pick-up and Delivery department* owns and negotiates the contracts between Company X and the hauliers responsible for the pick-up and delivery in the terminal's local area. In cooperation with the site managers at each terminal, targets are set for each haulier and the capacity need over the year is planned. The focus of the *Product department* is to ensure that the domestic operations are profitable. This is made by developing products and offering services, which meet the customers' demand. This is enabled by close cooperation with the Operations department and the Marketing & Sales support function. The *Performance department* makes sure that each department meets the predefined goals of the measured KPIs. The department creates visibility for the company's quality and process compliance. Also, they support the Operations department in the improvement work of delivering the best quality to the lowest cost to the customers. *Other departments* refer to functions within security, customer service and process development.

4.1.2 Business Strategy

The parent company of Company X aims to be the leading logistics provider worldwide with a large range of products. The strategy for the near future is to keep focus on quality and customer service. Projects concerning customer loyalty and improving profitability will be continued. Work between the departments will be encouraged to increase the integration and thereby provide better services.

4.1.3 Products

Company X offers their customers three kinds of products to business customers. These are parcels, general cargo and part loads. They differ in terms of maximum weight per shipment and how they are transported in the transportation system. Parcels include packages with a maximum weight of 150 kg/shipment. General cargo is goods with a maximum weight of 2 500 kg/shipment. Part loads are goods with a weight between 1 000 kg and 37 000 kg. In addition, parcels up to 20 kg/shipment are offered to consumers and are delivered to a certain convenience stores where the customer can pick it up. The differences in transportation between the products are explained below.

In the complete transportation network, approximately 10 million parcel shipments and 4 million general cargo shipments were transported in 2011. Part load shipments, transported directly from sending customer to receiving customer, are counted to approximately 800 000.

4.2 The Transportation Network

4.2.1 Transportation of Goods

The Company has 25 terminals in Sweden ranging from Malmö in the south to Luleå in the north. Company X does only provide road transports because of customers' requirements for fast deliveries. It is wishful to introduce railway as transport mode since that would give lower transportation costs and a more environmental sustainable way of transporting goods. Though, it is not possible today because of the structure of the railway network in Sweden and the limited possibilities to provide fast transports with this mode. All terminals do not have access to a railway loading zone where goods can be loaded on to a carriage, the goods then need to be transported to a loading zone by a local haulier.

For road transports, European and national highways are mostly used in Sweden, to provide as fast deliveries as possible. Since all goods are transported by truck, the transportation time is very dependent on the traffic situation. Weather, as snow and coldness, can affect the service as well as congestion due to a large traffic flow.

In the transportation network, transports of goods are carried out in different ways for the different products. In general, part loads are transported by hauliers directly from sender to receiver without passing one of Company X's terminals. However, parcels and general cargo are picked up and distributed out from the terminals by local hauliers. In between the terminals the goods are transported by regional hauliers. On these transports part loads can occur in order to increase the fill rate and lower costs, this is coordinated by the Production department.

The flow in the northern direction is approximately twice as large as the southern flow according to ordinary booked capacity for 2011 for general cargo and parcels. More goods are therefore transported from south to north.

As mentioned before, goods can also be transported via a hub and be consolidated with other goods before sent to the receiving terminal. This is further explained in the next section.

4.2.2 Design of the Transportation Network

General cargo and parcels are transported in the transportation network in the following way. Figure 4.2 below shows the design of the transportation network for these products.

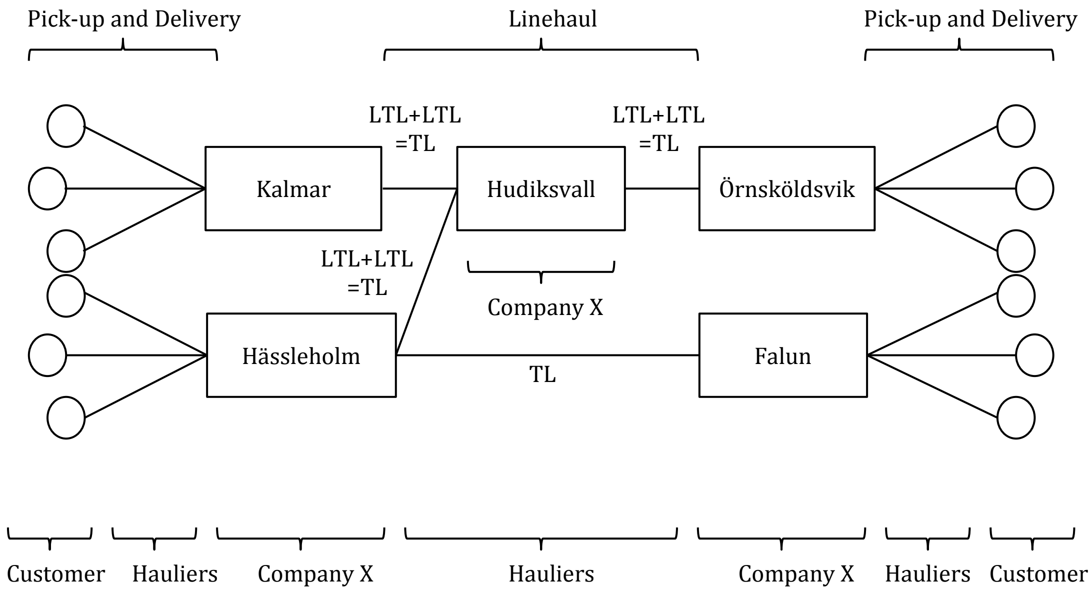

Figure 4.2: The design of the transportation network at Company X

Terminals send the sorted goods directly with full truckloads (TL) to the receiving terminal if the vehicle fill rate is large enough, as the transportation flow between terminals Hässleholm and Falun in Figure 4.2. If not, several less-than-truckloads (LTL) with different destinations at the Kalmar terminal are consolidated to one truck and send to the hub in Hudiksvall. Here, the goods with final destination Hudiksvall are distributed to the customers in the local area. The LTL-goods from Kalmar with final destination Örnsköldsvik is at the hub in Hudiksvall consolidated with LTL-goods from Hudiksvall and Hässleholm with final destination Örnsköldsvik. At the receiving terminal, the goods are sorted and delivered by pick-up and delivery trucks to the customers in the local area.

Pick-up and Delivery Transports

The pick-up and delivery (PuD) transports to and from the terminals are normally performed with milk runs, where local hauliers pick-up and deliver goods in their respective area, see Figure 4.3.

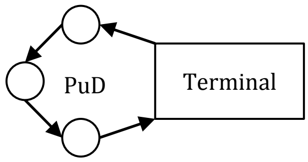

Figure 4.3: Milk run used for pick-up and delivery

Several vehicles drive the milk run to pick-up and deliver goods. In some cases, direct pick-up and delivery transports between the terminal and the customer occur if there are large quantities of goods to a customer.

Linehaul Transports

The terminals are linked together in a transportation network as described in section 3.2.4, where many of the terminals have line traffic in between each other, see Figure 3.5. Transports from one terminal to another can be seen as transports in transport corridors between one co-loading point and one split point, where the terminals are the points. These transportations are referred to as linehaul (LH) transports and are used to a large extent, see Figure 4.4.

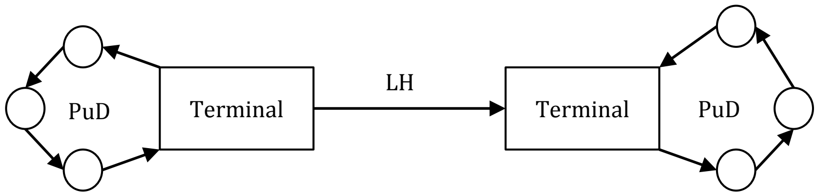

Figure 4.4: Transportation between two terminals

In addition, one co-loading point and two split points are used where the second split point also is denoted hub at Company X, see Figure 4.5.

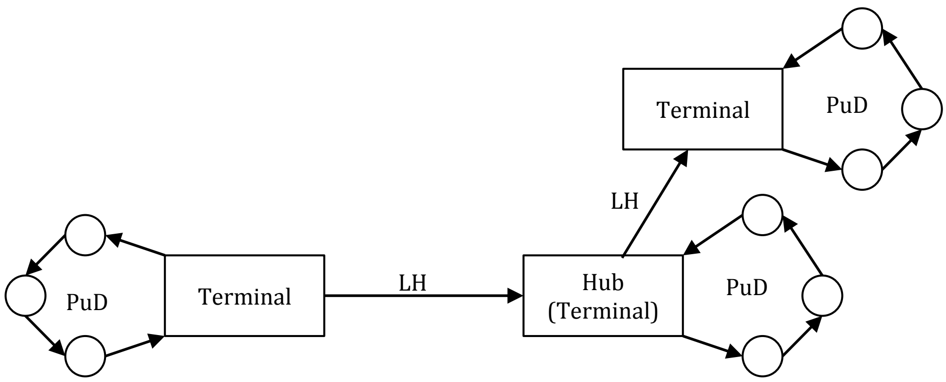

Figure 4.5: Transportation between two terminals via one hub

This structure is used for transports of goods which cannot be delivered within one day or transports with low volumes which need to be consolidated with other transports in order to fill a truck.

Terminals

The 25 terminals, which are spread out across the country all works in the same way. The terminals are rectangular and the gates are positioned on the long sides. Most often, the gates for the linehaul transports are located at one side and the gates for pick-up-and-delivery traffic are located on the other. As an example, it is in Figure 4.6 made clear at which hours trucks arrive to and depart from Terminal A with goods for both linehaul and pick-up-and-delivery transports.

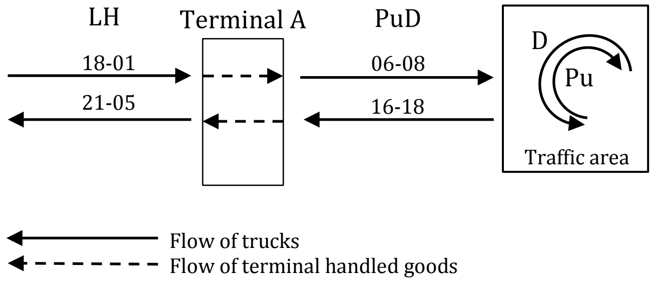

Figure 4.6: The flow of trucks and goods at Terminal A

At the terminal, goods arrive during the night, between 18:00 and 01:00 o'clock, from the linehaul hauliers, it is unloaded and then sorted based on zip code. Next, it is loaded on to the local hauliers' trucks and these hauliers deliver (D) their goods on a milk run in the midmorning. In the afternoon the same hauliers pick-up (Pu) the goods on the milk run and arrive back to the terminal. Here the goods are sorted based on the receiving terminal. When the linehaul hauliers arrive during the night, the trucks are unloaded and the goods from the local area are then loaded on the vehicle.

The main type of employees at the terminals is workers handling the loading and unloading of the vehicles. Company X is responsible for the training and education of personnel so the workers have the right competence for the work.

Hubs

As explained earlier some of the terminals, which handle goods in the second split point when three split points are used, are called hubs. When the trucks arrive to and depart from Hub B, which also acts as Terminal B, during the day can be seen in Figure 4.7.

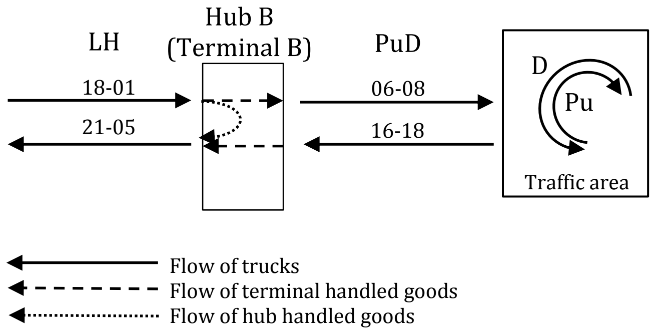

Figure 4.7: The flow of trucks and goods at Hub B (Terminal B)

The flow of goods through the hub can be explained in the same manner as the section above. In addition, the hubbed goods arrive with the linehaul hauliers during the evening/early night and are then consolidated with other goods and reloaded on to another linehaul haulier, which will drive to the receiving terminal.

4.2.3 Planning of the Linehaul Traffic

The linehaul traffic between the terminals is planned according to a timetable. The timetable contains departure times and arrival times at all terminals. It is affected by a number of factors.

First, the linehaul traffic is mainly for general goods and parcels but significantly affected by part loads to reduce costs in the system. The objective is to have as high utilization as possible and therefore adapt the timetable to the part load traffic to consolidate goods to fill the trucks. Second, the linehaul traffic and the pick-up and delivery traffic affect each other and need to be coordinated to function together. Driving and rest periods are also affecting the timetable. The drivers at the hauliers are only allowed to drive a specified amount of hours in one consecutive driving period. This limits the driving distances for Company X and also the times when the drivers are available. Consequently, this factor needs to be considered in the timetable.

The timetable is based on the ordinary capacity, booked for each line. This ordinary capacity is calculated based on historical data. The capacity is measured in load metre. The timetable is updated relatively seldom and can therefore be seen as fixed. In case of a new large customer, it can be updated to match the new flow. Though, it is never updated if the consequence is a worse delivery time to customer.

4.2.4 Delivery Time to Customers

The delivery time to customers is up to three working days depending on the distance between the sender and receiver. General cargo and parcels have the same delivery time, which is two, or three days, for goods through the hub, depending on the distance, see Figure 4.8.

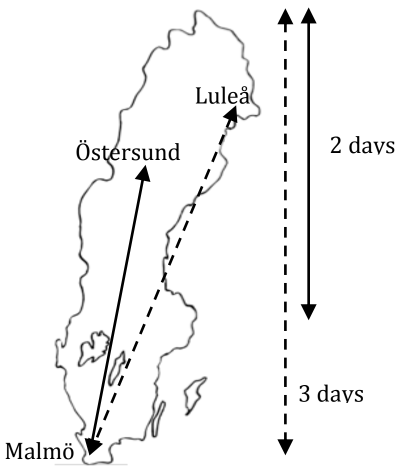

Figure 4.8: Delivery time depending on distance between sender and receiver

Because of the great distance between customers in the country customers can expect different delivery times depending on the distance between sender and receiver. For example, if a customer in Malmö should send goods to Östersund (the complete line) which is a distance of approximately 1000 km Company X can promise the customer a delivery time of two days. However, if the same customer should send goods to Luleå (the dashed line) which is a distance of 1470 km a delivery time of three days is promised to the customer by Company X. To generalise, transports of 1000 km or less can be delivered within two days while longer transports require 3 days.

The quality of service, that is, how many transports that achieve the promised delivery time, is measured continuously. The site managers at the terminals are accountable for deliveries in time. If a large amount of the transports do not achieve the set delivery time, it can be adjusted to increase the quality performance. Though, it is not wishful to increase the delivery time if not needed since customers value short lead times.

For part loads, the delivery time is set differently. The direct delivery from sender to receiver is only one day. If the part loads are consolidated with goods at a terminal, the delivery time can be up to three days as for general cargo and parcels.

An example of how the delivery time is set up is illustrated in Figure 4.9.

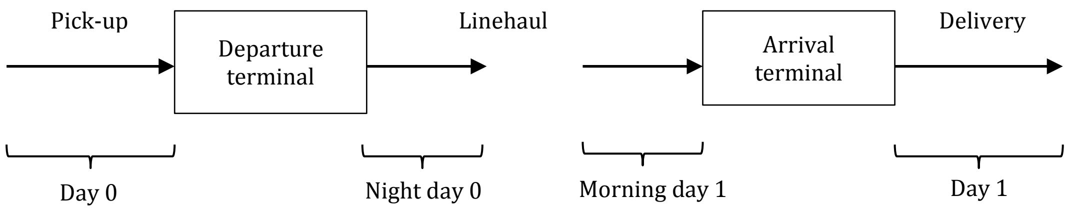

Figure 4.9: Illustration for delivery with day 0-traffic

To give an example for day 1-traffic between the sender and receiver; to enable a delivery to a customer day 1, the goods need to be delivered to the arrival terminal at latest in the morning. This means that the goods need to be transported from the departure terminal at latest day 0 to arrive before morning day 1. Consequently, the goods need to be picked up at the sender at day 0. Transports through a hub often requires day 1-traffic or day 2-traffic which can be translated into two or three working days of delivery.

4.2.5 Costs

Transportation Costs

The transportation cost for Company X that is, the compensation to the hauliers, is based on load metre and distance. The compensation is based on the fixed timetable, the ordinary capacity and extra capacity. The ordinary capacity is booked in advance and the negotiation with the hauliers gives a price in SEK per day or SEK per load metre, which is also based on the distance of the actual transport. The ordinary capacity is calculated based on historical data and experience. The goal with the booking of the ordinary capacity is to rather stay under the demanded capacity to afford extra capacity when needed than have too much capacity and thereby low utilization. The booking of ordinary capacity can be seen as strategic planning in a long-term perspective and as tactical planning for adjustments as seasonality variations. The extra capacity is operational decisions made on day-to-day basis. When extra capacity is needed because of daily variations it is booked for a price in SEK per load metre. The compensation to the hauliers is complemented with a fuel surcharge that is based on the cost of diesel.

Site-specific Costs

The costs that are related to the location of the terminals are location costs and costs for wages. The location costs cover either rental charge or interest charge depending on ownership of the facility or not.

The costs of wages for the terminal workers differ between each terminal. This is because there are different collective agreements connected to each terminal. The collective agreement has two parts, one base salary and one additional salary, where the last differ between the terminals.

4.2.6 Requirements of Site

A factor that needs to be considered when locating terminals is that it must be possible to find a suitable site which the company can get a proprietary right of for at least 20 years by the municipality. The site must also fulfil all environmental laws and regulations that are required in Sweden when building a facility.

