Master's degree thesis

LOG950 Logistics

Location of regional warehouses: A case study.

Stian Andersen

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Preface and acknowledgement

This master thesis concludes my five years at Molde University College – Specialized University in Logistics, and presents the main result from my academic work during this period. The work has been conducted in order to obtain an MSc degree in Logistics, and carried out from December 2014 to May 2015.

I would like to express my deepest gratitude to my supervisor Associate Professor Arild Hoff for supervising me and giving me good and much appreciated guidance throughout the process of writing the thesis.

I would also like to thank TOOLS Molde AS for giving me the opportunity and contacting me about this case, and especially to Klaus Inge Røsberg who has been an excellent contact and always responded quickly whenever I have had any questions or was in need of data.

Lastly, I would like to thank the faculty itself and its staff for giving me five eventful years, both academically and socially, and for challenging me to improve myself.

Stian Andersen
Oslo, Norway
May 2015

Abstract

This master thesis investigates the case of introducing regional warehouses in a value chain in order to decrease the total number of warehouses used, and to improve the overall performance. Tools Molde presented this case to me, and we have used real life data provided by them in the analysis. We address the problem of where to locate the regional warehouses, and how to implement them in the already existing value chain. In order to get a thorough view off the new warehouse network, we have performed the analysis on three scenario alternatives, and two distribution alternatives. Factors such as the average inventory, average order time and stock out probabilities has been used as measurements, in order to compare the solutions obtained. By investigating the effects of the new solutions, Tools will get a clearer view off what their warehouse-network would look like if they centralized their warehouse operations

Three main analyses have been conducted, including a facility location analysis to find out where to locate the regional warehouses, and a simulation analysis to see how the solutions behave when implemented. In addition, we have searched for improvements and tested the robustness of the solutions through a sensitivity analysis.

By comparing the results from the analyses to the current situation, we can say that we can expect a significant reduction in the average inventory and an improvement in the system performance by introducing regional warehouses and centralizing their operations.

Contents

List of Tables

List of Figures

1. Introduction

The Norwegian tool industry have an approximate annual turnover of 13.5 billion NOK (SSB.no, 2015a), and about 965 different actors (SSB.no, 2015b). In order to stay competitive and profitable, the operators must constantly improve their operations and be more efficient. A good place to start is to investigate the value chain, and try to improve their logistic operations. A big part the logistics operations is based around their warehouse and one should try to optimize these.

Service factors as lead time, availability, reliability, and the general management of a warehouse, can indirectly and directly have an effect on the profitability of a company (Jonsson, 2008). More and more companies tend to build larger and more centralized distribution centers and warehouses, in order to take advantage of economies of scale (Nahmias, 2009). By having fewer centralized warehouse, a company can increase their effectiveness, their revenue, and help to improve their day-to-day operations.

Since a warehouse is usually the largest single investment a company does, and they represent about 20 to 50 per cent of the total assets for a wholesaler (Stock and Lambert, 2001), the positioning of them is not a decision that is taken easily. In order to improve the logistics operations and effectiveness we have to plan and run test in order to find the best solution. In a simple and deterministic world, we could easily solve this problem to optimality but when we introduce uncertainty and a stochastic environment, it is a whole other story.

By using different modeling methods, we can investigate the effects of introducing regional warehouses instead of many small ones. Both the usage of optimization and simulation models is applied, and we compare the solution to the current situation.

1.1 Company overview

Tools AS is a subsidiary of the Swedish owned group B&B TOOLS AB. B&B TOOLS ABs main business area is within the industrial consumables and components in the Swedish, Norwegian and Finnish market. This market is valued to approximately 40 to 45 billion SEK (B&B TOOLS AB), and they are the largest supplier in this business with an annual turnover of approximately 8 billion SEK and 2 700 employees. About 50 % of their sales is from proprietary brands.

Tools AS is an actor in the Norwegian market, and supply their customers with construction tools, personal protective equipment, machines and industrial consumable materials. In short, they supply their customers with everything needed on a construction site. Their customer's business area is mostly within manufacturing, oil & gas, public sector and building & constructing (TOOLS.no). They have an annual turnover of approximately 2.4 billion NOK and 700 employees, so they are of a decent size in the Norwegian market.

They have 60 locations in Norway, whereas Tools AS owns 35 of these. These locations are tactically located around the country, in order to be best represented where the demand is. Out of the 35 self-owned locations, we will consider the 33 stores among them in this thesis.

2. Problem Description

This chapter presents the current situation, and the situation we intend to investigate. The main and sub research questions is presented at the end.

2.1 Warehouses

As of today, every location has its own warehouse. The inventory is more or less the same, but the warehouses differ some in size. It is unlikely that most of these warehouses can be 100 per cent removed, but they could at least decrease some in size. This should not only give lower cost of having warehouses (rent, insurance, electricity etc. (Emmet and Granville, 2007), (Piasecki, 2009)), but also give lower total inventory costs.

The main reason for the lower cost is the decrease in inventory. Each location needs to hold a minimum level for most of the products, which we call a safety stock. This means that for each warehouse we need a safety stock, which in turn increases the total square meter of warehouse space needed ((Stock and Lambert, 2001), chapter 10). In addition to the cost of having more safety stocks, there are also the general cost of owning, leasing or renting the space needed for each warehouse.

They divide their Norwegian market into three districts, namely east, west and north. In addition, they have two warehouses in Sweden, which operates as their main warehouses. The map over the different locations, warehouses and the distribution center owned by PostNord is in Figure 1.

Some locations have special customers that demand unique products. This means that some products must be tactically located in order to have short lead times. This is an important factor to keep in mind, so the distance from a location to its nearest warehouse cannot be too far. They have a product shelf of around 390 000 articles, from 900 different brands (TOOLS.no), so what to keep on stock, where to have it, what to order and when to order it, is a big challenge. In this thesis, we have only taken their three biggest suppliers into account, which represents about 52 % of the orders and 43 % of the value of the merchandise bought.