5 Model Construction

This chapter is aimed to explain the procedure of the model construction including analysis of collected data to the model and motivation of choices affecting the content of the model. It gives the reader a summary of the structure of the model, what data to use as input and reference on how to analyse the output.

5.1 Identifying the Qualifiers and Parameters of the Model

5.1.1 Introduction

The factors from the frame of reference were compiled and used as input to the model construction. The model construction first included two interviews that were held in order to identify which factors that suit the specific situation of Company X. As a result, 16 factors were removed while three were added. Second, a questionnaire was performed where the factors were identified as either a qualifier, a factor that a location need to fulfil, or a parameter that is wishful for a location to fulfil. Two factors were also added here by the participants. Third, a group discussion was held in order to identify the parameter weights. Finally, the output of this process was the qualifiers and weighted parameters which were inserted in the model. These steps are illustrated in Figure 5.1.

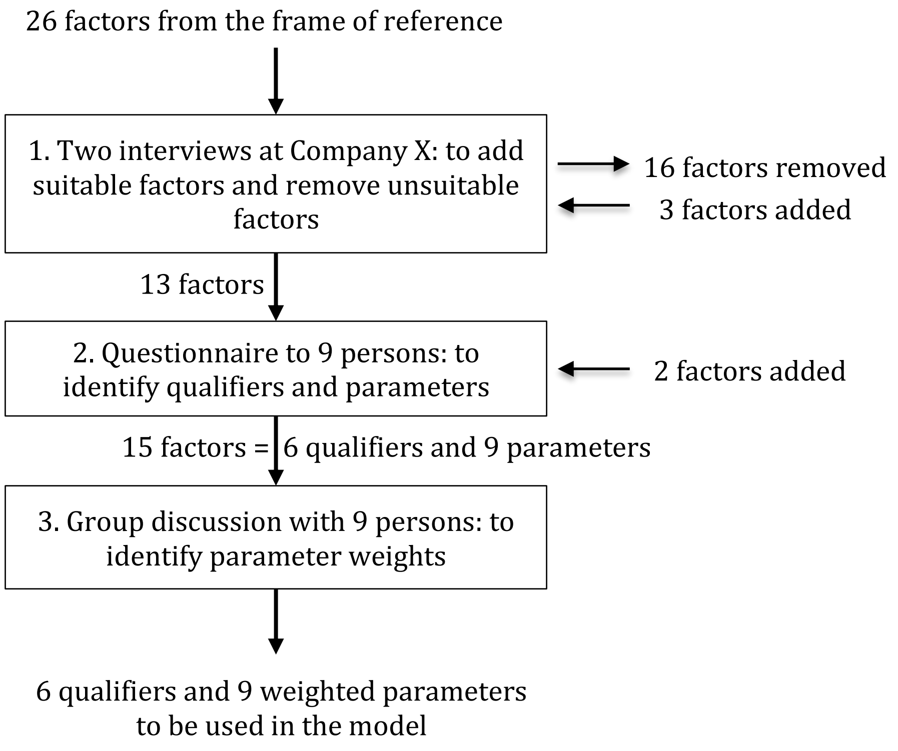

Figure 5.1: The procedure of identifying the qualifiers and parameters

Details of the procedure in Figure 5.1 follow in the next sections.

5.1.2 Analysis of Interviews

The factors from the frame of reference were discussed during two interviews with different managers. As a result, some of the factors were considered not to be suitable for the situation of Company X. These were therefore disregarded, see Table 5.1. The remaining factors were further investigated in the questionnaire.

Table 5.1: Outcome of factors affecting facility location after interviews

Category	No.	Factor	Outcome
Infrastructure factors	1	Highway access	Questionnaire
	2	Railway access	Questionnaire
	3	Congestion	Questionnaire
	4	Living costs & family conditions	Questionnaire
	5	Communication	Disregarded
	6	Utilities	Disregarded
Macro-economic factors	7	Taxes, tariffs, exchange rates	Disregarded
	8	Financial aid	Disregarded
Costs	9	Location costs	Questionnaire
	10	Transportation costs	Disregarded
	11	Wages	Questionnaire
Labour factors	12	Labour availability	Questionnaire
	13	Competent staff	Disregarded
Environmental aspects	14	Political stability	Disregarded
	15	Regional culture	Disregarded
	16	Environmental regulations	Questionnaire
	17	Climate	Disregarded
	18	Language	Disregarded
	19	Construction feasibility	Questionnaire
Market aspects	20	Closeness to competitors	Disregarded
	21	Closeness to customers	Disregarded
	22	Resource proximity	Disregarded
	23	Market risks	Disregarded
Strategy	24	Cost leadership	Disregarded
	25	Economies of scale/scope	Disregarded
Other	26	Driving and rest periods	Questionnaire

The disregarded factors are explained and motivated below.

The infrastructure factors, 5 and 6, see Table 5.1, communication and utilities, were recognized as satisfied in all parts of Sweden. Meaning, no matter the location of the hub it will have a sufficient level of communication and availability of utilities.

The macroeconomic factors, 7 and 8, were considered as not important since Company X just service customers in Sweden.

Moreover, factor 10, transportation cost, will be investigated in a separate part of the model and was therefore disregarded as a parameter. This was the supervisor's request and the argument is that it is desired that an output of the model is a transportation cost for each alternative for hub localisation.

Factor 13, competent staff, was disregarded since the company itself is responsible for the education of the staff. Therefore, no specific competence is needed for new employees.

The environmental factors, 14, 15, 17 and 18 were all omitted. Since the political stability is considered to be the same all over Sweden, this factor was removed. In addition, the culture in Sweden is recognized by the company as very similar all over the country, as a consequence the factor was disregarded. Moreover, the language factor was omitted as it is the same in all parts in Sweden. Also, the climate refers to having a climate that workers are attracted to and this is considered not being relevant for the Company X.

The market aspects, 20, 21, 22 and 23, were disregarded. The closeness to competitors and closeness to customers were disregarded and two similar factors were added that better explained the situation, see table 5.2. In addition, the resource proximity is not of importance for Company X since its core business is to just transport goods from point A to point B. Furthermore, market risks are decided to be removed after discussion with the supervisor at Company X since this factor does not affect the hub localisation at the company.

The strategy factors, 24 and 25, were removed, the factor cost leadership since the cost parameters are included in factor 9, 10 and 11. Next, the factor economies of scale/scope is not considered since in the case of Company X this is just related to the planning of how many facilities that should serve the market.

In addition, three factors were added since they were missing in the literature review and were considered to be influential on the specific situation of Company X, these are presented in Table 5.2.

Table 5.2: Added factors after interviews

Category	Factor	Explanation	Outcome
Environ-mental aspects	Weather	Influence of weather on the transports, such as snow and cold	Questionnaire
Market aspects	Closeness to similar companies	Closeness to companies in similar industries	Questionnaire
	Delivery time to customers	The hub needs to be able to deliver goods according to the timetable to the customers	Questionnaire

First, weather was added since the influence of weather on the company's transports is considered to be important. In addition, closeness to similar companies was added as this can give synergy effects when locating at a site close to companies in similar industries. Moreover, the factor delivery time to customers was added, this because the hub needs to be located at a site where goods are able to be delivered to the customers according to the company's timetable.

5.1.3 Analysis of Questionnaire

The purpose of the questionnaire was to evaluate the factors affecting hub localisation to identify which factors were qualifiers and which were parameters.

Findings from the Questionnaire

The factors from Table 5.1 and 5.2 were included in the questionnaire and were given a new number. A summary of the answers is presented in Appendix F. The factors are presented in Table 5.3 together with the outcome of the analysis of the answers, meaning which factors were identified as qualifiers and parameters.

Table 5.3: The resulting factors after questionnaire

Category	No.	Factor	Outcome
Infra-structure	1	Highway access	Qualifier
	2	Railway access	Parameter
	3	Congestion	Parameter
	4	Living costs and family conditions	Parameter
Costs	5	Location costs	Parameter
	6	Wages	Parameter
Labour	7	Labour availability	Qualifier
Environ-mental aspects	8	Environmental regulations	Qualifier
	9	Weather	Parameter
	10	Construction feasibility	Qualifier
Market aspects	11	Closeness to similar companies	Parameter
	12	Delivery time to customers	Qualifier
Other	13	Driving and rest periods	Qualifier

After the answers from the questionnaire were collected and compiled, a number of factors were identified as qualifiers. The factors, which had at least one answer as "necessary" were recognised as qualifiers. As a result, factor 1, 7, 8 and 10 were acknowledged as qualifiers with the following arguments.

Regarding factor 1, it is essential for Company X to have their hub located near a highway, this to reduce transportation time and ease access for the trucks. Concerning factor 7, there must exist available workforce in the proximity of the hub. Factor 8 is a qualifier since the company needs to fulfil the environmental laws and regulations when locating a hub at a specific site. About factor 10, it must be possible to find a suitable site which the company can get a proprietary right of for at least 20 years by the municipality.

In addition, factor 12 and 13 were, after discussion with the supervisor at the Company X, identified as qualifiers. This was because these factors could have been perceived differently because of the explanation in the questionnaire. The correct way when looking on these factors should be that Company X needs to guarantee a certain delivery time to their customers according to the pre-set timetable. Consequently, the hub needs to be located at a location where customers are relatively close.

The remaining factors, namely 2, 3, 4, 5, 6, 9 and 11, were identified as parameters.

In addition, two factors were added in the questionnaire by the participants, see Table 5.4.

Table 5.4: Added factors by participants of the questionnaire

Factor	Explanation	Outcome
Cost of return goods flows from northern Sweden	Cost due to low utilisation in southern direction	Parameter
Closeness to nearby terminal to support goods handling at hub	Advantages with a supporting terminal at peaks in flow volume	Parameter

The first factor, cost of return goods flows from northern Sweden, means it is of importance how high the utilisation of the trucks' cargo space is in both directions between the hub and the terminals located north of the hub. The cost of the return flow due to low utilisation increases with an increased transport distance. This interaction between the flows in each direction is important to consider since this is an indirect cost for Company X. The second factor, closeness to nearby terminal to support goods handling at hub, means in case of large handling volumes at the hub, there might be goods which will not fit the ordinary transports and it would be useful to have a terminal nearby which it would be possible to transport it to. In this case the goods would not be left an extra day at the hub but transported via another terminal to the receiving terminal. This is considered to be an important factor since it lowers the risks for possible delays of the goods.

Result Discussion

When analysing the results from the questionnaire, one must also discuss the results. Despite the fact that the factors were explained in the questionnaire, the participants could have interpreted the factors in different ways. If the explanation would have been more elaborated the risk of misinterpretation may have been reduced.

Another aspect to consider is the layout of the questionnaire and how well the participants have understood how to fill in the questionnaire. Since clear instructions together with an example were given as well as the authors contact information it is considered that the participants have filled in the questionnaire in a correct way.

However, there was not that many of the participants, who chose the most extreme answering alternatives; "not important" and "necessary", see Appendix F. This could of course be because the participants have filled in their true opinion. As can be seen in the next section this coincides with the group discussion where the discussed parameters were not considered either "not important" or "necessary". As a result, one can argue that the authors have chosen the most suitable qualifiers and parameters from the questionnaire.

5.1.4 Analysis of Group Discussion

Findings from the Group Discussion

The outcome from the group discussion presented in Appendix D was used to identify the remaining relations between the parameters according to the method explained in section 3.4.2. In order to perform the calculations of the remaining relations the spanning tree in Appendix B was used. The parameters discussed in the group discussion were:

A. Railway access
B. Congestion
C. Living costs and family conditions
D. Location costs
E. Wages
F. Weather
G. Closeness to similar companies
H. Cost of return goods flows from northern Sweden
I. Closeness to nearby terminal to support goods handling at hub

The result of the group discussion and the complementing calculated comparison values are presented in Table 5.5 which contains of 10 rows and 10 columns.

Table 5.5: Comparison values between the parameters

No.	A	B	C	D	E	F	G	H	I
A	1.00	**0.17**	**0.25**	0.50	1.00	**4.00**	0.83	0.44	0.67
B	**6.00**	1.00	1.50	**3.00**	6.00	24.00	**5.00**	2.67	4.00
C	**4.00**	0.67	1.00	2.00	**4.00**	16.00	3.33	1.78	2.67
D	2.00	**0.33**	0.50	1.00	2.00	8.00	1.67	0.89	1.33
E	1.00	**0.17**	**0.25**	0.50	1.00	4.00	0.83	0.44	0.67
F	**0.25**	0.04	0.06	0.13	0.25	1.00	0.21	**0.11**	**0.17**
G	1.20	**0.20**	0.30	0.60	1.20	4.80	1.00	0.53	0.80
H	2.25	0.38	0.56	1.13	2.25	**9.00**	1.88	1.00	1.50
I	1.50	0.25	0.38	0.75	1.50	**6.00**	1.25	0.67	1.00

One should read Table 5.5 the following way, starting at the element in row two, column three where parameter A, access to railway, is compared to parameter B, congestion, from the group discussion it was decided that access to railway is 1/6 (one sixth) as important as congestion. Naturally, congestion is 6 times more important as access to railway, which can be seen in the element in row three, column two. It should be noticed that the elements in the diagonal all equals 1. In Table 5.5 the cells marked in bold show the outcome of the group discussion, meaning these values were the result of the pairwise comparisons made. From these values the other values were calculated, these derived relations are assumed to be consistent.

From Table 5.5 the geometric mean and the weight for each parameter were calculated, see Table 5.6. Since the parameters A to I add up to nine parameters, the geometric mean was calculated in order 9. For example, the geometric mean of parameter A was calculated as in Equation 5.1.

$$Geometric\ mean_A = \sqrt[9]{x_{AA}x_{AB}x_{AC}x_{AD}x_{AE}x_{AF}x_{AG}x_{AH}x_{AI}} \text{ (Equation 5.1)}$$

Next, the geometric mean was normalised for each parameter, resulting in that each parameter was given a weight between 0 and 1, see equation 5.4 were the weight for parameter A is calculated. These weights correspond to the Relative Value Vector (RVV) described in section 3.4.2.

$$Weight_A = \frac{Geometric\ mean_A}{Sum\ of\ geometric\ means} \text{ (Equation 5.2)}$$

Table 5.6: Geometric mean and weight for the parameters

No.	Parameter	Geometric mean	Weight
A	Railway access	0.65	0.05
B	Congestion	3.90	0.31
C	Living costs and family conditions	2.60	0.21
D	Location costs	1.30	0.10
E	Wages	0.65	0.05
F	Weather	0.16	0.01
G	Closeness to similar companies	0.78	0.06
H	Cost of return goods flows from northern Sweden	1.46	0.12
I	Closeness to nearby terminal to support goods handling at hub	0.97	0.08
	Sum	12.47	1.00

To conclude, parameter B, congestion is seen as most important followed by parameter C, living costs and family conditions. Moreover, parameter H, cost of return goods flows from northern Sweden, and parameter D, location costs are next in order of importance. The least important parameter is parameter F, weather.

Result Discussion

Looking at Table 5.5 one can conclude that two values in the pairwise comparisons are larger than 9. The parameter congestion is considered 24 times more important than the parameter weather. Furthermore, the parameter living costs and family conditions is considered 16 times more important than the parameter weather. This is a result of assuming consistency in the group discussion, if the parameters would have been compared directly in the group discussion the values would not have exceeded 9, since this is the maximum value on the measurement scale. Consequently, if another spanning tree had been used, meaning other comparisons had been made, the parameter weights would have been different. An alternative way of performing this group discussion is to not assume consistency. If not assuming consistency, the group discussion needs to be redone with comparisons between all parameters. This may give a more reliable result but time need to be allotted to discuss 36 comparisons[5]. Consistency has been assumed in this study due to time limitations.

The result from the questionnaire, meaning average and standard deviation of the parameters, is compared with the parameter weights obtained from the group

[5] If n parameters need to be compared, $\frac{n(n-1)}{2}$ comparisons are needed.

discussion. The comparison can be seen in Table 5.7. Parameter H and I were added by participants in the questionnaire and therefore they did not receive an average and standard deviation.

Table 5.7: Comparison of results from the questionnaire and the group discussion

		Result from questionnaire		Result from group discussion
No.	**Parameter**	**Average**	**Standard deviation**	**Weight**
A	Railway access	3.00	1.414	0.05
B	Congestion	3.89	0.928	0.31
C	Living costs and family conditions	2.33	1.225	0.21
D	Location costs	3.78	0.667	0.10
E	Wages	2.78	0.972	0.05
F	Weather	3.11	1.054	0.01
G	Closeness to similar companies	1.25	0.926	0.06
H	Cost of return goods flows from northern Sweden	-	-	0.12
I	Closeness of nearby terminal to support goods handling at hub	-	-	0.08

It can be concluded that all the parameters' average and weight does not coincide. For example, parameter B received the highest average and the highest weight, however, parameter D that received the second highest average received a fairly low weight. Moreover, parameter F received the lowest weight but got a rather high average in the questionnaire.

The reason for the shifting results in the questionnaire and the group discussion can be that the participants interpreted the parameters in the questionnaire in different ways, while at the group discussion these were more explained and discussed between the participants. As a result, the participants are considered to have received a more equal opinion of the meaning of each parameter at the group discussion.

5.2 The Decision Support Model

5.2.1 The Four Sub Models of the Decision Support Model

The decision model is build out of four sub models and the structure is illustrated in Figure 5.2.