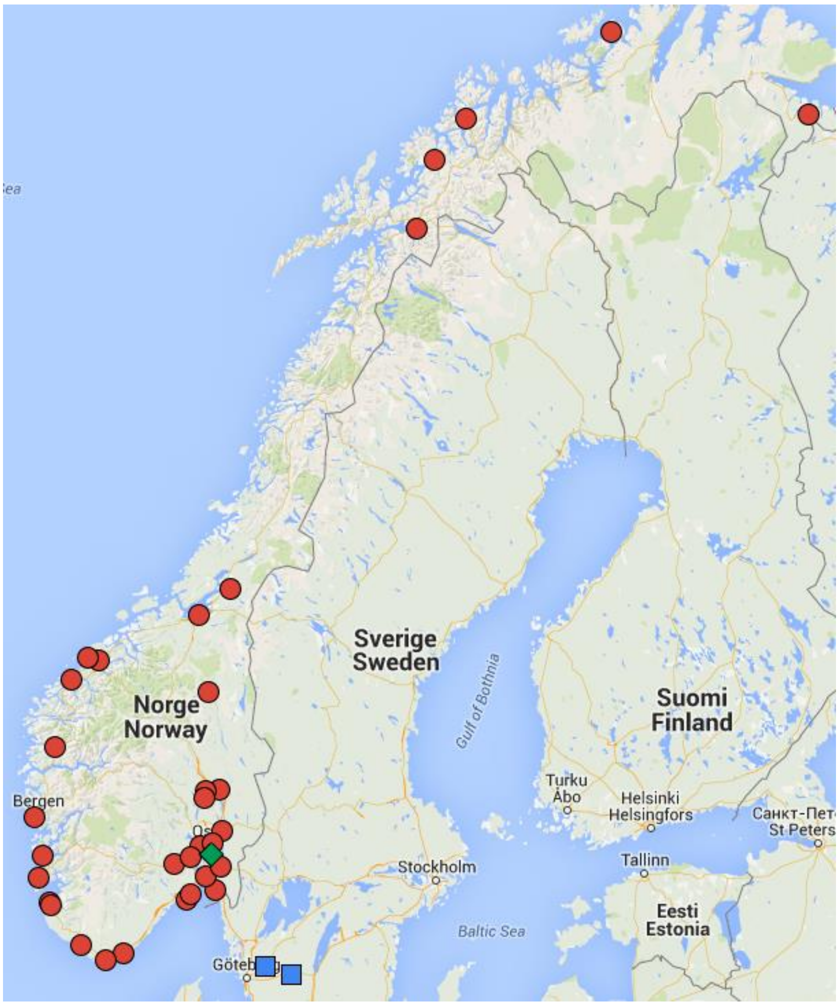

Figure 1: Markings where the different locations are where the blue squares are the two self-owned warehouses in Sweden, the green diamond is the distribution center owned by PostNord located in Langhus, and the red circles are the locations owned by Tools (Google Maps).

2.2 Inventory

The inventory costs varies from company to company but one should strive for it to be as low as possible but still have a satisfying service level. Tools holds inventory for around 200 million NOK at any given time, and their warehouses represents about 50 per cent of their total assets. When a customer places an order, the respective location fulfills it. If the location does not hold a sufficient inventory to fulfill the order, the warehouse in Sweden serves the order.

Tools uses an ordering policy that is similar to an (s, Q) system (Silver et al., 1998). Every warehouse has a reorder point *s*, and an order quantity *Q*. Their ERP-system produces a quantity to order, and a purchaser process this suggestion. The purchaser adjusts the minimum or maximum order size as he or she see fits.

2.3 Distribution

In order to get the products from the two warehouses in Sweden, namely Alingsås and Ulricehamn, to the different locations in Norway, they use the third party logistics operator PostNord Logistics that have a distribution center located in Langhus, Norway. Tools sends four trucks from their main warehouses to Langhus every day, and PostNord distributes the merchandises from there. Each location more or less gets direct deliveries from Langhus, so without saying there are many kilometers driven every day.

Tools strive to serve their customers as quick as possible, and want to deliver at latest the next day. This means that if an order comes in at midday day zero, the merchandise should arrive at the customer at latest midday day 1.

2.4 What to investigate

This thesis will investigate whether the usage of regional warehouses could improve their overall performance. This means that the goal should be to decrease the size or eliminate some of their existing warehouses, and instead use regional warehouses to supply their locations and/or customers. This could improve their efficiency, decrease their total inventory, and possibly their warehouse cost. After discussions with Tools, we have agreed upon looking at the Norwegian market as a whole. Our goal is to get some idea of the effects of changing the structure, and to identify the pros and cons by using a solution like this.

In addition to investigating the effects of using regional warehouses, we raise the question of whether or not they should distribute themselves. The initial thought is that the four trucks leaving from Sweden every day could drive directly to the regional warehouses, instead of to Langhus. This might decrease the delivery time, and the total distance travelled might be shorter.

When distributing themselves there might be challenges as reconstructing their operations in Sweden, investing in new trucks and employ people to work with the planning of the routing. This means that it might be a big investment, so the solution of distributing themselves should be considerably better if they should change to this strategy.

2.5 *Research questions*

This section presents the research questions, and the sub-questions.

2.5.1 Main research questions

1. Where should Tools locate the regional warehouses?

2. How should Tools manage the implementation of the regional warehouses?

2.5.2 Sub-questions

1.1. Should we use the existing locations, or build new regional warehouses?

1.2. Which location can be used as a regional warehouse?

1.3. How many regional warehouses do we need?

1.4. How do we measure the effect of using regional warehouses?

2.1. Which regional warehouse should serve which location?

2.2. What kind of order policy should the regional warehouses use?

2.3. How large should they be?

2.4. How should they get deliveries?

3. Literature Review

This chapter outlines the relevant theory. In order to introduce the theories and methods used, we explain subjects such as general facility location and inventory management. We sum up much of the research done so far, and give a brief explanation on some of the more relevant theories.

3.1 Facility location problem

The facility location problem is a widely studied problem in operation research. The decision of placing a facility is a strategic decision (Owen and Daskin, 1998), with a time horizon of many years. Owen and Daskin (1998) give a good general review of the problem, and classifies it into three categories: Static and deterministic location problems, dynamic location problems, and stochastic location problems. Arabani and Farahani (2012) also gives a good overview, and creates a classification over the different subjects. This paper will focus on the deterministic location problem.

The deterministic location problem is further divided into four sub-categories with different objectives (Owen and Daskin, 1998): median-problems, covering-problems, center-problems and additional facility location problems. ReVelle et al. (2008) provides a bibliography over some of the problem categories in the discrete location science, and it is a good place to start your research. ReVelle describes some of the basic models, and refers to articles for further elaboration of the different categories. Mirchandani and Francis (1990) has written a good book that can be used for further reading on the subject of discrete location theory, and it explains the most common models.

Both the p-median and the p-center problem was first introduced by Hakimi (1964). The models are very similar, where the p-median have the objective of minimizing the total cost of travelling from the facilities to the different locations, and the p-center objective is to minimize the single longest distance traveled from a facility to a location (ReVelle et al., 2008). Dantrakul et al. (2014) gives a good review of both problems and its application, and are interesting for further reading.

The p-median and p-center problem is NP-hard (Kariv and Hakimi, 1979a, Kariv and Hakimi, 1979b), meaning that it is difficult to solve to optimality using an exact model in reasonable time. Because of this, we have to discretize the problem and make it manageable. A way of doing this can be to introduce a finite set of possible locations, so the model do not keep on searching for better alternatives.

The set covering model, first proposed by Toregas et al. (1971), has the objective of finding out how many facilities you need in order to serve all the customers. The model decides the number of facilities from a set of possible locations, and minimizes the total distance. The fourth category is quite similar to the other three only that it includes a setup cost for a facility. Two possible models are the uncapacitated facility location problem (UFLP) (Balinski, 1965), and the capacitated facility location problem (CFLP).

When modeling the deterministic facility location problem, we get a very simplified and narrow view of reality. A more realistic approach is the stochastic facility location problem. Her we introduce uncertainty, which makes the problem much harder to solve. Parameters such as demand and time are not know or uncertain, so we try to estimate them using different statistical analysis or randomly generating them. Snyder (2006) gives a review of the research done so far in the field. He introduces different algorithms and heuristics, and gives a good overview of the problem.

3.2 Centralization and aggregating demand

The question of whether or not to centralize the warehouse operations is a complex and well-studied problem. Centralizing and aggregating the demand will decrease the total inventory, mainly because of the reduction in safety stock (Mangan et al., 2008), and enable the company to take advantage of economies of scale (Brandimarte and Zotteri, 2007). (Stock and Lambert, 2001), Ballou (1981) and Harrison et al. (2014) all gives good overviews of the subject, and is recommended for further reading.

There are two main part of demand aggregation: physical and virtual (Xu and Evers, 2003). Physical aggregation is the process of centralizing the actual warehouses, while virtual aggregation only centralizes the management. Xu and Evers (2003) further provide proof that full aggregation is never worse than partial aggregation. It is worth noticing that they have not taken factors such as lead times and transportation costs into account, so partial aggregation may in some cases be preferred. This thesis will consider physical aggregation.

Ballou (2004) estimates that the overall savings in the total logistical costs are 5-10 % when centralizing. This sounds great from a financial point of view, but there are some possible drawbacks. The biggest one is that the customer service level might decrease due to an increase in lead time (Brandimarte and Zotteri, 2007), but the different customers have different preferences. Chopra (2003) discusses the different factors when redesigning a distribution network, and outlines some critical points.

3.2.1 The "Square Root Law"

The "Square Root Law" (SRL) was initially presented by Maister (1976). It expresses the ratio of *n* decentralized inventories into *m* centralized inventories:

$$\frac{centralized\ sytem\ inventory}{decentralized\ system\ inventory} = \frac{\sqrt{m}}{\sqrt{n}} \qquad (1)$$

The SRL is applicable on the safety stock whatever the ordering strategy, and cycle stocks if the economic order quantity (Stock and Lambert, 2001) is used. As Maister points out, he has based the SRL on a set of assumptions presented in table 1.

Assumption
The total average demand is the same after consolidation.
There are no transshipments between facilities.
Lead times are independent of each other and identically distributed random variables.
Demands are independent of each other and identically distributed random variables.
The demand and lead times are independent of each other.
All facilities use the same safety factor approach to set the safety stock.
The variance in lead-time are zero for all facilities.
The facilities have the same average lead-time.
The demand at the decentralized locations are uncorrelated.
The demand variance when facing each of the decentralized facilities are equal.

Table 1: List of assumptions for the Square Root Law (Evers and Beier, 1993).

Ballou (1981) reviewed the SRL, and presented a number of results from different companies in order to show that the model was very simplified and optimistic regarding the inventory reduction when decreasing the number of warehouses. He showed that the actual savings where not as high as the SRL indicated, because of factors like forward buying and joint ordering.

Zinn et al. (1989) developed a model for determining the reduction in safety stock when decreasing the number of stocking points, in order to eliminate the assumptions that Maister (1976) had based the SRL on. Zinn et al. (1989) called this model the Portfolio Effect (PE) and defined it as (Zinn et al. (1989), page 3): “the percent reduction in aggregate safety stock made possible by consolidation of inventories from multiple locations into one location”. They only considered when we want to decrease to one warehouse, and provides proof for that the SRL is a special case of the PE.

Following that Zinn et al. (1989) only considered consolidating to one location, Evers and Beier (1993) generalized the model so that it is possible to model moving into more than one location. They also include variability in the lead-time, in order to eliminate even more assumptions. From there they continued with revisiting the SRL and made a different model that point out the ratio of a centralized safety stock *n* from a decentralized safety stock:

$$\frac{1}{\sqrt{n}} \tag{2}$$

They added a new assumption, which states that the demand at the decentralized facilities is equally divided across all the centralized facilities. By taking this assumption, Evers and Beier (1993) provide proof that as long as $n > m$, the same reduction in safety stock can be applied regardless of the number of centralized facilities.

We see that there is a significant difference between Maisters SRL, and the one worked out by Evers and Beier. We can say that the maximum detainable reduction in safety stock from a decentralized stocking location into a centralized stocking location is:

$$1 - \frac{1}{\sqrt{n}} \tag{3}$$

Both the SRL and the PE effect, arguments and provide proof that when centralizing the number of stocking points, we can decrease the total safety stock, which again leads to a smaller total inventory.

When studying the assumptions from table 1 and the new assumption provided by Evers and Beier (1993), we can compare them to the situation we are investigating. The new assumption where the demand for the decentralized facilities is equally divided at the centralized facilities does most likely not hold. Since we have large distances and the demand is not geographically equally spread, it is unlikely that the demand is evenly distributed when we consolidate the facilities. Example, if we use one facility in the north and one in the south, the demand is unevenly distributed and the underlying assumptions would not be valid. However, if the facilities is located so that the demand is approximately the same for all facilities, we can apply the rule.

We assume that we can apply the SRL provided by Maister (1976), if the demand is not evenly spread at the centralized facilities.

3.3 Inventory Management

Inventory is a critical factor for many companies, and it is a necessity. Nahmias (2009) lists seven motivational factors for having an inventory:

- **Economies of scale:** The more unit's that is produced at each run, the lower the setup cost and holding cost per unit are.
- **Uncertainties:** There are uncertainties in the market and in order to deliver in time, we need an inventory.
- **Speculation:** If we expect an increase in the price of an item, it might be more profitable to have a larger inventory of the item to a cheaper average price.
- **Transportation:** The longer the transportation time, the more expensive it is to transport. That is why we want to transport as large quantities as possible every time we make a delivery.
- **Smoothing:** Because of seasonal factors and sudden demand increases, it is wise to have an inventory so we do not have to do expensive changes and disruptions in production rates.
- **Logistics:** If we for example have to buy a minimum lot size or a manufacturer must have continuity in the production, we have logistical challenges.
- **Control costs:** The cost of controlling the inventory size is less and it is not so important if the inventory level decreases a bit if it is on a high enough level to begin with.

In short, Waters (2003) sums up by saying that the purpose of having an inventory is to create a buffer between supply and demand, which is critical in order to have smooth operations.

Inventory management is a very broad term, and a few critical factors is elaborated further below. Stock and Lambert (2001), chapter six and ten, gives a good overview of many of the elements in inventory management, and recommended for further reading.