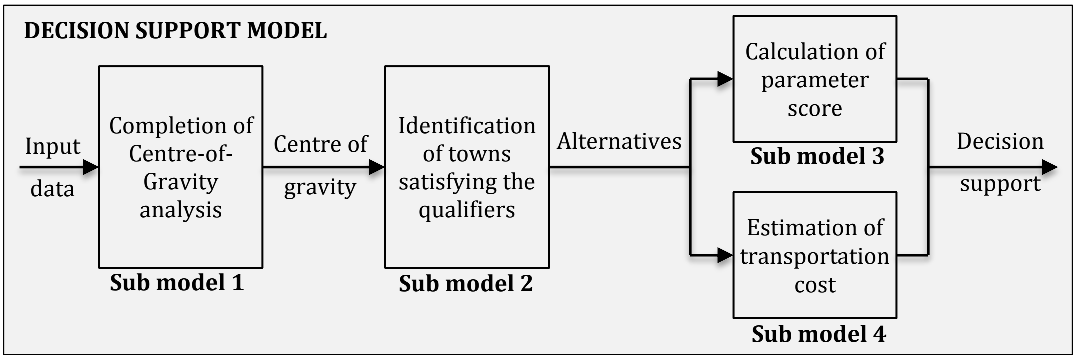

Figure 5.2: The outline of the decision support model

The arrows symbolise the input and the output respectively for each sub model. The boxes represent the four sub models, which are marked in bold in the figure. The sub models denote the main steps in the model, from the input data to a summary of results that is the basis for the decision of where to locate the hub. They are explained further below together with the output of the model.

5.2.2 Sub Model 1: Completion of a Centre-of-Gravity Analysis

The first sub model is to complete a Centre-of-Gravity analysis with some given input data. With the described input data and procedure, the location, which satisfies the centre of gravity, is found. This location will be the basis in search of locations that fulfil the qualifiers.

In the Centre-of-Gravity analysis, the centre of gravity will be found based on a set of gathered input data, see Appendix G, adapted on this problem from theory:

- The *n* terminals, which send and/or receive goods to and from the current hub. A specific terminal is denoted *i*, where *i* = 1, 2, …, *n*
- The coordinates of the *n* chosen terminals, X_i and Y_i
- The current flow of goods, Q_i (in load metre) between terminal *i* and the hub in both southern and northern direction
- The transportation cost for each line, T_i, excluding fuel surcharge cost, (in SEK per load metre and kilometre), meaning the cost to ship one load metre one kilometre from terminal *i* to the hub
- The fuel surcharge cost for each line, F_i (in SEK per load metre and kilometre), meaning the fuel surcharge cost to ship one load metre one kilometre from terminal *i* to the hub

The output of the method is coordinates for an optimal location *C*. By using equation 5.3 and 5.4 together with the input data the coordinates, X_C and Y_C is calculated.

$$X_C = \frac{\sum X_i Q_i (T_i + F_i)}{\sum Q_i (T_i + F_i)} \text{ (Equation 5.3)}$$

$$Y_C = \frac{\sum Y_i Q_i (T_i + F_i)}{\sum Q_i (T_i + F_i)} \text{ (Equation 5.4)}$$

These coordinates for the centre location C will be the basis for the choice of a number of possible hub locations situated near this location.

5.2.3 Sub Model 2: Identification of Towns Which Satisfying the Qualifiers

A couple of locations near the centre of gravity, that fulfil the qualifiers, are to be further analysed in the model which is denoted as sub model 2. In order to find these locations, towns, which are municipal capitals near the centre point of gravity, are to be investigated if they fulfil the qualifiers. The closest towns, which fulfil the qualifiers, will qualify as an alternative to where to locate the hub. It is also possible to add other towns, which fulfil the qualifiers.

The procedure to find suitable alternatives is iterative. First, the towns within a 30-kilometre radius from the centre point are analysed, the towns, which fulfil all the qualifiers, are set as an alternative. Second, towns within a 50-kilometre radius from the centre point are examined and the ones, which fulfil the qualifiers, are set as an alternative. Next, towns with in a 70-kilometre radius are investigated and the procedure continues until a couple alternatives have been found. The user chooses how many alternative locations that will be analysed. The tool "Radius around point" is used to draw circles with a specific radius, supplied by Free Map Tools (2012).

The different hub locations, denoted alternatives, have to be analysed considering the set qualifiers. The qualifiers are aspects that the locations need to fulfil in order to be considered as an alternative. The locations, which are found in the proximity of the centre of gravity, are to be analysed with the following qualifiers. It is further explained how to analyse the alternatives according to each qualifier.

Highway Access

Highway access is referred to the location being close to a junction point. A junction point is considered to be where two large roads cross each other where at least one is a European highway and the other one is a national highway. A junction point enables several transport routes but also reduces risks of delays due to roadblocks. When measuring the distance from each terminal in Company X's current network to the nearest highway entrance, the longest distance were 4 km. This can be set as the maximum distance from the town to a junction point.

Labour Availability

The labour availability can be analysed by looking at the number of unemployed 20-64 year olds in the municipality of the town. This is because it is assumed for simplicity that all unemployed inhabitants in the municipality are considered to have the ability to work in the town. The population in each municipality at a specific time point need to be gathered, from SHB (2012) as a suggestion. In addition, the share of unemployed 20-64 year olds of Sweden's total population needs to be collected, from Ekonomifakta (2011) as a suggestion. Next, the number of unemployed 20-64 year olds in each municipality should be calculated by equation 5.5.

$$Number\ of\ unemployed\ 20-64\ year\ olds = (Population) * (Share\ of\ unemployed\ 20-64\ year\ olds) \quad \text{(Equation 5.5)}$$

The output of the equation can give a hint if the location has enough available workers in case of locating a hub there.

Delivery Time to Customers

The delivery time need to be achieved according to the set delivery time to customers in Sweden, which is determined by the company's timetable. The fulfilment of this qualifier can be checked with an approximate illustration to estimate if the goods can arrive in time, see Figure 4.9. It is assumed that the timetable can be changed due to the hub localisation if it is needed to achieve the required delivery time.

Driving and Rest Periods

The regulations concerning driving and rest periods need to be considered and fulfilled for the drivers. The current transports in the network can give an indication if these regulations are possible to fulfil. The driving period can at maximum be 9 hours. The daily rest is restricted to 11 consecutive hours or 12 hours divided in two periods of 3 hours and 9 hours at the end of the shift (Transportstyrelsen, 2011). The driving time per line together with the driving period restrictions can be the basis for the estimation if this qualifier is fulfilled.

Environmental Regulations

Environmental regulations refer to the regulations concerning building of facility, which is an interesting qualifier to discuss when deciding of the specific site at the location. Since this qualifier concerns specific sites for the hub and not the geographic location, the regulations and laws concerning the environment need to be investigated when a location has been decided in order to decide if the planned specific site is acceptable.

Construction Feasibility

The construction feasibility when building a facility concerns the possibility of building a hub or expanding a current terminal in order to transform it to a hub at a specific site. When performing such a large investment Company X wants at least 20 years proprietary right from the municipality, this in order to be able to practise a long-term and competitive business. In addition, the specific site must be large enough to have the possibility to either build a new facility or expand an existing one. Consequently, these issues need to be further examined when a location has been decided and a specific site should be chosen.

5.2.4 Sub Model 3: Calculation of Parameter Score

The alternatives are then to be evaluated on how well they score on each parameter, which was found in section 5.1. But, in order to analyse the alternatives according to the parameters, the parameters first need to be compared pairwise. This is because the parameters are of different importance to Company X and it is wishful to capture this in the analysis. Therefore, the parameters are compared pairwise according to the AHP-method, which is described in section 3.4.2. By performing a group discussion by using a spanning tree and assuming consistency in the opinion of the group not all parameters need to be compared pairwise.

From the result of the group discussion the remaining pairwise comparisons of the parameters can be calculated. Next, the geometric mean of each parameter is calculated and then the parameter weight is obtained, which is described in detail in section 5.1.4. This gives the Relative Value Vector (RVV).

To get a quantification of how well each alternative fulfil the parameters, the Weighting selection criteria was used, see section 3.3.2. The alternatives are pairwise compared for each parameter. This is made by using the measurement scale presented in Table 5.8, where if for example alternative A is considered much better than alternative B on one parameter the weight 5 is used to quantify this.

Table 5.8: Measurement scale used in the pairwise comparisons of the alternatives

Importance	Equally good	Little better	Much better	Very much better	Absolute better
Weight	1	3	5	7	9

The alternatives are evaluated based on the instructions for each parameter. How well the different alternatives fulfil the parameters is showed in the score for each alternative in each parameter respectively.

The geometric mean and a score are calculated for each alternative for each parameter respectively, which is the Option Performance Matrix (OPM). The final score of the alternatives is calculated by multiplying the weight for each parameter with the alternative's score for the respective parameter. The sum of these products is then the final score for each alternative, also called the Value for money (VFM). The alternative with the highest score is the location which best fulfil the parameters. The parameters and how to evaluate them are explained below.

Railway Access

Railway access can in the future be important for Company X since it is a cost efficient and environmental-friendly transport mode. It requires a loading zone at the railway for companies handling goods to use the railway. There are about 130 loading zones in Sweden and an alternative location gets a higher weight the closer it is located to the loading zone. The loading zones can be seen in Trafikverket (2012).

Congestion

Much congestion near the facility can delay the transports and thereby worsen the service and increase the costs since the transport with driver are longer at the road than planned. Congestion can therefore affect hub localisation in a negative way. It mainly arises because of large traffic flows and the average traffic flow per day can thereby compiled for the different alternative locations. The traffic flow for roads in Sweden can be seen in Trafikverket (2010).

Living Costs and Family Conditions

Living costs and family conditions are important to have healthy workers satisfied with the environment. The better living conditions nearby the work, the happier worker and hopefully the better and more effective workers. There are several factors that can affect the workers' environment. The way to evaluate this parameter can be to use the ranking of the municipalities in Sweden based in living conditions, presented by Fokus (2011). This ranking includes 44 variables concerning life as young, life as older, family conditions, work climate and fundamental variables as crime, taxes and healthiness.

Location Costs

The parameter location costs is important since it covers the costs of rent and depreciation for the facility per year. As a result, a newer facility will receive a higher location cost than an older one. The rental costs for the existing facilities can be compared while the rental costs for a new-built facility have to be estimated.

Wages

This parameter was decided at the group discussion to include wages for the terminal workers and not office-workers since there are such a large proportion of terminal workers so the office-workers can be disregarded. It should be seen as a cost for the company and an alternative with a lower wage is therefore considered to get a higher weight. Company X has today a collective labour agreement, which controls the wages for the terminal workers. All new employees get the same wage but currently employees' wages differs between the terminals. The basis for the comparison values for this parameter is suggested to be an additional salary that is paid to terminal workers per worked hour which differs between terminals and new and currently employees.

Weather

Weather is a parameter that can affect Company X's transports but the company cannot affect the weather or the consequences that can arise. Weather in Sweden that can affect road transports is delimited to snow and coldness. Therefore, the average number of days per year with snow from 1961 to 1990 at different regions can be used to quantify this parameter. This data can be seen in SMHI (2012).

Closeness to Similar Companies

The parameter, closeness to similar companies, refers to the number of companies in the same business within the same area at each alternative location. The same business is defined as companies with the same frequency of transports, to and from the facility, for example 3PL companies or companies with large warehouses or consolidation facilities. The advantage of having similar companies nearby is the possibility of getting better infrastructure due to many companies in the same area using highways and railway. Gas stations and garages can also locate near the area if there are many possible customers, which benefits the companies. This parameter can be evaluated by estimating how many similar companies, which are located at the alternative location.

Cost for Return Goods Flows From Northern Sweden

The parameter, cost for return goods flows from northern Sweden, refers to the fact that it is wished for to have a low cost for the imbalance in the goods flow between the hub and the terminals north of the hub. The imbalance in goods flow is due to the social structure of northern Sweden, this affects the company in a way where much more goods are sent to this part of the country than sent from. For example, if 800 load metres are transported in one year from the hub to terminal A while only 400 load metres are transported from terminal A to the hub, denoted the return goods flow, it will be more expensive to buy capacity from the hauliers for the return goods flow.

By comparing the northbound and southbound flows to and from northern Sweden from the current hub location one can conclude the imbalance. The longer the alternative hub is located from northern Sweden, the higher is the cost of return flows estimated to be. The utilisation for transports from northern Sweden is low and since the cost is measured per kilometre, the cost increases with the distance.

Closeness to Nearby Terminal to Support Goods Handling at Hub

The distance from each alternative to the nearest terminal can be measured in order to quantify the closeness to nearest terminal to enable support of goods handling at hub. The closeness can increase the integration of the terminals and enable support when handling large volumes and there is a risk for delay because of shortage in resources. Having terminals nearby is a way to decrease the risk of possible delays.

5.2.5 Sub Model 4: Estimation of Transportation Cost

The transportation cost for the different alternatives is to be considered separately. It is estimated for each alternative with the current flow of volume, the current transportation cost per load metre and kilometre and the distance for each line. This gives a total transportation cost for each alternative if locating a hub at that location. It is assumed that the current transportation cost between the hub and the terminals is the same for the new alternative location to the terminals.

5.2.6 The Output of the Model: Decision Support

The parameter score and estimated transportation cost for the alternatives forms the output of the model, namely a decision support for hub localisation. It is the user's responsibility to decide which alternative that is the best hub localisation according to this decision support.

6 Analysis of Current Hub Location

This chapter aims to present the analysis of the optimal hub location using the constructed model. First, the Centre-of-Gravity analysis is described, second, the alternatives found in the first part are analysed in order to decide which alternatives that fulfil the set qualifiers. Third, the alternatives that fulfil the qualifiers are analysed and weighted according to a set of parameters. Moreover, the transportation cost is calculated for each alternative. Finally, the result of the entire analysis is presented and discussed.

6.1 Completion of Centre-of-Gravity Analysis

6.1.1 Introduction

The first part of the analysis of current hub location is a Centre-of-Gravity analysis, which finds the coordinates for the hub location with the lowest transportation costs at Company X. This analysis is performed by the first sub model, see Figure 6.1.

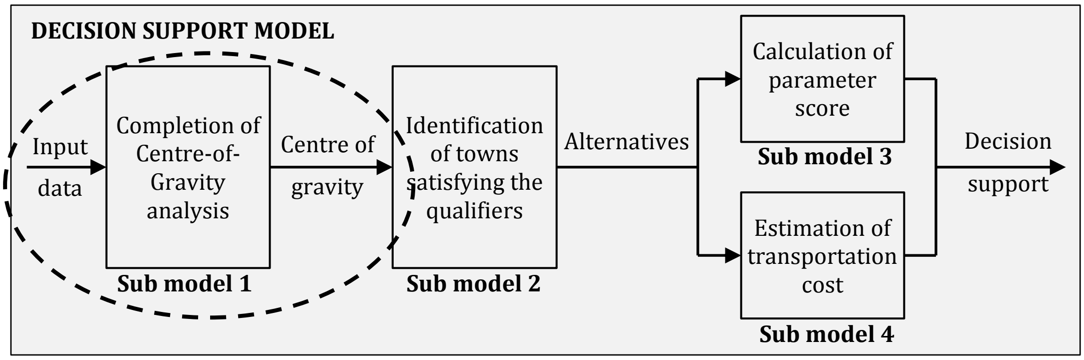

Figure 6.1: Sub model 1 of the decision support model

The terminals which today send and/or receive goods from the current hub location have been chosen to be part of the analysis. This is the case for 21 of the terminals in the network. There are other terminals that function as hubs but it is chosen to only include the main hub due to complexity limitations.

The input to this analysis was geographical coordinates of the terminals, X_i and Y_i, the flow of goods between the terminals and the current hub, Q_i, and transportation cost of each line, T_i, see Appendix G.

6.1.2 Analysis

The southern and the northern flow through the current main hub were included in the analysis. The transportation cost for each line was registered as a total transportation cost plus fuel surcharge per kilometre and the load metre transported, see Appendix G. Since the cost was different for the southern and the northern flow, the cost for one direction was multiplied with the flow in the same direction. The costs for each direction were held separated to get a more reliable result. The equations used in this analysis are presented in section 5.2.2.

6.1.3 Result

This analysis resulted in the following coordinates for the optimal hub location, X_C = 60.30448 and Y_C = 16.81687. These coordinates correspond to a location in mid Sweden, just southwest of the town Gävle, see Figure 6.2.

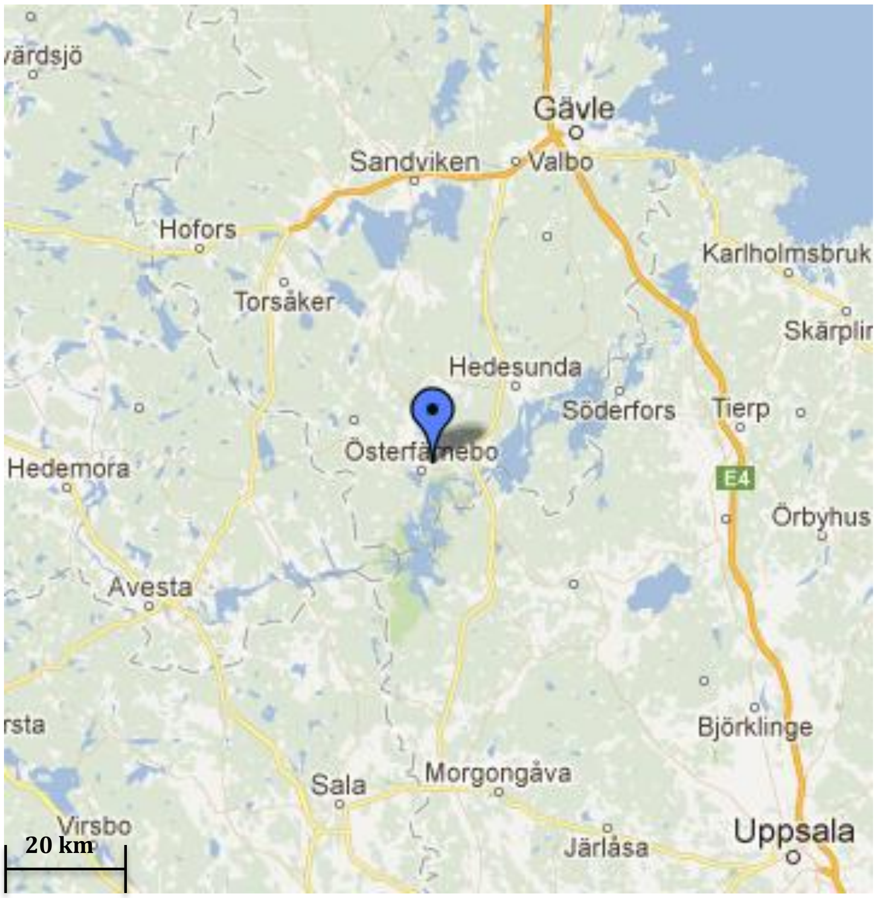

Figure 6.2: The centre of gravity of the analysis

Since most of the terminals are located south of this region and just a few in the north of Sweden, the result of the analysis seems reasonable.