3.3.1 Carrying Costs

Carrying cost, or holding costs, is simply the cost associated with having an inventory. This includes (Piasecki, 2009):

- **Cost of capital:** represents the cost of having money tied up in the inventory. Usually measured as the interest on the debt one have one the inventory.
- **Insurance:** Simply the cost of insuring the inventory. The actual cost of insuring the inventory depends on how much the average inventory is.
- **Taxes:** For example property tax.
- **Storage costs:** The cost of running the inventory. This could be rent, maintenance, electricity etc.
- **Risk of damage, theft, spoilage or obsolescence:** Most companies that uses an inventory experiences damaged goods, spoilage, obsolescence etc. Although not everyone experiences thefts, it is a risk one should account for.
- **Labor costs:** When running an inventory one needs employees, and they have to be paid. The labor costs represents all cost associated with the employees.

3.3.2 Safety Stock

The main purpose of having a safety stock, is to compensate for demand variability (Piasecki, 2009). One uses forecasting and the best methods available for predicting the future, but forecasts are almost never 100 % correct. So in order to keep the customers satisfied and to have as high service level as possible (Waters, 2003), one introduces a safety stock. The higher the shortage cost, lead time uncertainty and demand uncertainty, the higher the safety stock (Stock and Lambert, 2001).

There are many methods for calculating the safety stock. The most simple and basic one, are to use the demand for a given set of time. This method is overly simple and only good when the demand is deterministic and no variation. This is off course not the case in reality, and we could say that the demand in many cases is stochastic. A more appropriate way of calculating the safety stock, is to include some sort of statistical analysis. The easiest way of doing this is to include the standard deviation or the mean absolute deviation (Brown, 1959), (Emmet and Granville, 2007). You then multiply either the standard deviation or the MAD with the amount that corresponds to the desired service level, and we have the safety stock.

A more extensive method of calculating the safety stock using different statistical methods, is provided by Piasecki (2009) in chapter six.

3.3.3 Order system

When we are to decide what kind of ordering system to use, we differ between two main types of monitoring the inventory level (Nahmias, 2009): periodic and continuous review. Continuous review means that one constantly monitor the inventory level, while in periodic review we only monitor the inventory level at certain periods of time.

One common inventory policy when we talk about continuous review, is the (s, Q) system (Silver et al., 1998). This means that we order size *Q* whenever we reach reorder point *s*. This is a quite simple and effective system, and used by many companies. The order size, *Q*, is to set by the company, and a common approach is to use the economic order quantity (EOQ). The reorder point, *s*, is not that easy to find. If the lead time and the demand in lead time is known it is simply the demand in lead time (Waters, 2003), but this is rarely the case. If there is uncertainty we need to introduce the demand variety, the lead time variance, and the standard deviation (Ballou, 1981).

However, monitoring the system at all time might be time consuming and expensive if there is no automated system. An (R,s, S) system (Silver et al., 1998) is a system that monitors the inventory in a periodical basis. We check the inventory level at time *R*, and if the inventory level is below the pre-specified level *s*, we place an order so that the inventory level reaches the order-up-to point *S*.

3.3.4 ABC analysis

The concept of an ABC-classification is that a small portion of the products accounts for a large piece of the total profit. In the same way does a large portion of the products, account for a small piece of the profit. The concept is from economics, and was first introduced by Vilfredo Pareto (Nahmias, 2009) in the 19th century. He called it the Pareto Effect, and it is adapted into the ABC analysis. A normal approach is to use the 80/20 rule that states that approximately 20 % of the products accounts for 80 % of the profit, 30 % of the products accounts for 15 % of the profit, and the last 50 % of the products represents about 5 % of the total profit. Both Nahmias (2009), Waters (2003), (Ballou, 1981) and Emmet and Granville (2007) has all provided good explanations and examples of an ABC classification.

3.4 Discrete-Event Simulation

Simulation modeling is a well-known tool in the world of engineering and applied science. Rossetti (2009), page v, introduces simulation modeling as a tool that "*is used to represent manufacturing, transportation, and service systems in a computer program for the purpose of performing experiments*". Phillips et al. (1976) defines computer simulation as: "*a numerical technique for conducting experiments on a digital computer which involves logical and mathematical relationships that interact to describe the behavior of a system over time*".

The main purpose of simulation modeling is that you are able to model a system and gather information about it through observations over time. Simulation gives us the opportunity to test different engineering designs, without making any actual changes to the real life system. We apply both probability theory and statistics, so it is a very flexible tool. Rossetti (2009) splits simulation into two types, namely discrete event and continuous simulation. Discrete systems changes state at discrete points in time only when a certain change happens, while a continuous system changes state all the time. This means that while we in discrete systems gather observations only when the system changes state, we gather observations continuously in continuous systems. In a discrete system, we call the time where the state changes, an event. This could for example be when a truck arrives a customer order is delivered.

4. Methodology

This chapter elaborates on how we intend to answer the research questions, and the methods used.

4.1 Facility location analysis

In order to perform the facility location analysis, we apply different linear optimization techniques. The language and solver that is used are AMPL and CPLEX. These tools have been available to me through the university college, so they are most convenient to use. The goal of this analysis is to use the different models to investigate where to place the regional warehouses, and how many to place. The model also suggests which location each regional warehouse should serve, and the sizes of them.

We use the p-median and the p-center model as a basis, and evolve the optimization models from there. A big part of the expansion is turning them into multi-echelon models. This gives us the opportunity to model the routing from Sweden to a location, through the distribution center in Langhus and the regional warehouses.

Since Tools have a strict delivery policy, the models must be able to set a maximum distance in order to deliver in time. The challenge when distributing in Norway is the distances, and especially the distances in the northern district. In order to cope with this, we divide the locations into clusters. This gives us the possibility of setting a maximum distance for the different locations, so that the delivery time will be as small as possible. This will give a more precise view of reality, and it allows Tools to provide specifications for the distribution pattern. By modelling the problem with different sets of clusters, we should be able to get a good view off the most important locations in the network. The different clusters is in table 2.

Clusters	Locations
North	Finnsnes, Narvik, Tromsø, Hammerfest, Kirkenes
Southern	Verdal, Trondheim, Molde, Aukra, Ålesund, Tynset, Førde, Bergen, Stord, Haugesund, Stavanger, Åsen, Flekkefjord, Kristiansand, Mandal, Gjøvik, Raufoss, Hamar, Jessheim, Oslo, Askim, Fredrikstad, Moss, Bærum, Drammen, Kongsberg, Sandefjord, Larvik

Table 2: The different clusters used with their corresponding locations

The analysis considers two different value chain alternatives. They are presented in figure 2 through 4, where figure 2 is the current situation.

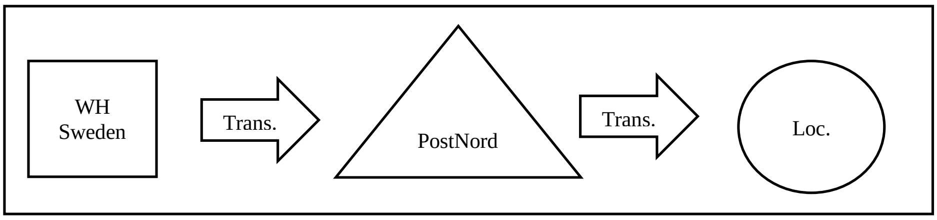

Figure 2: The current situation.

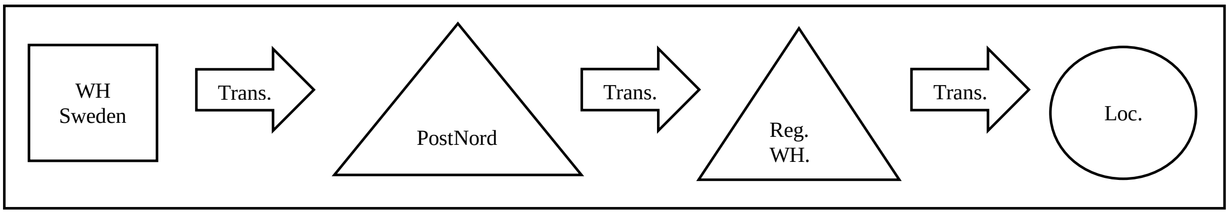

Figure 3: Distribute through regional warehouses with PostNord as a distribution partner.

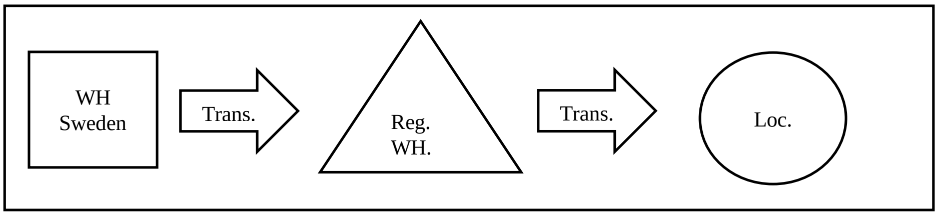

Figure 4: Distribute through regional warehouses without PostNord.

The purpose of using three different alternatives is to point out the pros and cons when distributing themselves, and to test whether it would improve the system performance.

In cooperation with Tools, we have worked out four different scenarios in order to see the different solutions on the warehouse-network. We use scenarios to show the effect of varying the number of warehouses. In addition to comparing them, they give a good basis for future predictions of where the demand might increase in the years to come. For example, since it is a large oil discovery in northern Norway, and especially in Hammerfest, it is interesting to see what the solution looks like if we want to have a warehouse located close to Hammerfest. The different scenarios is in table 3.

Since the p-median model uses a fixed number of facilities, we need to do some analysis to find out the minimum number of facilities needed. Each scenario is initially ran with the scenario specifications specified above, and a high additional setup cost. By including a high setup cost, the model will automatically minimize the number of facilities needed. We remove the setup cost after the initial run, and run the models with the desired number of facilities for further analysis.

Scenario	Name	Explanation
1	Initial solution	The situation as off today with 33 warehouses in total.
2	One in the north	There are five warehouses allowed, where only one, namely Tromsø, is allowed to open in the northern cluster.
3	Two in the north	The same as Scenario 2, only now Tromsø and Hammerfest will open in the Northern cluster so we have six warehouses in total.
4	One in the south	Only one warehouse in the southern cluster, and Tromsø and Hammerfest in the northern leaving three warehouses in total.

Table 3: The different scenarios where the first one is the situation.

4.2 Simulation Analysis

We perform a simulation analysis in order to test the solutions from the facility location analysis, and to see how the different models and scenarios behave when implemented. The program used for the analysis is Arena, provided by Rockwell Automation. The models are built using different modeling techniques learnt during courses at the master program, and designed to give results that make the solutions easier to compare and analyze.

In cooperation with Tools, we have found and discussed some of the different parameters so that the simulation model best represents the real life situation. We compare the different scenarios with the current situation, and uses this as a baseline. After some thought, the model is run with two different order strategies (Silver et al., 1998):

1. Order up to the inventory level *S* at time *R* if inventory level is below point *s* (R, s, S) system
2. Order *Q* whenever reorder point *s* is met (s, Q) system

When modeling the systems mentioned above, we have a couple of challenges. Firstly we have the challenge of the 390 000 articles that are kept on stock at all time. We have not done an analysis of these products and figured out where the different product variations are, simply because there is too many for us to handle on the restricted time we have. Not only would we spend all our time analyzing the different products when we are supposed to figure out where to locate the facilities, but the run time on the model would be very long. It would be very hard to get a good answer within reasonable time. In order to cope with this, we make the assumption of that all the products is represented by one master product. This means that each warehouse only requests one product, which represents a mix of the products requested at each location.

Secondly, we do not know the different order sizes for the different warehouses since we do not go into detail for each product at each location. Because of this, we assume that every order size is the same for each warehouse. This is elaborated further in section 6.3.2.

By simulating the two policies, we will get an indication on how much the average stock is, how long the average service time is, and how often there is a stock out situation. An analysis will elaborate further on the subject later on.

4.3 Sensitivity Analysis

Since the orders sizes, reorder and order-up-to point are fabricated numbers, it is interesting to see how a change in these will affect the system performance. In order to do so, we perform a sensitivity analysis.

The program used is Process Analyzer, provided by Rockwell Automation. It works by using an output file from the original simulations done in Arena. The user inserts different scenarios into the Process Analyzer, and we can add control variables and responses as we wish. The only thing to keep in mind is that we can only add a control that exists as a variable in the original simulation file, so we should be foresighted when modeling. The Process Analyzer runs the simulation again with the variable changes the user has implemented, and displays the responses in the response controls.

The goal is to see how an increase or decrease in the variables that affects the order sizes and the delivery frequency will affect the performance. We will investigate whether we can improve the solution, or if we only will make it worse. By testing to see how this affects the system, we can compare the scenarios and say something about the sensitivity.

We model five different situations when doing the sensitivity analysis:

1. Increase/decrease the order-up-to point
    - Performed on the (R, s, S) system
2. Increase/decrease the minimum delivery size
    a. Performed on the (R, s, S) system
3. Increase/decrease the capacity of a vehicle
    a. Performed on the (R, s, S) system
4. Increase/decrease the reorder point
    a. Performed on the (s, Q) system
5. Increase/decrease the order quantity
    a. Performed on the (s, Q) system

5. Facility Location Analysis

In this chapter, we explain the facility location analysis. The first section explains the assumptions. We continue by explaining the mathematical models, the data collection, and the results. The facility location analysis sets the basis for the simulation analysis, and we shortly elaborate on the best solution.