6.2 Identification of Towns Satisfying the Qualifiers

6.2.1 Introduction

The exact location, which corresponds to the centre of gravity acquired from the Centre-of-Gravity analysis, may not be a reasonable hub location for Company X. Therefore, the nearby towns have been investigated in order to see if they fulfil the qualifiers. This is done according to sub model 2, see Figure 6.3.

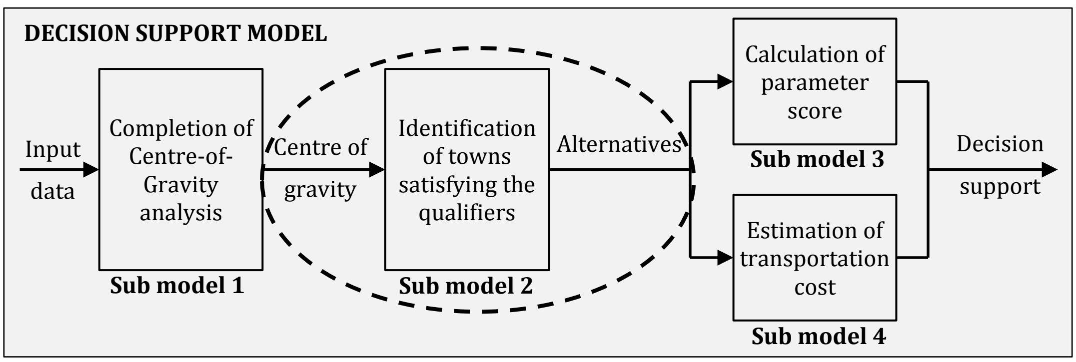

Figure 6.3: Sub model 2 of the decision support model

The closest towns, which fulfil the qualifiers, are to be found and these will qualify as alternatives for the hub location. In addition, the current hub location is added as an alternative in order to compare it to the other alternatives. The iterative procedure described in section 5.2.2 is followed in order to identify the alternatives.

6.2.2 Analysis

Three circles with a radius of 30, 50 and 70 km were drawn around the centre point, see Figure 6.4.

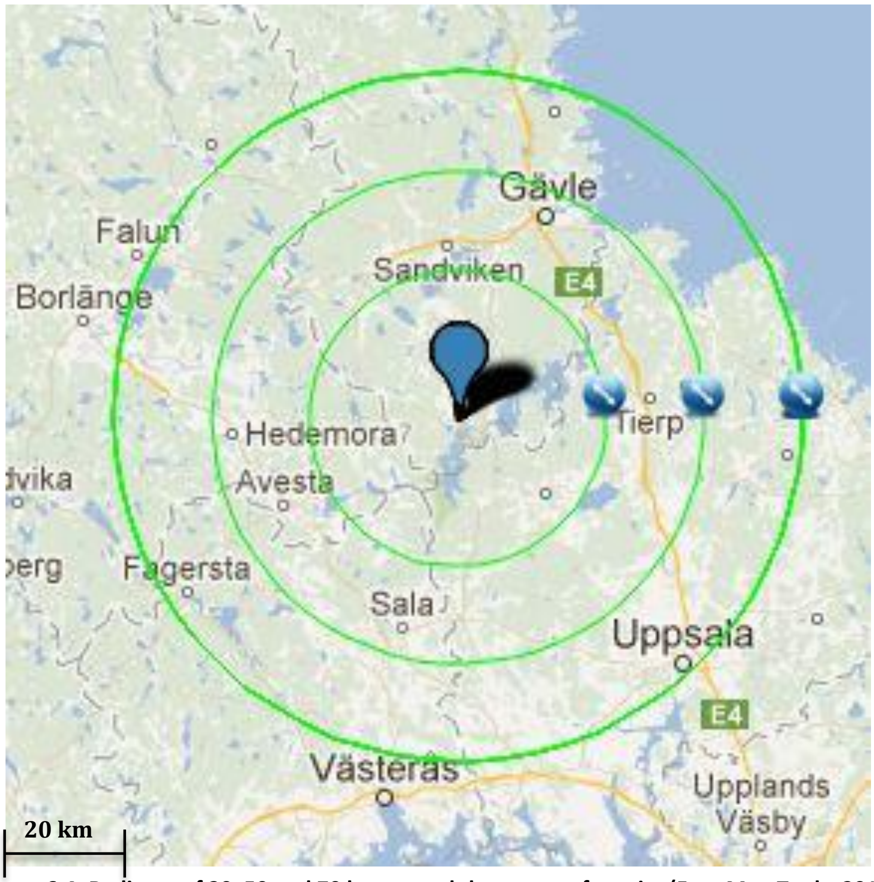

Figure 6.4: Radiuses of 30, 50 and 70 km around the centre of gravity (Free Map Tools, 2012)

In each iteration, meaning each time a circle was drawn, a number of towns were found, see Table 6.1. The towns found in each iteration were analysed according to the qualifiers. Three iterations were needed since no towns fulfilling the qualifiers were found in the first iteration and only one town in the second iteration. The towns with the same distance from the optimal coordinates do not necessarily have the same transportation cost. The cost depends on the flow and the variable cost per load metre and kilometre from all other terminals in the network. For simplicity, the circles are used to find possible locations near the optimal coordinates since the radius is small and no extreme differences in costs are expected.

Table 6.1: Towns identified in the three iterations

Iteration	Identified towns
2	Tierp
2	Heby
2	Gävle
2	Älvkarleby
2	Sandviken
2	Hofors
2	Hedemora
2	Avesta
2	Sala
3	Uppsala
3	Ockelbo
3	Säter
3	Fagersta
3	Norberg

In addition to the identified towns, the current hub is added to the analysis. Next, it is explained how the towns were analysed with respect to each qualifier.

Highway Access

The towns' highway access were analysed by investigating if a junction point were found within a 4 km radius from the town, the result is presented in Table 6.2. The large roads, which create the junction point, are also presented and refer to a European or a national highway. The towns, which have a junction point closer than 4 km, qualify to the next qualifier.

Table 6.2: Evaluation of the town's highway access

Town	Large road(s)	Junction point within 4 km
Tierp	E4	No
Heby	56, 72	No
Gävle	E4, 68, 76, 80	Yes
Älvkarleby	76	No
Sandviken	68, 80	No
Hofors	80	No
Hedemora	70	No
Avesta	68, 70	No
Sala	56, 70	No
Uppsala	E4, 55, 72	Yes
Ockelbo	-	No
Säter	70	No
Fagersta	66, 68	No
Norberg	68	No
Current hub	EXX, XX	Yes

Gävle, Uppsala and the current hub all fulfil the qualifier highway access and these are further investigated in the analysis of the next qualifier.

Labour Availability

The population in each municipality in the end of 2011 was collected from SCB (2012). From Ekonomifakta (2011) the share of unemployed 20-64 year olds of Sweden's total population was collected, which was 4 % by the end of year 2011. Next, the number of unemployed 20-64 year olds in each municipality was calculated by equation 5.5. The result can be seen in Table 6.3.

Table 6.3: Evaluation of the towns' labour availability

Town	Population in municipality	Share of unemployed 20-64 year olds of total population	Number of unemployed 20-64 year olds in municipality	Town qualified
Gävle	95 428	4%	3 817	Yes
Uppsala	200 001	4%	8 000	Yes
Current hub	100 000[6]	4%	4 000	Yes

All towns do all qualify since the number of unemployed 20-64 year olds in the municipality is considered to be high enough to have available workers for a new hub.

Delivery Time to Customers

After discussions with the supervisor at Company X, it could be concluded that the region around the optimal hub location would be able to achieve the set delivery time to customers. This statement is illustrated in and confirmed with Figure 6.5.

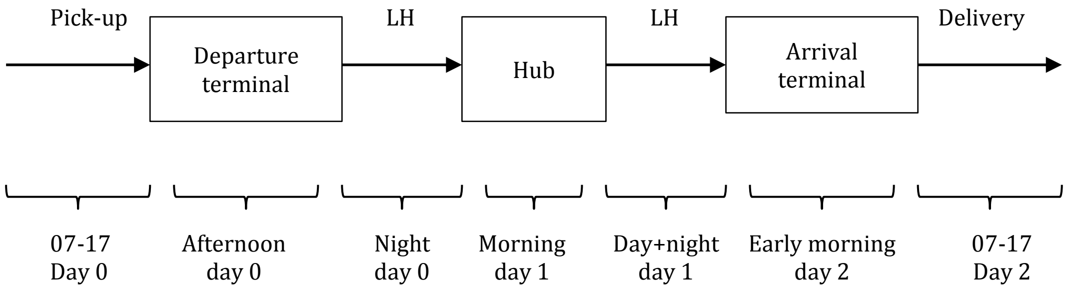

Figure 6.5: Illustration of the achievement of the delivery time for the alternative hub locations

If goods are sent from Skåne, in south Sweden, day 0, it arrives at the nearest terminal at the afternoon day 0. To enable a delivery to customers in Lappland, in north of Sweden, within the set delivery time of two days, the goods have to be delivered to their closest terminal at latest in the early morning day 2. The time to transport goods the region with the optimal hub location to the terminal in Lappland is approximately 9 hours. Consequently, the transport need to departure from the hub at the evening day 1. This means that there is about 24 hours for letting the sending terminal transport the goods

[6] The exact population in the current hub has been disguised, but is in the magnitude of 100 000.

to the hub and letting the hub handle and prepare the goods for the next transport to the receiving terminal. It is considered to be enough time for those activities.

For delivery day 1, the goods are sent from the middle of Sweden day 0, it arrives at the nearest terminal at the afternoon day 0. To enable a delivery to customers in north Sweden within the set delivery time of one day, the goods have to be delivered at the closest terminal at latest in the early morning day 1. As said, the time to transport goods from the hub to the north of Sweden is around 9 hours. The time from transport from the sending terminal to the hub is approximately 1 hour since the hub is located in middle of Sweden. So the goods need to departure the hub at latest 10 PM day 0 to arrive in north of Sweden in the early morning. This schedule is also considered reasonable.

It is concluded that the region with the optimal hub location is able to achieve the set delivery time. The current hub location does also achieve the delivery time since it is the hub in the current network and the delivery times to customers are achieved today.

Driving and Rest Periods

The requirements of driving and rest periods are also considered to be fulfilled. Currently, there are transports from the region with the optimal hub location to the terminals in the north of Sweden. Since the driving time can be longer than the accepted driving period, this is solved by changing driver on the way. After discussion with the supervisor, it is therefore concluded that this qualifier is fulfilled for all the alternatives.

Environmental Regulations

Since this analysis only investigates the geographic location of a hub and not specific sites at the location, this qualifier is not considered in the analysis in this thesis.

Construction Feasibility

This is also a site-specific qualifier and is therefore not considered in this analysis according to the same arguments as above.

6.2.3 Result Discussion

The locations that fulfil the qualifiers are Gävle, Uppsala and the current hub. After discussion with the supervisor at Company X, it is confirmed that these locations are feasible as alternatives for a hub location. They are located within 4 km from a junction point, have available labour and they fulfil the requirements of delivery time and driving and rest periods. It is not analysed if the locations fulfil the existing environmental regulations and the construction feasibility. That analysis has to be made when a specific site is chosen at the location.

6.3 Calculation of Parameter Score

6.3.1 Introduction

The alternatives considered to fulfil the qualifiers are then analysed according to nine parameters. It is not required that the alternative locations have to fulfil the parameters but the more they fulfil the parameter the higher weight do they get in the evaluation. This is part of sub model 3, see Figure 6.6.

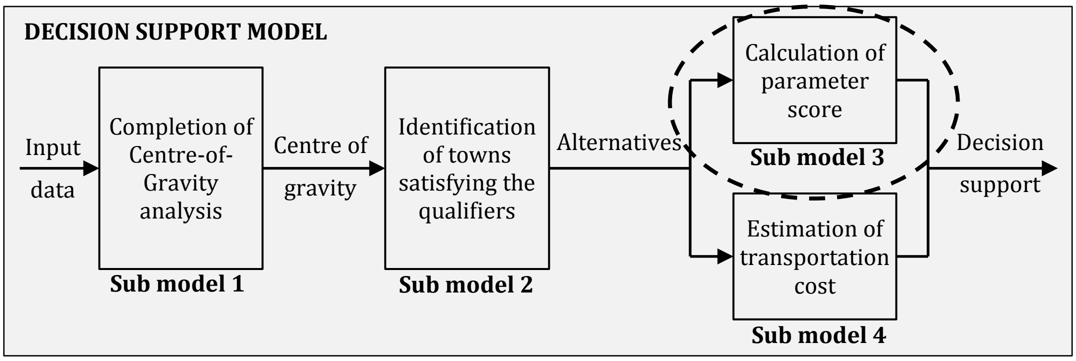

Figure 6.6: Sub model 3 of the decision support model

The purpose of this analysis is to find the eigenvector for the alternatives for each parameter. The weighting is performed to conclude which alternative that is the best hub location according to the parameters. In turn, the parameters are also weighted to include the importance of the parameters according to Company X's opinion. Table 6.4 shows how the importance is translated into weights.

Table 6.4: Scale used to quantify the importance of the parameters

Importance	Equally good	Little better	Much better	Very much better	Absolute better
Weight	1	3	5	7	9

If alternative A is "Little better" than alternative B, then A gets a weight of 3 in comparison with B. Consistency is not assumed when weighting the alternatives.

6.3.2 Analysis

To analyse each alternative location, the authors searched information about the parameters for each alternative to enable a quantification and weighting. The parameters included in the analysis were railway access, congestion, living costs and family conditions, location costs, wages, weather, closeness to similar companies, cost of return goods flow from northern Sweden and closeness to nearby terminal to support goods handling at hub. The analysis of the alternatives for each parameter is presented below.

Railway Access

Railway access for a company handling goods, require a loading zone at the railway. There are about 130 loading zones in Sweden (Trafikverket, 2012). There are loading zones in Uppsala and at the current hub. They are therefore considered to be equally good at railway access. Though, for Gävle, the goods need to be transported to the nearest loading zone when using the railway. The comparison values and the input data are shown in Table 6.5.

Table 6.5: Comparison values for railway access

Input data	Comparison values: Railway access			
Distance (km)		Gävle	Uppsala	Current hub
38	Gävle	1.00	0.14	0.14
0	Uppsala	7.00	1.00	1.00
0	Current hub	7.00	1.00	1.00

The input data is presented in the first column and is the distance between the alternatives and a loading zone. Gävle is located approximately 38 km from a loading zone. The locations with 0 km have a loading zone in the city and it would be possible to locate a hub 0 km from there. The tables in this section should be read from left. So the weights represent how much better the alternatives in the left column are compared to the alternatives in the upper column. Since Gävle has to transport goods by truck from the hub and to the loading zone, Upppsala and the current hub location are considered to be "Very much better" than Gävle at railway access and got a comparison value of 7 compared with Gävle. These two cities do not have to be supported by trucks when using the railway since there is a loading zone nearby.

The comparison values in Table 6.5 resulted in weights for each alternative location. These were calculated in the same way as the weights of the parameters, explained in section 5.2.4. The geometric average was calculated and from that, each weight. The weights for the locations concerning railway access are presented in Table 6.6.

Table 6.6: Weights for railway access

Alternative	Gävle	Uppsala	Current hub
Weight	0.07	0.47	0.47

The sum of the weights is 1. It can be concluded that Uppsala and the current hub have the highest weights of 0.47 since they are closest to a railway loading zone. Gävle has the weight 0.07 because the loading zone is 38 km from there.

Congestion

Congestion can affect both Company X's quality of service and costs. The opinion of Company X according to the group discussion was that congestion is an important parameter to consider because of its effects on transports to and from a facility. The values of each comparison as well as the input data are presented in Table 6.7.

Table 6.7: Comparison values for congestion

Input data	Comparison values: Congestion			
Average traffic flow (Vehicles/day)		Gävle	Uppsala	Current hub
24 000	Gävle	1.00	4.00	4.00
29 410	Uppsala	0.25	1.00	1.00
30 070	Current hub	0.25	1.00	1.00

The traffic flow considered for each alternative regards the road near the city with the largest average of vehicles per day and is presented as Input data in the first column (Trafikverket, 2010). Gävle is considered to be almost "Much better" than Uppsala and the current hub since Gävle has 6 000 less vehicles per day at the most crowded road. The comparison value for Gävle is therefore 4 compared to Uppsala and the current hub.

The weights for the locations concerning congestion were calculated which resulted in Table 6.8.

Table 6.8: Weights for congestion

Alternative	Gävle	Uppsala	Current hub
Weight	0.67	0.17	0.17

Gävle has the highest weight of 0.67 since it is the location with the least traffic flow and therefore is considered to have the least congestion.

Living Costs and Family Conditions

Living costs and family conditions are considered by the company as very important when deciding of a hub location. The alternatives are analysed according to Fokus (2011) which presents a ranking of the municipalities in Sweden based on living conditions. This ranking includes 44 variables concerning life as young, life as older, family conditions, work climate and fundamental variables as crime, taxes and healthiness. The comparison values for living costs and family conditions and the input data are presented in Table 6.9.