5.1 Assumptions

We have made several assumptions in order to simplify the situation enough so we can apply a mathematical model on it. We presents the assumptions below, and elaborates further in section 5.5.

- Each location must be served by one, and only one, facility.
- The facilities does not hold inventory, but are only used to serve the locations.
- The 2014 demand is representative for the future demand.
- Since Aukra, Bærum and Stavanger opened during 2014, we only have partial demand. To cope with this we assume that the demand is the same for each month, so we are able to multiply the demand so it represents a full year.
- There is only one order per delivery. In reality, each delivery might contain several orders, but in this simplified deterministic world, we assume that we do not have transshipments.
- The distances from google maps is the same as the actual distances. Delays and detours does not occur.
- The two warehouses in Sweden is located at the same place because of the short distance between them, and the fact that when driving from Ulricehamn you go past Alingsås. The location used is Alingsås.
- The relationship between the distance in kilometers and the time it takes to drive is the same, so we use the distances as the cost of driving.

5.2 Multi-Echelon p-median

The following model is built with the p-median formulation from Dantrakul et al. (2014) as a basis.

Model formulation:

$$\min \sum_{d\in D}\sum_{f\in F}\sum_{l\in L} z_{dfl} * (dd)_{dfl} + \sum_{w\in W}\sum_{d\in D} w_{wd} * (wd)_{wd} \qquad (4)$$

subject to

$$x_{fl} \leq y_f \qquad \forall\, f \in f, l \in L \qquad (5)$$

$$\sum_{f\in F} x_{fl} = 1 \qquad \forall\, l \in L \qquad (6)$$

$$\sum_{f\in F} Y_f \leq P \qquad (7)$$

$$\sum_{d\in D} z_{dfl} \geq d_l * x_{fl} \qquad \forall\, f \in F, l \in L \qquad (8)$$

$$\sum_{w\in W} w_{wd} = \sum_{f\in F}\sum_{l\in L} z_{dfl} \qquad \forall\, d \in D \qquad (9)$$

$$x_{fl} * (ld)_{fl} \leq (mn) \qquad \forall\, f \in F, l \in (CN) \qquad (10)$$

$$x_{fl} * (ld)_{fl} \leq (ms) \qquad \forall\, f \in F, l \in (CS) \qquad (11)$$

$$\sum_{f\in (CN)} y_f \leq 1 \qquad (12)$$

$$y_{"Troms\o"} = 1 \qquad (13)$$

$$x_{fl} \in \{0,1\} \qquad \forall\, f \in F, l \in L \qquad (14)$$

$$y_f \in \{0,1\} \qquad \forall\, f \in F \qquad (15)$$

$$z_{dfl} \geq 0 \qquad \forall\, d \in D, f \in F, l \in L \qquad (16)$$

$$w_{wd} \geq 0 \qquad \forall\, w \in W, d \in D \qquad (17)$$

Sets:

L	set of locations
F	set of facilities/regional warehouses
D	set of depots

W	set of warehouses
(CN)	set of northern locations
(CS)	set of southern locations

Parameters:

$(ld)_{fl}$	distance from facility *f* to location *l*, $f \in F, l \in L$
$(wd)_{wd}$	distance from warehouse *w* to depot *d*, $w \in W, d \in D$
$(dd)_{dfl}$	distance from depot *d* to location *l* through facility *f*, $d \in D, f \in F, l \in L$
d_l	demand for location *l*, $l \in L$
P	maximum number of facilities allowed
(mn)	maximum distance from facility to location in the northern cluster
(ms)	maximum distance from facility to location in the southern cluster

Decision variables:

x_{fl}	1 if route from facility *f* to location *l* is used, 0 otherwise, $f \in F, l \in L$
y_f	1 if facility *f* is opened, 0 otherwise, $f \in F$
z_{dfl}	orders sent from depot *d* to location *l* through facility *f*, $d \in D, f \in F, l \in L$
w_{wd}	orders sent from warehouse *w* to depot *d*, $w \in W, d \in D$

Description:

The objective function (4) says to minimize the total distance driven when serving all the locations. It include both the cost of driving from warehouse *w* to depot *d*, and from depot *d* to location *l*. The first constraint, equation number (5), forces the model to open the facilities in order to serve the locations. If route x_{fl} is used, facility *f* must open. Equation (6) limits the total number of facilities that can serve a location. It specifically says that each location must be served by only one facility. Equation number (7) is similar to the previous one, only that it limits the total number of facilities allowed.

Equation (8) is the demand constraint. It says that the sum of all orders sent to each location must be at least as much as the demand for the corresponding location. In addition, it forces the corresponding route to open, which links to equation (5). Equation number (9) guarantees balance in the system. The sum of what going into the depot must be equal to the sum of what that is going out. Equation (10) and (11) restricts the maximum allowed distances from a location to the facility that serves it. Equation (12) and (13) is there in order to model the different scenarios. In Scenario 2 described here, we only allow for one facility in the northern cluster, namely Tromsø. Equation (14) through (17) is binary and non-negativity constraints.

5.3 Multi-echelon p-center

The following model contains many of the same elements as the p-median, and a few changes. The model is built up with the p-center formulation from Dantrakul et al. (2014) as a basis. We describe the new constraints and the changes below.

Model formulation:

$$\min W \qquad (18)$$

subject to

$$W \geq \sum_{d \in D} \sum_{f \in F} Z_{dfl} * (dd)_{dfl} \qquad \forall\, l \in L \qquad (19)$$

$$W \geq 0 \qquad (20)$$

Sets:

L	set of locations
F	set of facilities/regional warehouses
D	set of depots
(CN)	set of northern locations
(CS)	set of southern locations

Parameters:

$(ld)_{fl}$	distance from facility *f* to location *l*, $f \in F, l \in L$
$(dd)_{dfl}$	distance from depot *d* to location *l* through facility *f*, $d \in D, f \in F, l \in L$
d_l	demand for location *l*, $l \in L$
P	maximum number of facilities

(mn) maximum distance from facility to location in the northern cluster

(ms) maximum distance from facility to location in the southern cluster

Decision variables:

W objective variable, most expensive weighted distance from depot to location

x_{fl} 1 if route from facility *f* to location *l* is used, 0 otherwise, $f \in F, l \in L$

y_f 1 if facility *f* is opened, 0 otherwise, $f \in F$

z_{dfl} orders sent from depot *d* to location *l* through facility *f*, $d \in D, f \in F, l \in L$

Description:

The objective function, equation (18), says to minimize the variable *W*. This means that the maximum weighted distance between depot *d* and location *l* should be as small as possible. Equation (19) is the p-center constraint. It says that variable *W* must be larger than or equal to the maximum weighted distance between depot *d* and location *l*. The last constraint is the non-negativity constraint for the *W* variable.

In addition to the constraints described above, equation (5), (6), (7), (8), (10), (11), (12), (13), (14), (15) and (16) is included in the model.

5.4 Changes for scenario and distribution alternatives

Since there are four different scenarios and three different value chain alternatives, the models needs a few changes for each alternative. The models described above represents the value chain where we distribute using PostNord, and the second scenario with one warehouse in the northern cluster and five in total. In order to change the model into Scenario 3 or 4, it is quite easy to add, remove, or change the constraints that specifies the facilities opened in each cluster.

When changing into Scenario 3 with two facilities in the northern cluster and six in total, we change equation (12) from ≤ 1 into ≤ 2, and facility Hammerfest must open in the same way that Tromsø is in equation (13). In addition, we change the *P* parameter from five to six. If we want to model the fourth scenario where there are one facility in the south, two in the north, and three in total, we simply add a constraint saying that there is a maximum of one facility allowed in the southern cluster similar to equation (12). In addition, we remove the maximum distance in the southern cluster, and changes the P parameter into three.

When modeling the initial solution, there are some simplifications and changes to do in order for the model to represent the current situation. Since it is very simplified, the p-median and p-center objective will give the same answer. Therefore, w only model Scenario 1 with the p-median objective, with the following changes from Scenario 2:

- Set F, (CN) and (CS) is removed.
- Parameter $(ld)_{fl}$, $(wd)_{wd}$, P, (mn) and (ms) is removed since every location gets direct deliveries from Langhus, and we do not use clusters or facilities.
- The depot distance matrix changes from $(dd)_{dfl}$ to $(wd)_{wdl}$, where we leave the facilities out, and insert the warehouse in Sweden instead.
- Variable $w_{wd},\ x_{fl}$ and y_f is removed because there are no facilities.
- Variable z_{dfl} changes index to z_{wdl}, which now represents the orders sent from warehouse *w* to location *l* through depot *d*.
- We remove the constraints represented by equation (5), (6), (7), (9), (10), (11), (12) and (13) is removed.
- The warehouse distance matrix needs to change into $(wd)_{wdl}$.
- The remaining demand constraint needs to be updated with the new variable into:

$$\sum_{w\in W}\sum_{d\in D} z_{wdl} \geq d_l \qquad\qquad \forall\, l \in L \tag{21}$$

- The objective function is simplified and changed into:

$$\sum_{w\in W}\sum_{l\in L} z_{wdl} * (wd)_{wdl} \tag{22}$$

When turning the p-median into the current situation, we see that we have a simplified model. The main thing we do is that we remove the opportunity to open facilities, and distributes straight to the locations from the warehouse in Sweden, through the depot in

Langhus. This means that we have direct deliveries, but many more warehouses instead of a few larger ones. In addition, we remove the clusters since we have no distance specifications.

When changing the models from distributing through PostNord to distributing alone, there is also some minor changes:

- Remove set D in the p-median, and change it into set W in the p-center.
- Remove distance matrix $(wd)_{wd}$ from the p-median.
- Distance matrix $(dd)_{dfl}$ changes to $(wd)_{wfl}$ in order to implement the new distances from Alingsås to the regional warehouses.
- Variable z_{dfl} is changed to z_{wfl}, where we now distributes directly from the warehouse in Alingsås to the different locations, through the regional warehouses.
- Remove variable w_{wd} in the p-median since we no longer distribute from Alingsås to Langhus.
- The objective function in p-median is changed into:

$$\sum_{w \in W} \sum_{f \in F} \sum_{l \in L} z_{wfl} * (wd)_{wfl} \tag{23}$$

- The p-center constraint is changed into:

$$W \geq \sum_{w \in W} \sum_{f \in F} z_{wfl} * (wd)_{wfl} \qquad \forall l \in L \tag{24}$$

The main change when distributing alone, is that we remove the depot. We no longer distribute through Langhus, but straight from Alingsås to the regional warehouses. This means that we skip a link, and it should give shorter distances.

5.5 Data Collection

The data used, is mainly secondary data. Through meetings and continuous contact with Tools, the data is received evenly trough the semester. This section explains the different methods and calculations when processing the data, in order to use it in the analysis.

5.5.1 Locations

Representatives from Tools have suggested the 33 locations considered. These locations have data available through Tools database, and it is a good representation of the total 60 locations. All the locations are implemented in the customized map from google presented in figure 1.

From the map, we see that there are some natural clusters. There are many locations gathered in the east, 12 locations evenly spread throughout the south/west/middle, and 5 locations located in the north. The distance from the middle and up to the northern locations is large, and gives us some challenges when trying to distribute economically.

5.5.2 Facilities

When asking the question of where to locate the possible regional warehouses, it was two options: either to use the already existing locations, or to place them randomly in the country. Since we are considering the whole country and the distances between some of the locations are quite large, the method of placing them randomly is not very suitable. In order to get an applicable solution, we need to include Tools in this decision. After discussing with them, we end up with using the already existing locations as potential facilities. This is not only for modeling purposes, but to build a whole new warehouse or several warehouses is a much bigger investment than expanding the ones already existing.

As specified in section 4.1, we initially run the p-median model with a setup cost in order to find out how many facilities we need in each scenario. This is because we want to use as few regional warehouses as possible, but still have enough to serve the total demand. Since it is hard to get an accurate and realistic setup costs for each warehouse and make it proportionally correct with the transportation cost, we only uses the setup cost to figure out the minimum number of facilitate needed in each scenario. If we would have included the setup cost, we should have done an analysis of each location and found the different setup costs for each facility. Nevertheless, for minimizing the number of warehouses, setting it significantly high compared to the distances, serves our purpose. The maximum allowed facility is set to 33 in the initial run, and adjusted to the number needed for each scenario for the rest of the facility location analysis. We add the setup cost to the objective function in the following way:

$$\ldots + \sum_{f \in F} y_f * s \quad (25)$$

where

s = fixed high setup cost for a facility

The number of facilities needed is specified in table 3.

5.5.3 Distances

We use the customized map, provided by Google, to find the different distances. They are in kilometer, and presented in appendix A. The warehouse used in the distance matrix, is Alingsås.

The p-center based model does only have one routing variable instead of two like in the p-median based model have. This is because the p-center constraint will not work correctly if we split the routing in two separate sections. This means that we cannot define this constraint with the transportation from warehouse *w* to depot *d* plus the transportation from depot *d* to location *l* as two separate sections in the constraint, since the model would minimize the two variables as two individual sections and not one. Because of that, we implement the distances from the warehouse to the depot directly in the distance matrix without it showing in the variable index.

In order to deliver in time, the maximum distance from a location to its corresponding warehouse cannot be too long. These distances differ from the northern and southern cluster, and they are worked out in cooperation with representatives from Tools. The distance in the southern cluster is set to be 250 km, and 850 km in the northern cluster. Since each scenario and value chain alternative uses a fixed number of facilities in the northern cluster, the maximum distance will not affect the results of the models, but in order to be able to make changes if desired we include it.