Table 6.9: Comparison values for living costs and family conditions

Input data	**Comparison values: Living costs and family conditions**			
Ranking		Gävle	Uppsala	Current hub
207	Gävle	1.00	0.14	0.33
45	Uppsala	7.00	1.00	5.00
162	Current hub	3.00	0.20	1.00

Uppsala has the best ranking of 45 and Gävle has the worst of 207, see the first column Input data. From this, Uppsala is for example "Very much better" than Gävle since their difference in ranking is about 150 placements. Uppsala has therefore a comparison value of 7 compared with Gävle.

Table 6.10 summarizes the weights, calculated based on the comparison values above. The table presents the weights regarding living costs and family conditions.

Table 6.10: Weights for living costs and family conditions

Alternative	Gävle	Uppsala	Current hub
Weight	0.08	0.73	0.19

These weights are calculated based on the ranking in Table 6.9. Uppsala, which has the best ranking, has also the highest weight of 0.73.

Location Costs

The analysis of the location costs for the different alternative locations is based on the current rental charge for the terminals. The rental charge for a couple of terminals with different building years have been mapped and the location costs for the alternatives have been estimated based on that. The comparison values based on this mapping are shown in Table 6.11.

Table 6.11: Comparison values for location costs

Comparison values: Location costs			
	Gävle	Uppsala	Current hub
Gävle	1.00	7.00	1.00
Uppsala	0.14	1.00	0.14
Current hub	1.00	7.00	1.00

The input data to these comparison values is not presented due to confidentiality. It is considered that Gävle and the current hub location has a comparison value of 7 and is therefore ”Very much better” than Uppsala at location costs. Consequently, they are considered to get a lower location cost than Uppsala based on the current rental charges.

The weights based on the comparison values above are presented in Table 6.12.

Table 6.12: Weights for location costs

Alternative	Gävle	Uppsala	Current hub
Weight	0.47	0.07	0.47

The weights reflect the estimation of the future location costs for the alternative locations. Uppsala is considered to be most expensive and gets therefore a weight of 0.07 while Gävle and the current hub get a weight of 0.47.

Wages

The basis for the comparison values for this parameter is an additional salary that is paid to terminal workers and differs between terminals and new and currently employees. This information is confidential and is not presented as input data to the weighting. The comparison values are presented in Table 6.13.

Table 6.13: Comparison values for wages

Comparison values: Wages			
	Gävle	Uppsala	Current hub
Gävle	1.00	1.00	4.00
Uppsala	1.00	1.00	4.00
Current hub	0.25	0.25	1.00

If the hub would be located in Gävle or Uppsala, there would be a need of hiring new employees and they would then get the wage according to the collective labour agreement. If it is concluded that the best hub location would be where it is currently located, their agreement with the wages for currently employees would remain. It is therefore considered that Gävle and Uppsala is almost "Much better" than the current hub since the current hub pays higher salaries which is a higher cost for Company X.

The weights, calculated based on the comparison values, are presented in Table 6.14.

Table 6.14: Weights for wages

Alternative	Gävle	Uppsala	Current hub
Weight	0.44	0.44	0.11

Since Gävle and Uppsala would pay the same wage for new employees, they get the same weight of 0.44. The current hub, which has a higher additional wage, gets a weight of 0.11.

Weather

The comparison values for the weather are presented in Table 6.15. They are based on the average number of days per year with snow from 1961 to 1990 at different regions, which is the input data in the table.

Table 6.15: Comparison values for weather

Input data	**Comparison values: Weather**			
Days with snow		Gävle	Uppsala	Current hub
125	Gävle	1.00	0.20	3.00
75	Uppsala	5.00	1.00	7.00
150	Current hub	0.33	0.14	1.00

Uppsala has in average 75 days with snow, Gävle has 125 days and the current hub has 150 days with snow (SMHI, 2012). With this input data it is considered that Gävle is "Little better" than the current hub at weather since Gävle has in average 25 less days with snow per year and Gävle gets therefore a comparison value of 3 compared to the current hub. Uppsala is "Much better" than Gävle since Uppsala has 50 less days with snow and gets thereby a value of 5 compared to Gävle.

The table above has been further calculated as for the other parameters, which resulted in Table 6.16. This table presents the weights for each alternative concerning weather.

Table 6.16: Weights for weather

Alternative	Gävle	Uppsala	Current hub
Weight	0.19	0.73	0.08

The current hub has 150 days with snow and therefore a weight of 0.08. Gävle has 125 days with snow and therefore a weight of 0.19 and Uppsala has a weight of 0.73.

Closeness to Similar Companies

The parameter closeness to similar companies refers to the number of companies in the same business, as 3PL companies and companies with wholesale warehouses, located within the same area at each alternative location. It is assumed that the number of businesses increases as the population but not necessarily proportionally. Consequently, the alternative locations are compared based on population but it is assumed that as the population increases the rate of increasing number of companies decline. The input data and the comparison values are presented in Table 6.17.

Table 6.17: Comparison values for closeness to similar companies

Input data	**Comparison values: Closeness to similar companies**			
Population		Gävle	Uppsala	Current hub
95 428	Gävle	1.00	0.33	2.00
200 001	Uppsala	3.00	1.00	4.00
50 712	Current hub	0.50	0.25	1.00

Uppsala, with a population of 200 000 citizens are considered to be almost "Much better" than the current hub and "Little better" compared to Gävle and has therefore a comparison value of 4 and 3 respectively. Gävle has a comparison value of 2 since it is considered to be almost "Little better" than the current hub with 50 000 more citizens.

The weights, calculated from the matrix above, are shown in Table 6.18.

Table 6.18: Weights for closeness to similar companies

Alternative	Gävle	Uppsala	Current hub
Weight	0.24	0.63	0.14

The weights reflect the population, Uppsala with the greatest population has got the highest weight of 0.63.

Cost for Return Goods Flows From Northern Sweden

The cost for return goods flows from northern Sweden is an important factor to take into consideration when locating a hub according to the group discussion. Northern Sweden refers to the terminals located north of the current hub. The comparison values of each comparison are presented in Table 6.19. Input data is also presented.

Table 6.19: Comparison values for cost for return flows from northern Sweden

Input data	**Comparison values: Cost for return goods flows from northern Sweden**			
Distance (km)		Gävle	Uppsala	Current hub
213	Gävle	1.00	2.00	0.25
312	Uppsala	0.50	1.00	0.20
0	Current hub	4.00	5.00	1.00

The cost for return goods flow from northern Sweden is assumed to be correlated to the distance from the hub to northern Sweden. A longer distance to transport low utilised vehicles implies a higher cost. Therefore, the distance from each alternative location to the current hub has been compared. Since the distance to the current hub is measured, this alternative gets the input data of 0 km. The current hub is considered to be almost "Much better" than Gävle and "Much better" than Uppsala. This is because all the other alternatives have a longer distance to northern Sweden.

The weights for the locations concerning cost for return goods flows from northern Sweden were calculated, which resulted in Table 6.20.

Table 6.20: Weights for cost for return flows from northern Sweden

Alternative	Gävle	Uppsala	Current hub
Weight	0.20	0.12	0.68

The current hub has the highest weight of 0.68 while Gävle score 0.20 and Uppsala 0.12 since the two last are located further away from northern Sweden than the current hub.

Closeness to Nearby Terminal to Support Goods Handling at Hub

The distance from each alternative to the nearest terminal has been measured in order to quantify the closeness to nearest terminal to enable support of goods handling at hub. The comparison values for the closeness to a nearby terminal for each alternative and the input data are presented in Table 6.21.

Table 6.21: Comparison values for closeness to nearby terminal

Input data	**Comparison values: Closeness to nearby terminal**			
Distance (km)		Gävle	Uppsala	Current hub
104	Gävle	1.00	0.33	4.00
39	Uppsala	3.00	1.00	8.00
189	Current hub	0.25	0.13	1.00

Gävle has 104 km to the nearest terminal, see the left column Input data. Uppsala has 39 km to the nearest terminal and the current hub has 189 km. Uppsala was considered to be "Little better" than Gävle and got a comparison value of 3 while the distance to the nearest terminal was significantly shorter than for the current hub. Uppsala has therefore got a comparison value of 8 compared to the current hub.

The weights concerning closeness to nearest terminal were calculated and are presented in Table 6.22.

Table 6.22: Weights for closeness to nearby terminal

Alternative	Gävle	Uppsala	Current hub
Weight	0.26	0.67	0.07

Since the current hub has the longest distance to the nearest terminal it got the lowest weight of 0.07. Gävle got a weight of 0.26 and Uppsala with the nearest terminal got a weight of 0.67.

6.3.3 Result Discussion

The result of the analyses in the section above is summarized in Table 6.23. The calculations of the weights for each parameter in the left column (RVV) are presented in section 5.2.4.

Table 6.23: Parameter weights and weights for each alternative according to the parameters

Parameter	Parameter weight	Gävle	Uppsala	Current hub
Railway access	0.05	0.07	0.47	0.47
Congestion	0.31	0.67	0.17	0.17
Living costs and family conditions	0.21	0.08	0.73	0.19
Location costs	0.10	0.47	0.07	0.47
Wages	0.05	0.44	0.44	0.11
Weather	0.01	0.19	0.73	0.08
Closeness of similar companies	0.06	0.24	0.63	0.14
Cost of return goods flows from northern Sweden	0.12	0.20	0.12	0.68
Closeness of nearby terminal	0.08	0.26	0.67	0.07
Total score	**1.00**	**0.36**	**0.37**	**0.27**

The columns for Gävle, Uppsala and the current hub correspond to the Option Performance Matrix (OPM) in section 3.4.2. The value in the last row presents the total score of each alternative considering all parameters, also called Value for money (VFM). This total score gives an indication of which alternative that is considered to be best according to the set parameters. Uppsala is the alternative with the highest score of 0.37. However, the difference between the scores is marginal, Uppsala is only slightly better compared to Gävle, which is next best. One reason for Uppsala's high score can be that it has a high weight of living costs and family conditions, which is considered by Company X to be a very important parameter. Gävle has a high weight of congestion which is also considered to be a parameter with a large impact on hub localisation.

6.4 Estimation of Transportation Cost

6.4.1 Introduction

The transportation cost is estimated for each alternative location to give an indication of the difference in costs between the alternatives. This is part of sub model 4, see Figure 6.7.

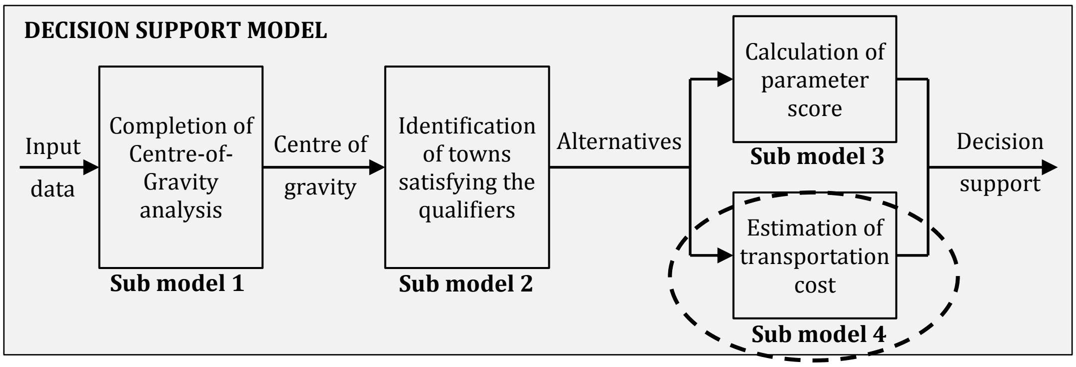

Figure 6.7: Sub model 4 of the decision support model

The input to these calculations was cost per load metre and kilometre for each line in the network, the amount of load metre for each line and the distances between the terminals and the alternative locations.

6.4.2 Calculations and Result Discussion

The transportation costs for each alternative were calculated according to the formula in equation 6.1.

$$Transportation\ cost = \frac{Cost}{Load\ metre\ and\ km} * Amount\ of\ load\ metre * Distance\ (km)$$

(Equation 6.1)

The transportation costs for each line per alternative location were added to get the total cost per alternative. The costs for the alternative locations do not exist today so they have been assumed to be the same as the costs through the current hub. An estimation of the total cost for each alternative is presented in Table 6.24.

Table 6.24: The estimated total transportation cost for each alternative

Alternative	Gävle	Uppsala	Current hub
Transportation cost	47 069 402	47 709 359	53 663 706

Gävle and Uppsala have almost the same costs for transporting goods through the respective hub. The current hub's transportation costs are about 6 million more than the other alternatives. This since the current hub is located a longer distance from the centre of gravity. Consequently, the current hub is 14.0% more expensive than Gävle, which is the cheapest alternative, and 12.5% more expensive than Uppsala.

6.5 Output: Decision Support

The final result of the analysis above includes a summary of the parameter score and an estimated transportation cost for each alternative. The output of the model is illustrated in Figure 6.8.

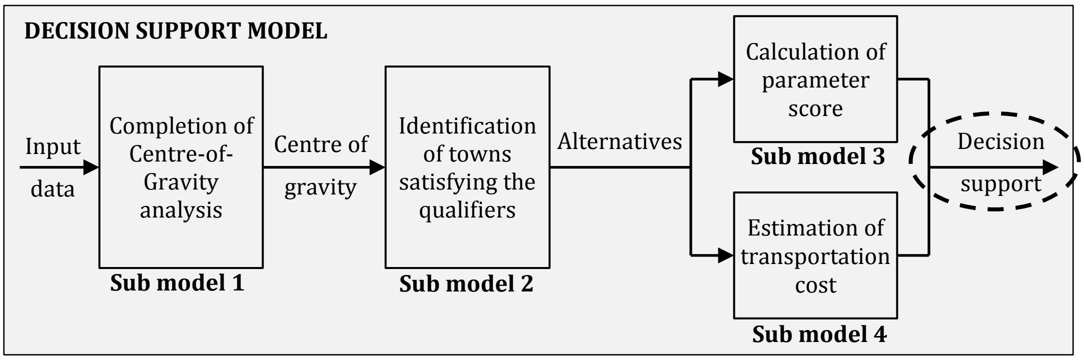

Figure 6.8: The output of the decision support model

The score and the cost for the alternative hub locations are presented in Table 6.25.

Table 6.25: The parameter score and transportation cost for the alternative locations

Alternative	Gävle	Uppsala	Current hub
Parameter score	0.36	0.37	0.27
Transportation cost	47 069 402	47 709 359	53 663 706

Table 6.25 shows that Uppsala is the alternative with the highest parameter score closely followed by Gävle. As a result, Uppsala is the alternative which best satisfies all the parameters. If only considering the parameter score, Uppsala would be the best location where to have a hub based on the current situation for Company X.

From Table 6.25 it can be concluded that Gävle has the lowest transportation cost. Therefore, if only looking at the transportation cost the hub should be located in Gävle. In addition, the Uppsala has a transportation cost which is relatively close to the cost of Gävle. The current hub has a much larger transportation cost than the other alternative locations, due to the large distance between the current hub and the centre of gravity.

To sum up, there is no alternative with both the highest parameter score and the lowest transportation cost. Though, the parameter score do not differ significantly and neither do the transportation cost for Gävle and Uppsala. Since the current hub has the highest transportation cost and the lowest parameter score, it is not considered to be the best hub location according to this model. Uppsala has a slightly better parameter score compared to Gävle which on the other hand has a 1.3% lower transportation cost. The difference in parameter score and transportation costs is marginal for Gävle and Uppsala and it is considered that a decision of an optimal hub location cannot be taken on this basis. Since the transportation cost is estimated and the parameter score is performed subjectively by the authors, and the difference between the alternatives is marginal, the risk of errors affecting the result is too high. It is therefore agreed that Gävle and Uppsala are equally good as hub localisations.

6.6 Sensitivity Analysis

To investigate how sensitive the model is a sensitivity analysis has been performed. Sub model 1, 3 and 4 will be analysed where it will be examined how changes in input data will change the output data for each sub model. If changes in the output are small when the input data is altered the model is not considered to be sensitive.

6.6.1 Sensitivity of the Centre of Gravity

Changes of Flow of Goods in Northern and Southern Direction

The sensitivity of the model when changing the input data of the flow of goods to the Centre-of-Gravity analysis was investigated. First, the northern and the southern goods flows for all lines were increased with 10 % and decreased with 10 % respectively. The northern flow refers to all goods transported with lines to or from the current hub in the north direction and the southern flow vice versa. The different scenarios and the outcome are presented in Table 6.26.

Table 6.26: Centre of gravity after changes of goods flow in northern and southern direction

No.	Scenario	X-coordinate	Y-coordinate
A	Southern flow -10%	60.32130	16.83769
B	Northern flow +10%	60.31973	16.83575
C	Original data	60.30448	16.81687
D	Southern flow +10%	60.28861	16.79723
E	Northern flow -10%	60.28690	16.79512

To further illustrate the changes of the different scenarios, the coordinates were plotted together with the centre of gravity from the original data, see Figure 6.9.

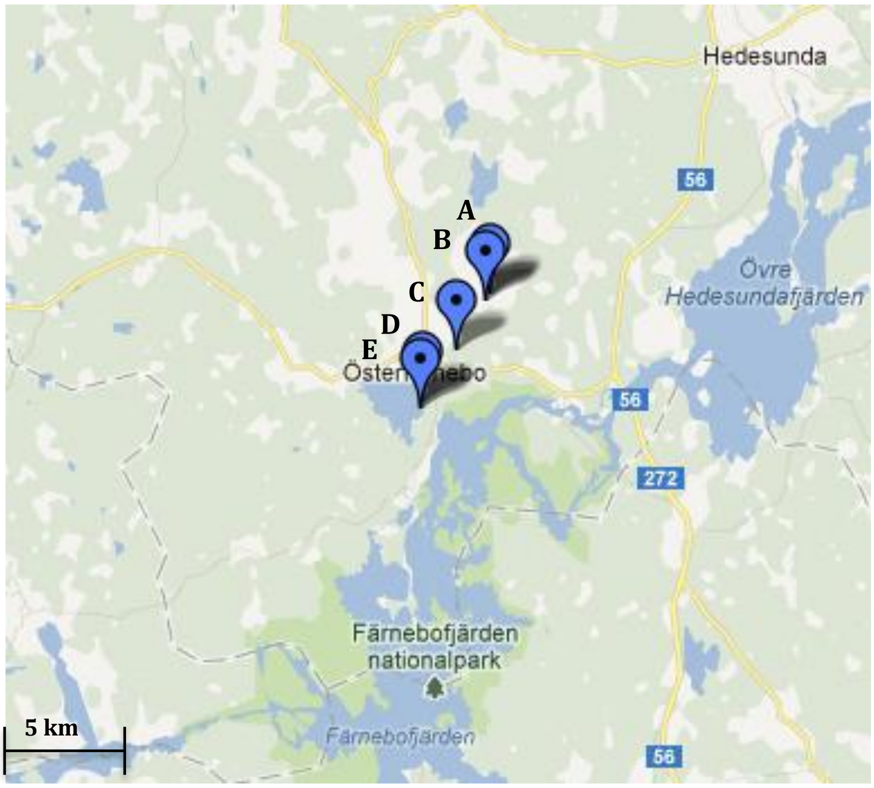

Figure 6.9: Centre of gravity for scenarios when changing the southern and northern flows

As can be seen in the figure, the coordinates for the different scenarios are located almost at the same place. The coordinates for scenario A and B are located very close to each other, this is also the case for scenario C and D. This can be explained by the fact that an increase in one direction is almost the same as a similar decrease in the other direction. The distance between the original centre point and the other locations is about 2 km.

The conclusion one can draw from this analysis is that the model is not very sensitive when changing the size of the goods flows in one direction. When increasing or decreasing the goods flows in one direction with 10% results in a new centre point which is located approximately 2 km from the original one.

Changes in Goods Flows on the northern lines

The sensitivity of the model has also been analysed by only changing the size of the goods flow for the northern lines. The northern lines are here defined as the lines between the hub and the terminals north of the hub. Since the change of flows in northern and southern direction did not result in any significant change of the centre of gravity this was investigated. Moreover, as an increase in the northern flow almost gives the same result as a decrease in the southern flow, it was decided to only analyse a change in the goods flows for the northern lines.

The scenarios with an increase of 10% and 20% respectively and a decrease of 10% and 20% respectively in the flow of the northern lines in both directions were analysed. The outcome of this analysis is presented in Table 6.27.

Table 6.27: Centre of gravity after changes of flow for the northern lines

No.	Scenario	X-coordinate	Y-coordinate
A	Flow northern lines +20%	60.44628	16.95384
B	Flow northern lines +10%	60.15295	16.67050
C	Original data	60.30448	16.81687
D	Flow northern lines -10%	60.57926	17.08229
E	Flow northern lines -20%	59.99064	16.51372

The coordinates for the different scenarios have been plotted in a map and can be seen in Figure 6.10. Each location in the map have been labeled with the same letter as in Table 6.27.

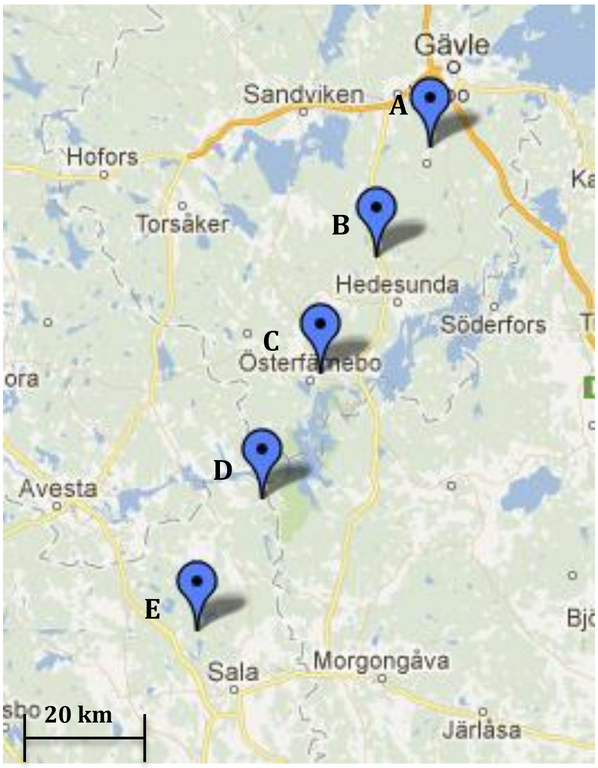

Figure 6.10: Centre of gravity for scenarios when changing the flows for the northern lines

The scenarios in this sensitivity analysis give a larger change in the centre point of gravity than the previous sensitivity analysis. However, Figure 6.10 shows that the model is not very sensitive to changes in the goods flow for the northern lines. The greatest distance between the centre point for the scenarios and the original centre point is around 35 km. Accordingly, the model is not considered to be sensible for changes in the input goods flow data.

Changes in Transportation Cost

By examining how changes in the transportation cost, which includes the fuel surcharge cost, affects the centre of gravity, the sensitivity of the model is analysed. The lines to and from the northern terminals where chosen to be the focus of this investigation, meaning that the transportation cost for these lines were changed at the same time. This procedure was chosen since no change in the centre of gravity was identified when changing the transportation cost for all lines simultaneously. An alternative to this analysis could be to change the transportation cost for the lines to and from the southern terminals instead. However, this was not selected since the result of the analysis would be more or less the same if analysing the southern terminals.

The following scenarios where studied; an increase of the transportation cost by 10 % and 20 % and a decrease of 10 % and 20 % for the transportation cost respectively for the lines to and from the northern terminals. The resulting coordinates for the centre of gravity were compared with the result from the original data. The outcome of the analysis is presented in Table 6.28.

Table 6.28: Centre of gravity after changes of the transportation cost for the northern lines

No.	Scenario	X-coordinate	Y-coordinate
A	Transportation cost northern lines +20%	60.57926	17.08229
B	Transportation cost northern lines +10%	60.44628	16.95384
C	Original data	60.30448	16.81687
D	Transportation cost northern lines -10%	60.15295	16.67050
E	Transportation cost northern lines -20%	59.99064	16.51372

The coordinates for the centre of gravity of the different scenarios have been plotted in a map which can be seen in Figure 6.11. Each location in the map have been labeled with the same letter as in Table 6.28.

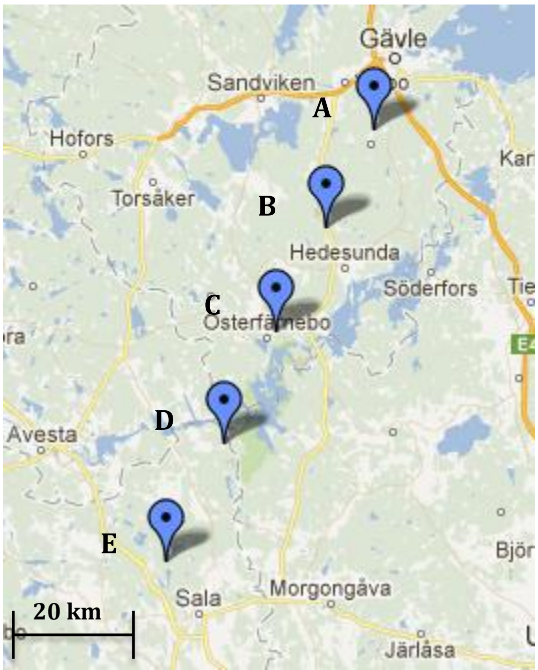

Figure 6.11: Centre of gravity when changing the transportation cost for the northern lines

It can be concluded that the model is not very sensible for changes in the transportation cost. The largest difference in centre of gravity from the original solution C, is scenario E where its location is located about 35 km southwest of location C. Since the towns, which have been investigated in the analysis, all are located in the proximity of points A, B, D and E the model is considered not to be sensible for changes in transportation cost.

6.6.2 Sensitivity of the Parameters' Comparison Values

In the group discussion, managers at Company X discussed eight different comparisons in order to weight parameters according to their importance, see Appendix D. The group's views were scattered in three of the comparisons, namely comparison 2, 3 and 4. They agreed on comparison values but the discussion showed that there were different opinions regarding how the parameters should be valued. The sensitivity of these three comparisons and how a difference in comparison value would affect the parameter score for each alternative is analysed here.

Changes in Comparison 2

The second comparison included the parameters living costs and family conditions and railway access. It has been analysed how much the comparison value between those two parameters can vary without resulting in a new alternative with the highest parameter score. The total parameter score for the alternatives have been plotted together with the comparison value of how much more important living costs and family conditions are compared to railway access, see Figure 6.12. The comparison value of the parameters is presented on the x-axis and the total parameter score is presented on the y-axis.

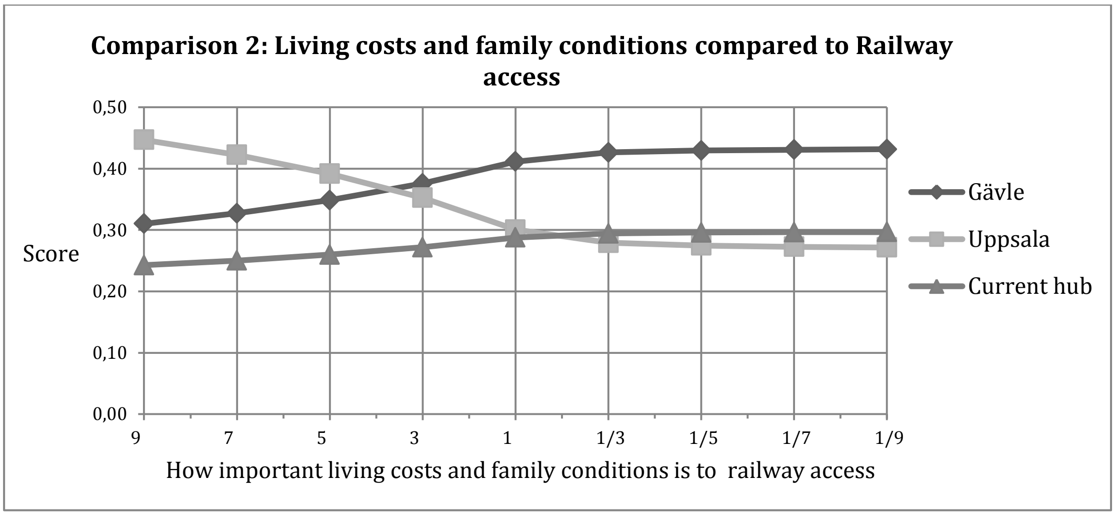

Figure 6.12: Parameter score depending on comparison values in comparison 2

Living costs and family conditions have an original comparison value of 4 compared to railway access. At this comparison value Uppsala is the alternative with the highest parameter score closely followed by Gävle. However, Uppsala only has the best score for the comparison values between 9 and 4, between 4 and 1/9 Gävle is the alternative with the highest score. A comparison value of 1/9 is the same as letting railway access having a comparison value of 9 compared to living costs and family conditions.

Consequently, if the group agrees on the current comparison value or that it is even higher, Uppsala would remain the alternative with the highest score. However, if the group agrees on that living costs and family conditions are less important than the current comparison value Gävle would be the alternative with the highest parameter score. To conclude, the alternative with the highest parameter score changes as the comparison value varies, this makes the result of the parameter score sensible for changes in this comparison value.

Changes in Comparison 3

Comparison 3 is between the parameters congestion and location costs. The parameter score for different comparison values has been plotted in Figure 6.13.

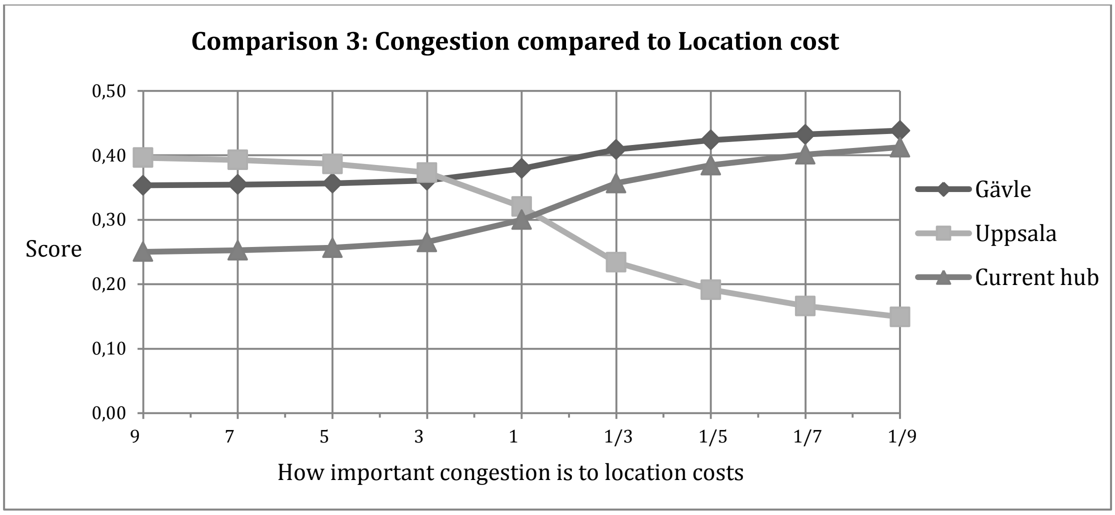

Figure 6.13: Parameter score depending on comparison values in comparison 3

The original comparison value of congestion was 3 compared to location costs, which means that congestion was considered to be more important than location costs. In this case, Uppsala is the alternative with the highest score and is between comparison values 9 and 3. Though, with a comparison value between 2 and 1/9 Gävle has the best score.

Accordingly, if the opinion of the group is changed and it is decided that location cost is more important than congestion another alternative would have the highest parameter score. Therefore, the result of the parameter score is also in this comparison very sensible for changes in the comparison value.

Changes in Comparison 4

The discussion about Living costs and family conditions and wages was named comparison 4. The parameter score for different comparison values has been plotted in Figure 6.14.

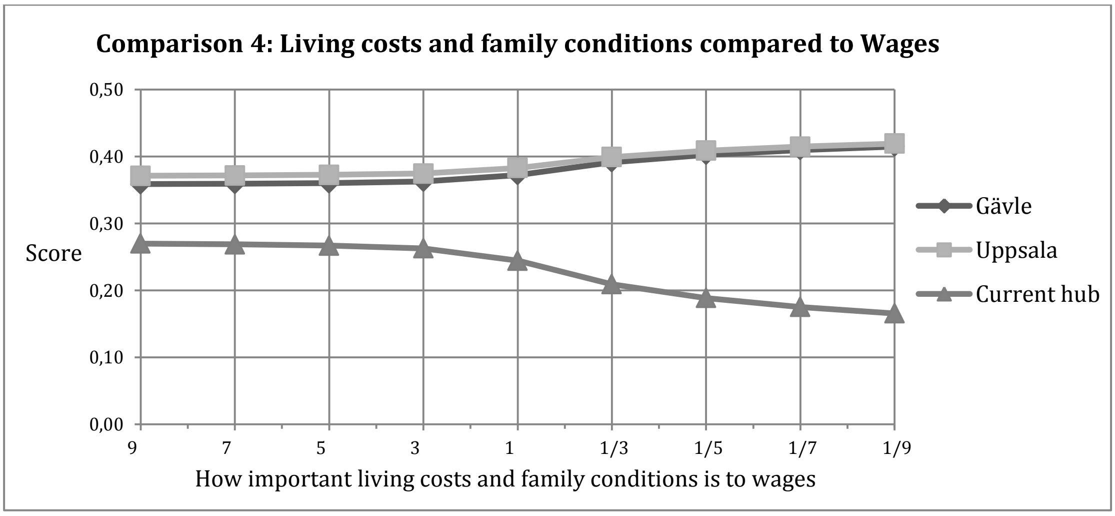

Figure 6.14: Parameter score depending on comparison values in comparison 4

The group agreed that living costs and family conditions are more important than wages which resulted in a comparison value of 4. Naturally, Uppsala has the highest parameter score for this value. The figure shows that the alternative with the highest parameter score is the same no matter which comparison value is chosen. For all comparison values Uppsala has the highest score closely followed by Gävle.

To sum up, changes in this comparison value do not affect which alternative that has the highest parameter score. However, this can be explained by that both Uppsala and Gävle has the same weights for the parameter E, wages.

Conclusion of the Sensitivity Analysis of the Parameter Weights

The conclusion of the sensitivity analyses of the comparisons is that the result of the alternative with the highest parameter score can change depending on the comparison value. Since the group's opinions differed at the group discussion for the three comparisons above, the result of Uppsala as the best alternative for hub localisation could be questioned. To justify the result, a new group discussion is recommended to be held to confirm that the comparison values are correct according to Company X's opinion.

6.6.3 Sensitivity of the Estimated Transportation Cost

Changes in Cost, Flow and Distance Variables

As mentioned before, the transportation cost for each alternative is estimated by cost per load metre and kilometre multiplied with the flow in load metre and the distance in kilometre. When changing one cost parameter, the total cost changes proportionally. The sensitivity of the total transportation cost is therefore proportional to the changes in the cost parameters. Consequently, this means that the model is not sensible for changes in the input data in this aspect.

7 Conclusion

The aim of this final chapter is to answer the initial research questions in order to achieve the purpose of the thesis. In addition, a recommendation to the Company is presented and last, suggestions for further research are discussed.

7.1 Returning to the Purpose of the Thesis

In the introduction chapter it was concluded that Company X doubted the design of their transportation network since problems with delivering goods in time to northern Sweden were discovered. A reason for the issues could be that the company lacks an evidence-based decision-making tool for questions regarding the hub. Moreover, there has not been an evaluation of the hub and its transportation network for many years. Hence, the purpose of this thesis was twofold; first, to develop a decision model, which should be used for decision support to evaluate where to locate a hub, and second, to perform an analysis of the current hub localisation.

Next, the research questions are answered to verify that the purpose has been achieved in the thesis.

7.2 Answering the Research Questions

The first research question was concerning the factors affecting hub localisation:

> *Which factors have to be taken into consideration by Company X when deciding where to locate a hub?*

A number of factors affecting the facility localisation were identified in the literature review. To find the factors which affect the hub localisation for Company X interviews, a questionnaire and a group discussion were held with a number of managers. From the outcome of these, some factors could be disregarded while others were added. The following 16 factors, for Company X to consider when deciding where to locate a hub, were recognised; highway access, labour availability, delivery time to customers, driving and rest periods, environmental regulations, construction feasibility, railway access, congestion, living costs and family conditions, location costs, wages, weather, closeness to similar companies, cost of return goods flows from northern Sweden, and closeness to nearby terminal to support goods handling at hub.

The second research question referred to how to find the optimal hub localisation:

> *How should the alternative hub localisations be identified and evaluated to arrive at a decision support for an optimal hub localisation?*

The alternative hub localisations, short alternatives, were identified and evaluated to arrive at a decision support for an optimal hub localisation by using the constructed model, presented in Figure 7.1.

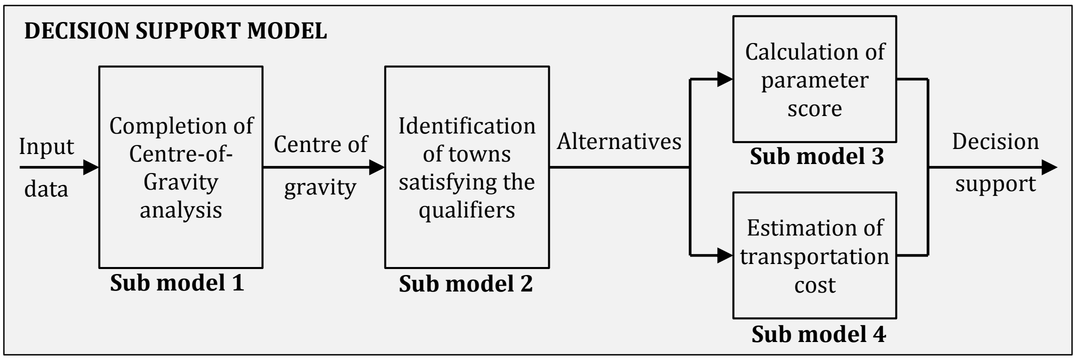

Figure 7.1: The outline of the decision support model

With sub model 1 and 2 the alternatives can be identified by first completing a Centre-of-Gravity analysis where the output is a centre of gravity. Second, towns in the proximity of this point, which satisfies a number of qualifiers, can be identified. Furthermore, the alternatives can be evaluated in sub model 3 and 4 to arrive at a decision support for an optimal hub localisation. In these two sub models a parameter score can be calculated and a transportation cost can be estimated for each alternative. The user can then from the decision support make a decision based on what he or she values the most regarding which hub localisation is the optimal one. Each sub model of the decision support model is further explained in detail.

First, a Centre-of-Gravity analysis for a set of chosen lines can be completed using a set of quantitative input data such as coordinates for current terminals, goods volumes per line, and cost of goods volumes per line. The output of this analysis is a location, called centre of gravity, with a minimised transportation cost for the analysed lines.

Second, the towns in the nearby area of the centre of gravity can be analysed with respect to the factors which were identified as qualifiers. The towns which satisfy these qualifiers, meaning factors which each town needs to fulfil, can be recognised as alternatives. The towns are examined in an iterative process where the towns closest to the centre of gravity can be analysed first. If not enough alternatives are identified, the user can investigate the towns a little further away from the centre of gravity. The iteration is recommended to be stopped when the desired number of alternatives is identified. The user has also the opportunity to add other towns to the analysis. The following qualifiers were identified; highway access, labour availability, delivery time to customers, driving and rest periods, environmental regulations, and construction feasibility. In brief, highway access can be evaluated by looking at the distance from the town to a junction point of two major roads. Moreover, labour availability can be analysed by investigating the number of unemployed 20-64 year olds in the municipality of the town. The achievement of delivery time to customers can be examined by estimating if goods can be delivered to customers within the current timetable. Next, driving and rest periods can also be estimated if they are fulfilled for all the transport lines. Since environmental regulations concerns the specific site this will have to be investigated when the location has been decided. Likewise, the construction feasibility regards the specific site and has to be examined when the location has been decided.

Third, the alternatives can be evaluated by calculating a parameter score for each one. This can be done by using the Analytical Hierarchy Process (AHP) where the parameters are compared pairwise to identify how important they are to consider when deciding of a hub localisation. Then, the alternative hub locations can be evaluated of how well they satisfy each parameter. By using the AHP, they are pairwise compared with regards for each parameter and as a result, each alternative will receive a parameter score. These parameters were identified; railway access, congestion, living costs and family conditions, location costs, wages, weather, closeness to similar companies, cost of return goods flows from northern Sweden, and closeness of nearby terminal to support goods handling at hub. In short, railway access can be evaluated based on the closeness to a railway loading zone. Moreover, congestion can be analysed by looking at the average traffic flow per day near each town. Living costs and family conditions can be examined by using a ranking of the living conditions in the town's municipalities. In addition, location costs can be estimated based on costs for rent and depreciation. The wages concern the difference in terminal workers collective labour agreements. The weather can be analysed by investigating the difference in snow days and cold. Closeness to similar companies can be examined by estimating the number of businesses in the same industry. The cost for return goods flows from northern Sweden can be estimated by comparing the distance from each alternative to northern Sweden. Finally, the closeness to nearby terminal to support goods handling at the hub can be evaluated based on the distance to the closest terminal.

Fourth, the cost of transporting goods via each alternative is estimated based on the input data of cost, goods flow and distance for the lines from sub model 1. Consequently, an estimation of the transportation cost for each alternative is obtained.

Finally, the user receives a decision support where the alternatives' parameter score and transportation cost can be compared. Based on what the user value the most he or she can make a decision of which hub localisation that is the optimal one.

The third research question regards the final result of the analysis of the current situation:

> *What is the optimal hub localisation for the chosen lines according to the developed model and how reliable is the result?*

The output of the decision model is a parameter score and a transportation cost which are used as support to make a decision. The result of the analysis shows that Uppsala has the highest parameter score of 0.37 but is only slightly better than Gävle, which has a score of 0.36. Though, Gävle has the lowest transportation cost even if it is only 1.3% lower compared to Uppsala. With this output of the model, it is considered that it is not possible to make a decision of which location that is best for the hub. The differences between the alternatives are too small to result in an argument for one or the other as the optimal hub location.

However, one must consider how well the model represents the reality and which assumptions that have been made in order to build the model and perform the analysis. The location of both Gävle and Uppsala is reasonable since they are located in mid

Sweden and have good communications to all the other terminals in the transportation network.

The fact that the alternatives fulfil the qualifiers and the way they fulfil the parameters are discussed and validated with the supervisor at Company X. The evaluation of the alternatives according to the parameters is subjective, as the model is built this way, but is considered feasible due to reliable data and awareness of the subjectivity during the performance of the analysis. Due to delimitations of the thesis, some factors affecting the hub localization and the transportation network are not considered in this study. These can have an impact on the decision and need to be considered separately.

A sensitivity analysis has been conducted and the conclusion is that the Centre-of-Gravity analysis is not that sensitive for changes in the input data. The parameters' comparison values are more sensitive and it is confirmed that the alternative with best parameter score changes as the comparison value varies. Therefore, it is difficult to conclude which alternative that is the optimal hub location. Though, the model gives an indication to Company X how well the alternatives suites as hub localisations and can be used as a basis for further discussions.

7.3 Recommendation to Company X

The recommendation to Company X is to implement the model in the organisation and use it as a basis for decisions regarding hub localisation. Since the conclusion of the analysis is that Uppsala or Gävle are the best alternatives for a hub location, it is suggested to question the location of the current hub. Therefore, the location of the current hub should be further analysed to get an overall picture, including the parameters that are excluded in this study. The following points are suggested to take into consideration.

It is advised to analyse other parameters that affect hub localisation which are not included in the model. The effects of the PuD-traffic as well as the alternative of transporting goods directly to the receiving terminal would be interesting to analyse. With a new hub location, there could be goods that are preferable to send directly, which would also reduce the cost of damages that can occur due to increased goods handling at hub.

It is also suggested to map estimated new negotiated transportation costs for lines through the different hub alternatives. This to get a more exact cost that can be compared between the alternatives. Additionally, the cost of investment of a new hub has to be taken into consideration before making a decision.

It is recommended to redo the group discussion and compare all parameters without assuming consistency. This would give a more reliable result of the parameter weights since the parameters are of different aspects. A couple of parameters could be chosen for such a group discussion to reduce the number of comparisons and thereby increase focus on the important ones.

7.4 Suggestions for Future Research

An alternative to expand the existing model is to include additional costs factors in the cost calculations. Except from the transportation costs, wages, location costs and investment costs could be included. This would give a total cost for each alternative and it would enable a more justice comparison between the alternative hub locations.

Another complement to the model would be to develop a simulation model to illustrate the flows in the network. A simulation model would enable an evaluation if a new hub location would achieve the requirements of delivery time. It would also enable an assessment of the fulfilment of driving and rest periods for the drivers. The required changes in the current timetable could be easier to discover and the changes could also be simulated to see if they are reasonable. Key performance indicators would be possible to measure and as a result bottlenecks could be identified.

During this study, it has been discovered that literature regarding localisation of hub from a 3PL perspective is meagre. The literature used in this research is general facility localisation models and the authors have from there developed a model adapted to hub localisation for a 3PL business such as Company X. It is therefore suggested that research concerning hub localisation from a 3PL perspective is an area, which would be interesting to study further.

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Appendix A

Questionnaire

Följande faktorer ska tas i beaktning, se Table A.1.

Table A.1: Factors affecting hub facility localisation for the questionnaire

Kategori	Nr	Faktor	Förklaring
Infrastruktur	1	Tillgång till motorväg	Tillgång och närhet till motorväg
	2	Tillgång till järnväg	Tillgång och närhet till järnväg
	3	Trafikstockning	Låg risk för trafikstockning
	4	Levnadskostnader och familjeförhållanden	Låga levnadskostnader och bra förhållanden för familjer såsom sjukvård, skola etc.
	5	Tillgänglig arbetskraft	Tillgänglighet på arbetskraft
Kostnader	6	Lokaliseringskostnader	Låga kostnader för lokalisering av faciliteter, mark och hyra
	8	Löner	Låg lönenivå i området
Miljöaspekter	9	Miljömässiga lagar	Uppfyller krav från miljömässiga lagar och förordningar som kan påverka byggnad och transporter
	10	Väder	Låg påverkan på transporter på grund av väderklimat i regionen
	11	Möjlighet att bygga faciliteten	Möjlighet att bygga faciliteten, dvs. tillgänglighet på mark
Marknads-aspekter	12	Närhet till liknande företag	Närhet till liknande företag
	13	Närhet till kunder	Närhet till kunder
	14	Närhet till åkerier	Närhet till åkerier

Nedan följer de sammanställda faktorerna, vänligen fyll i hur viktig respektive faktor är vid lokalisering av en hubb, se Table A.2. Fyll i ett X i den ruta som bäst passar in med din åsikt.

Table A.2: Questionnaire

Nr.	Faktor	Inte alls viktig	Mindre viktig 1	2	Viktig 3	4	Mycket viktig 5	Nöd-vändig
1	Tillgång till motorväg							
2	Tillgång till järnväg							
3	Trafikstockning							
4	Levnadskostnader och familjeförhållanden							
5	Tillgänglig arbetskraft							
6	Lokaliseringskostnader							
7	Löner							
8	Miljömässiga lagar							
9	Väder							
10	Möjlighet att bygga faciliteten							
11	Närhet till liknande företag							
12	Närhet till kunder							
13	Närhet till åkerier							

Har du förslag på faktorer som saknas i sammanställningen och som påverkar lokalisering av en hubb, vänligen fyll i dessa nedan, se Table A.3.

Table A.3: Table where added factors can be written here

Faktor	Inte alls viktig	Mindre viktig 1	2	Viktig 3	4	Mycket viktig 5	Nöd-vändig

Appendix B

Parameters and Spanning Tree for the Group Discussion

Parameters for the group discussion, see Table B.1:

Table B.1: Parameters for the group discussion

No.	Parameter
A	Railway access
B	Congestion
C	Living costs and family conditions
D	Location costs
E	Wages
F	Weather
G	Closeness of similar companies
H	Cost of return goods flows from northern Sweden
I	Closeness to nearby terminal to support goods handling at hub

Spanning tree used in the group discussion, see Figure B.1:

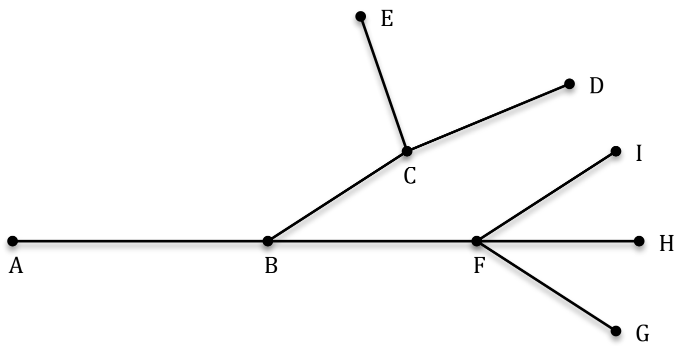

Figure B.1: Spanning tree for the group discussion

Appendix C

Questionnaire to the Group Discussion: Pairwise Comparisons of the Parameters Which Affects Hub Localisation

Vänligen ställ de två parametrarna i respektive jämförelse mot varandra och fundera på vilken som är viktigast vid lokalisering av ny hubb. När du bestämt vilken parameter som är viktigast försök då sätta en siffra på hur mycket viktigare den ena parametern är jämfört med den andra. T.ex. i jämförelse A, om man anser trafikstockning klart viktigare än tillgång till järnväg så kryssar man i ruta ”5” på andra raden.

Parametrar:

1. Tillgång till järnväg
2. Trafikstockning
3. Levnadskostnader och familjeförhållanden
4. Lokaliseringskostnader
5. Löner
6. Väder
7. Närhet till liknande företag
8. Kostnad för returlaster från norra Sverige
9. Närliggande terminal för volymavlastning

Följande skala ska användas vid de parvisa jämförelserna, se Table C.1:

Table C.1: Measurement scale used in the comparisons

Lika viktiga		Lite viktigare		Klart viktigare		Mycket viktigare		Helt klart viktigare
1	2	3	4	5	6	7	8	9

På följande två sidor följer åtta stycken jämförelser, A till H.

Jämförelse A:

1. **Tillgång till järnväg**: Hur viktigt är det att ha tillgång till järnväg i närhet av hubben? Med närhet menas så pass nära att man med fördel skulle kunna utnyttja det till de transporter av gods som bäst sker på järnväg.
2. **Trafikstockning**: Hur viktigt är det att ta hänsyn till risken för trafikstockning när man ska lokalisera en hubb?

	1	2	3	4	5	6	7	8	9
Järnväg över trafikstockning									
Trafikstockning över järnväg									

Jämförelse B:

1. **Tillgång till järnväg**: Hur viktigt är det att ha tillgång till järnväg i närhet av hubben? Med närhet menas så pass nära att man med fördel skulle kunna utnyttja det till de transporter av gods som bäst sker på järnväg.
3. **Levnadskostnader och familjeförhållanden:** Hur viktigt är det att ta hänsyn till levnadskostnader och familjeförhållanden på orten där hubben ska ligga? Familjeförhållanden avser till exempel närhet till sjukvård och skola.

	1	2	3	4	5	6	7	8	9
Järnväg över levnadsförhållanden									
Levnadsförhållanden över järnväg									

Jämförelse C:

2. **Trafikstockning**: Hur viktigt är det att ta hänsyn till risken för trafikstockning när man ska lokalisera en hubb?
4. **Lokaliseringskostnader**: Hur viktigt är det att ha låga hyres- och investeringskostnader för hubben? T.ex. låga ränte- och amorteringskostnader.

	1	2	3	4	5	6	7	8	9
Trafikstockning över lokaliseringskostnader									
Lokaliseringskostnader över trafikstockning									

Jämförelse D:

3. **Levnadskostnader och familjeförhållanden:** Hur viktigt är det att ta hänsyn till levnadskostnader och familjeförhållanden på orten där hubben ska ligga? Familjeförhållanden avser till exempel närhet till sjukvård och skola.
5. **Löner:** Hur viktigt är det att ta hänsyn till lönenivån i området där hubben ska ligga? Hur viktigt är det att titta på denna aspekt när man beslutar var hubben ska ligga?

	1	2	3	4	5	6	7	8	9
Levnadsförhållanden över löner									
Löner över levnadsförhållanden									

Jämförelse E:

1. **Tillgång till järnväg**: Hur viktigt är det att ha tillgång till järnväg i närhet av hubben? Med närhet menas så pass nära att man med fördel skulle kunna utnyttja det till de transporter av gods som bäst sker på järnväg.
6. **Väder**: Hur viktigt är det att väga in vädret i området där hubben ska ligga för att få en låg påverkan på transporterna från snö och kyla?

	1	2	3	4	5	6	7	8	9
Järnväg över väder									
Väder över järnväg									

Jämförelse F:

2. **Trafikstockning**: Hur viktigt är det att ta hänsyn till risken för trafikstockning när man ska lokalisera en hubb?
7. **Närhet till liknande företag:** Hur viktigt är det att en hubb ligger i samma område som liknande företag? (Om det till exempel kan ge infrastrukturella fördelar som att motorvägen förbättras om flera speditörer finns i samma område).

	1	2	3	4	5	6	7	8	9
Trafikstockning över liknande företag									
Liknande företag över trafikstockning									

Jämförelse G:

8. **Väder**: Hur viktigt är det att väga in vädrets effekter i området där hubben ska ligga för att få en låg påverkan på transporterna från snö och kyla?
9. **Kostnad för returlaster från norra Sverige**: Hur viktigt är det att ha en hög fyllnadsgrad av bilarna i båda riktningarna från hubben när man lokaliserar en hubb?

	1	2	3	4	5	6	7	8	9
Väder över fyllnadsgrad									
Fyllnadsgrad över väder									

Jämförelse H:

6. **Väder:** Hur viktigt är det att väga in vädrets effekter i området där hubben ska ligga för att få en låg påverkan på transporterna från snö och kyla?
9. **Närliggande terminal för volymavlastning:** Hur viktigt är det att ta hänsyn till att man har en närliggande terminal som skulle kunna avlasta hubben vid stora volymer och minimera risken för kvarlämnande av gods på hubben?

	1	2	3	4	5	6	7	8	9
Väder över närliggande terminal									
Närliggande terminal över väder									

Appendix D

Result from the Group Discussion

The following parameters were discussed in the workshop:

A. Railway access
B. Congestion
C. Living costs and family conditions
D. Location costs
E. Wages
F. Weather
G. Closeness to similar companies
H. Cost for return goods flows from northern Sweden
I. Closeness to nearby terminal to support goods handling at hub

Eight comparisons were made in the group discussion and the result is presented in Table D.1.

Table D.1: Weights for the comparisons from the group discussion

Comparison	1st parameter			2nd parameter		
	No.	**Parameter**	**Weight**	**No.**	**Parameter**	**Weight**
1	A	Railway access	1	B	Congestion	6
2	A	Railway access	1	C	Living costs and family conditions	4
3	B	Congestion	3	D	Location costs	1
4	C	Living costs and family conditions	4	E	Wages	1
5	A	Railway access	4	F	Weather	1
6	B	Congestion	5	G	Closeness to similar companies	1
7	F	Weather	1	H	Cost for return goods flows from northern Sweden	9
8	F	Weather	1	I	Closeness to nearby terminal to support goods handling at hub	6

Motivation of the pairwise comparisons

The motivation of the decided weights for each comparison which the group had, is described below.

The importance of railway access and congestion were discussed in comparison 1. The group agreed on that congestion is more important to consider when locating a hub than railway access because of the poor railway network in Sweden today. Company X is not able to provide the delivery time that the customers require, with railway transports. When deciding of a hub localisation it is therefore more important to consider congestion than railway access which has a huge impact on the delivery time.

The discussion of comparison 2 motivated the result in the same way as above. Railway transports is not an alternative transport mode today. On the other hand, living costs and family conditions for the employees are of importance for Company X. They value healthy and happy workers since they think that this will increase the effectiveness and in the end provide better service for the customers. Even though the group was not completely agreed, they decided of a weight for this comparison.

Comparison 3 discusses congestion and location costs which are included in the trade-off between service and costs. The group thought that location costs are important since they strive for low costs but on the other hand, low costs can not compensate for poor service due to congestion. Congestion was therefore considered to be more important than location costs when deciding on hub localisation even though the group was not completely agreed on this comparison either.

For comparison 4, specific collective labour agreements control the wages for the workers at a hub but the wages for the officials can vary depending on location. The managers' opinions were spread but the group agreed upon that living costs and family conditions were considered to be more important than wages.

Weather is a parameter that can affect the delivery time but something that the company cannot affect, discussed in comparison 5. The vision of railway transport is something that could be implemented in the future and the group agreed that railway access is better to consider than weather when locating a hub.

As written before, the group put a high value of the service quality. Comparison 6 discusses that congestion increases the risk of poor service and is therefore more important than the infrastructural advantages that similar companies in the local area can give.

According to the discussion of comparison 7, since the purpose of a hub is to lower costs in the network, low costs for return goods flows from northern Sweden to the hub is of importance. As said, weather is not a parameter that the company can affect. Low costs of return flows is therefore considered to be more important than weather.

In comparison 8, service is also the argument for the result. When there are large hub volumes, there could be too less space in transports and the solution could be to keep some goods at the hub overnight. It is agreed by the group that this affects service more than bad weather. The group also thinks that it is more important to consider parameters for hub localisation which the company can affect rather than weather than the company cannot affect.

Appendix E

Procedure for the Pairwise Comparisons

First, an initial matrix for the firm's pairwise comparisons, in which the diagonal contains entries of 1, is provided as each factor is as important as itself, see Table E.1 (Coyle 2003).

Table E.1: Initial matrix of prioritize expense, operability, reliability and flexibility

	Expense	Operability	Reliability	Flexibility
Expense	1			
Operability		1		
Reliability			1	
Flexibility				1

Next, the decision makers perform the pairwise comparisons of the criterions. It should be noted that the element that appears in the left-hand column is always compared with the element appearing in the top row, and the value is given to the element in the column as it is compared with the element in the row. If it is regarded less favourably, the judgment is a fraction, otherwise it is an integer (Saaty 1999).

The firm decides that operability is slightly more important than expense and is therefore rated as 1/3 in cell row two, column three. Subsequently, the reciprocal value of 1/3, namely 3 is rated in cell row three, column two. Likewise, expense is seen as far more important than reliability, which gives 5 in cell row two, column four and thus 1/5 in cell row four, column two. Similarly, expense is judged just as important as flexibility, putting 1 in cell row two, column five and 1 in cell row five, column two. These comparison valuse can be seen Table E.2 which contains five rows and five columns (Coyle 2003).

Table E.2: Initial matrix of prioritizing

	Expense	Operability	Reliability	Flexibility
Expense	1	1/3	5	1
Operability	3	1		
Reliability	1/5		1	
Flexibility	1			1

In the same manner the matrix is completely filled in for the remaining pairwise comparisons, see Table E.3. This is called the Overall Preference Matrix (OPM) (Coyle 2003).

Table E.3: The Overall Preference Matrix

	Expense	Operability	Reliability	Flexibility
Expense	1	1/3	5	1
Operability	3	1	5	1
Reliability	1/5	1/5	1	1/5
Flexibility	1	1	5	1

Eigenvector Calculations
Next, the eigenvector, which is called the Relative Value Vector (RVV), is calculated as in Table E.4 (Coyle 2003).

Table E.4: RVV for expense, operability, reliability and flexibility

	RVV
Expense	0.232
Operability	0.402
Reliability	0.061
Flexibility	0.305

There are several methods for calculating the eigenvector. Multiplying together the entries in each row of the matrix and then taking the n^{th} root of that product gives a very good approximation to the correct answer and is called the geometric mean. The n^{th} roots are summed and that sum is used to normalise the eigenvector elements to add to 1.00. In the matrix below, the 4^{th} root for the first row is 1.136 and that is divided by 4.899 to give 0.232 as the first element in the eigenvector. Table E.5 gives the complete calculation of the eigenvector which can be seen as the weights for each factor (Coyle 2003).

Table E.5: Eigenvector calculations

	Expense	Operability	Reliability	Flexibility	n^{th} root of product of values	Eigenvector
Expense	1	1/3	5	1	1.136	0.232
Operability	3	1	5	1	1.968	0.402
Reliability	1/5	1/5	1	1/5	0.299	0.061
Flexibility	1	1	5	1	1.495	0.305
Sum					4.899	1.000

The Option Performance Matrix Procedure
Next, focus is on the three potential machines, X, Y and Z. Here four set of pairwise comparisons are needed in order to compare these alternatives, one for each of the criterions: expense, operability, reliability and flexibility (Coyle 2003).

Table E.6 is, with respect to expense, ranking the three machines as follows. As one can see, machine X is considerably better than Y in terms of expense and even more so for Z. The eigenvector for the matrix can be seen in Table E.7 (Coyle 2003).

Table E 6: Ranking of the machines with respect to expense

Expense	Machine X	Machine Y	Machine Z
Machine X	1	5	9
Machine Y	1/5	1	3
Machine Z	1/9	1/3	1

Table E.7: The eigenvector for the machines with respect to expense

Expense	Eigenvector
Machine X	0.751
Machine Y	0.178
Machine Z	0.071

The next three matrices are conducted in the same way for the alternatives with respect to the different factors operability, reliability and flexibility, see Tables E.8-E.13 (Coyle 2003).

Table E.8: Ranking of the machines with respect to operability

Operability	Machine X	Machine Y	Machine Z
Machine X	1	1	5
Machine Y	1	1	3
Machine Z	1/5	1/3	1

Table E.9: The eigenvector for the machines with respect to operability

Operability	Eigenvector
Machine X	0.480
Machine Y	0.406
Machine Z	0.114

Table E.10: Ranking of the machines with respect to reliability

Reliability	Machine X	Machine Y	Machine Z
Machine X	1	1/3	1/9
Machine Y	3	1	1/3
Machine Z	9	3	1

Table E.11: The eigenvector for the machines with respect to reliability

Reliability	Eigenvector
Machine X	0.077
Machine Y	0.231
Machine Z	0.692

Table E.12: Ranking of the machines with respect to flexibility

Flexibility	Machine X	Machine Y	Machine Z
Machine X	1	1/9	1/5
Machine Y	9	1	2
Machine Z	5	1/2	1

Table E.13: The eigenvector for the machines with respect to flexibility

Flexibility	Eigenvector
Machine X	0.066
Machine Y	0.615
Machine Z	0.319

The reason that Y scores better than Z on this criterion is that the firm does not really believe the manufacturer's claims for Z. The AHP deals with opinion and hunch by the decision makers, just as easily as with fact (Coyle 2003).

Appendix F

Result from Questionnaire

In Figure F.1, the second column represents the number of persons with the opinion that the factor is “not necessary” to fulfil when deciding of a hub localisation. The third column represents the number of persons with the opinion that the factor is “necessary” to fulfil when deciding of a hub localisation. The fourth column presents the average, calculated from the opinions in the questionnaire, except those “not necessary” and “necessary”. The scale was set from 1, “less important”, to 5, “very important”. The standard deviation of the opinions, marked in the scale, is presented in the last column.

Table F 1: Average and standard deviation from questionnaire

No.	Factor	Nbr of “not necessary”	Nbr of “necessary”	Average	Standard deviation
1	Highway access	0	5	3.25	1.25
2	Railway access	0	0	3.00	1.41
3	Congestion	0	0	3.89	0.92
4	Living costs and family conditions	0	0	2.33	1.22
5	Location costs	0	0	3.78	0.66
6	Wages	0	0	2.78	0.97
7	Labour availability	0	3	3.17	1.16
8	Environmental regulations	0	4	4.00	1.33
9	Weather	0	0	3.11	1.05
10	Construction feasibility	0	5	3.75	0.95
11	Closeness to similar companies	1	0	1.25	0.92
12	Delivery time to customers	0	0	3.00	2.00
13	Driving and rest periods	0	0	2.78	1.64

Two factors were added by the managers since they thought they were missing in the questionnaire and that they affected a hub localisation. These factors were:

- Cost of return goods flows from northern Sweden
- Closeness to nearby terminal to support goods handling at hub

Appendix G

Fixed Input Data

The following data is fixed in the model. For confidentiality, the numbers have been changed to camouflage the real data.

Coordinates for Terminals

For the different terminals the coordinates have been compiled in the format of Decimal degrees (DD) which express latitude and longitude geographic coordinates as decimals fractions, see Table G.1. This data was used in the Centre-of-Gravity analysis.

Table G 1: Coordinates for terminals

Terminal	X-coordinate	Y-coordinate
Terminal A	59.44713	13.78110
Terminal B	62.28004	16.48298
Terminal C	61.17022	17.60240
Terminal D	62.50205	18.35068
Terminal E	59.48451	12.83648
Terminal F	58.35471	13.79676
Terminal G	57.70075	13.67032
Terminal H	59.49557	15.16937
Terminal I	61.14691	14.50699
Terminal J	67.60092	23.58570
Terminal K	57.29138	13.91946
Terminal L	60.36264	17.32885
Terminal M	60.98942	16.21310
Terminal N	58.96676	17.59476
Terminal O	65.10763	15.66622
Terminal P	66.67257	22.43674
Terminal Q	61.36094	19.13006
Terminal R	61.07792	19.27465
Terminal S	64.31967	18.52808
Terminal T	60.16792	15.12230
Terminal U	65.75948	21.63283
Terminal V	61.64680	18.90054
Terminal X	58.93022	15.02048
Terminal Y	58.59628	15.80591

Distances between Terminals

The distance between each of the Company's terminals has been gathered in Table G.2. This data was provided by Company X and was used as input in the estimation of the transportation cost. The table is not complete because of the size but shows an example of the structure and the content.

Table G 2: Distance between terminals

Departure Terminal	Arrival Terminal	Distance (km)
Terminal A	Terminal B	422
Terminal A	Terminal C	348
...	...	...
Terminal A	Terminal Y	172
Terminal B	Terminal A	422
Terminal B	Terminal C	180
...	...	...
Terminal B	Terminal Y	485
Terminal C	Terminal A	348
Terminal C	Terminal B	180
...	...	...
Terminal C	Terminal Y	377
...	...	...

Varied Input Data Depending on the Analysis Performed

The following data was collected to be input data to the analysis of the current hub localisation.

Transportation Volume between Terminals

The transportation volume, in load metres, between the terminals and the hub in both directions, has been gathered from the Company's business system, see Table G.3. Only the terminals that send goods via the hub are included in the tables. The flow in the northern direction is shown in the table below.

Table G 3: Transportation volumes between the terminals and the hub in northern direction

Departure Terminal	Arrival Terminal	Transportation volume Load metre
Terminal A	Hub	15113
Terminal B	Hub	10322
Terminal C	Hub	0
Terminal D	Hub	9564
Terminal E	Hub	0
Terminal F	Hub	10317
Terminal G	Hub	13827
Terminal H	Hub	0
Terminal I	Hub	7586
Hub	Terminal J	34008
Terminal K	Hub	19787
Terminal L	Hub	10859
Terminal M	Hub	0
Terminal N	Hub	7853
Hub	Terminal P	18315
Terminal R	Hub	0
Terminal T	Hub	8177
Hub	Terminal U	35104
Terminal V	Hub	5331
Terminal X	Hub	10909
Terminal Y	Hub	12243

The flow in the southern direction is shown in Table G.4.

Table G 4: Transportation volume between the terminals and the hub in southern direction

Departure Terminal	Arrival Terminal	Transportation volume Load metre
Hub	Terminal A	15113
Hub	Terminal B	5983
Hub	Terminal C	7357
Hub	Terminal D	6609
Hub	Terminal E	7021
Hub	Terminal F	0
Hub	Terminal G	5935
Hub	Terminal H	2601
Hub	Terminal I	3587
Terminal J	Hub	17892
Hub	Terminal K	10938
Hub	Terminal L	3583
Hub	Terminal M	0
Hub	Terminal N	5224
Terminal P	Hub	11744
Hub	Terminal R	17099
Hub	Terminal T	0
Terminal U	Hub	31948
Hub	Terminal V	3454
Hub	Terminal X	0
Hub	Terminal Y	3576

Transportation Cost between the Terminals and the Hub

The transportation cost, SEK per Load metre per km, of the transportation flows was calculated based on data from the business system, see Table G.5. This cost is aggregated out of two costs, the cost paid to the haulier and the fuel surcharge. The cost presented below is the transportation cost per load metre and km for the northern flow.

Table G 5: Transportation cost in northern direction

Departure Terminal	Arrival Terminal	Transportation cost per load metre and km
Terminal A	Hub	1.41
Terminal B	Hub	1.44
Terminal C	Hub	0.00
Terminal D	Hub	2.96
Terminal E	Hub	0.00
Terminal F	Hub	2.11
Terminal G	Hub	2.43
Terminal H	Hub	0.00
Terminal I	Hub	2.55
Hub	Terminal J	2.52
Terminal K	Hub	1.75
Terminal L	Hub	1.95
Terminal M	Hub	2.60
Terminal N	Hub	0.00
Hub	Terminal P	2.33
Terminal R	Hub	0.00
Terminal T	Hub	3.73
Hub	Terminal U	2.26
Terminal V	Hub	3.33
Terminal X	Hub	2.70
Terminal Y	Hub	2.42

Table G.6 presents the transportation cost per load metre and km for the southern flow.

Table G 6: Transportation cost in southern direction

Departure Terminal	Arrival Terminal	Transportation cost per load metre and km
Hub	Terminal A	1.44
Hub	Terminal B	3.43
Hub	Terminal C	0.25
Hub	Terminal D	3.39
Hub	Terminal E	1.48
Hub	Terminal F	0.00
Hub	Terminal G	1.77
Hub	Terminal H	2.95
Hub	Terminal I	2.51
Terminal J	Hub	0.69
Hub	Terminal K	1.32
Hub	Terminal L	2.60
Hub	Terminal M	0.00
Hub	Terminal N	2.71
Terminal P	Hub	0.46
Hub	Terminal R	1.32
Hub	Terminal T	0.00
Terminal U	Hub	0.73
Hub	Terminal V	1.59
Hub	Terminal X	0.00
Hub	Terminal Y	2.01