5.5.4 Demand

Since the objective of the models is to minimize the total number of kilometers traveled, the historical data of delivery frequency works as the demand. Since it is not possible to include all 390 000 different products, the alternative would be to do an ABC-analysis.

However, since the models do not consider vehicles, the total orders delivered to each location serves as a good representation of the total demand.

Since Aukra, Stavanger and Bærum opened during 2014, and there is no way of getting an exact measurement of the total deliveries made, we multiply the months we have so it represents 12 months.

5.6 Results

All models is implemented using AMPL modeling language and, CPLEX 9.0.0 solver. The solve time varied between approximately 0,02 and 0,25 seconds, so there is no need for heuristics. The variation in solve times, is graphically presented in figure 5.

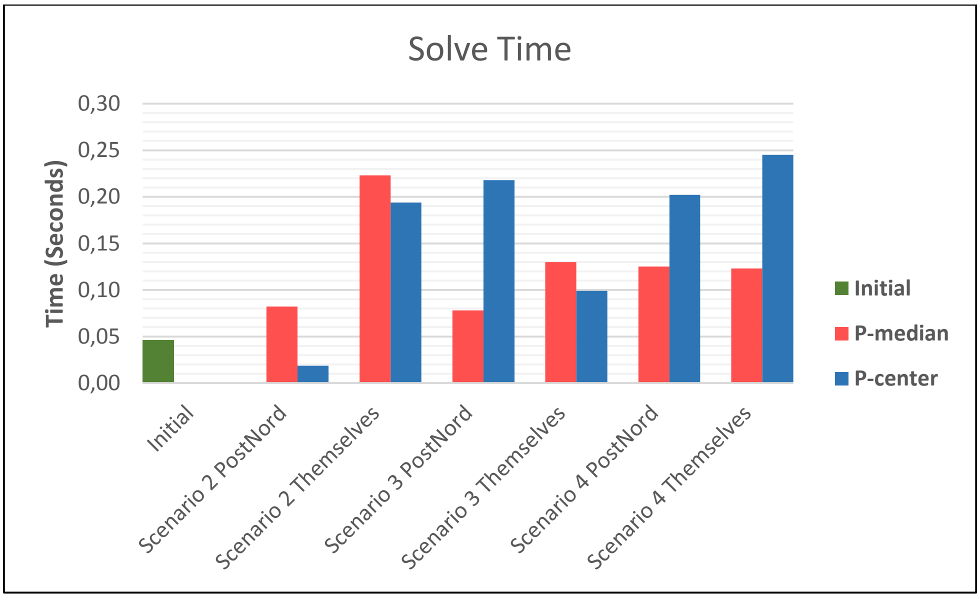

Figure 5: Solve time for the mathematical models sorted by the different scenarios and different models used.

Since we uses two different objectives, we have to compare and analyzed the results. From table 4 we see the total and the maximum distance travelled, where the best results depending on the objective is marked in green and red.

Model	Scenario	Solve Time	Total distance	Max distance
Initial	Scenario 1 PostNord	0,0460	45 105 737	4 304 048
P-median	Scenario 2 PostNord	0,0820	51 523 918	5 126 744
P-center	Scenario 2 PostNord	0,0187	53 857 312	5 126 744
P-median	Scenario 2 Themselves	0,2230	46 278 080	4 724 692
P-center	Scenario 2 Themselves	0,1940	46 385 516	4 724 692
P-median	Scenario 3 PostNord	0,0780	51 055 682	5 126 744
P-center	Scenario 3 PostNord	0,2180	52 564 798	5 126 744
P-median	Scenario 3 Themselves	0,1300	**45 692 469**	**4 724 692**
P-center	Scenario 3 Themselves	0,0990	48 545 673	4 724 692
P-median	Scenario 4 PostNord	0,1250	48 262 534	5 126 744
P-center	Scenario 4 PostNord	0,2020	48 426 558	5 126 744
P-median	Scenario 4 Themselves	0,1230	46 828 096	4 724 692
P-center	Scenario 4 Themselves	0,2450	47 053 020	4 724 692

Table 4: Solve time, total distance travelled (p-median objective) and maximum distance travelled (p-center objective).

We see that when distributing themselves the total distance is shorter. This is what we expected, and not very surprising. If we take a closer look, we notice that the maximum weighted distance is the same for each scenario. This means that for every scenario, the p-median will give at least as good solution as the p-center does. We can explained this by looking at their objectives. Since the p-median objective is to minimize the total distance and p-center only minimizes the maximum distance, p-median will always give the same or lower total distance as long as the most expensive one is the same. Figure 6 graphically explains the results, and shows that for each scenario alternative the total weighted distance is lower using the p-median objective.

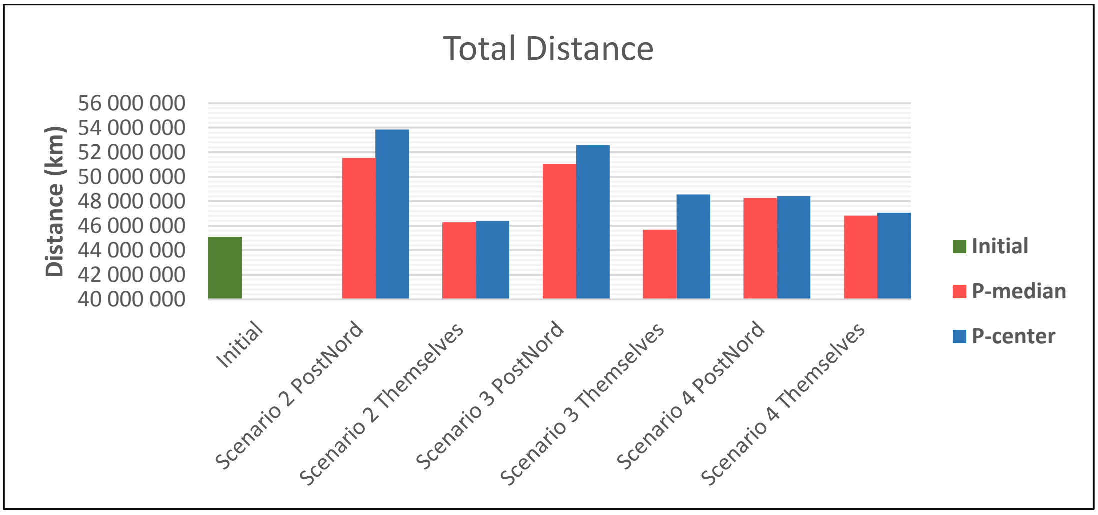

Figure 6: Total distance travelled presented scenario for scenario, and objective by objective.

Scenario 3, when they distribute themselves, gives the lowest total weighted distance travelled. We can take a closer look at the solution and see how to distribute in table 5.

Location/Facility	Flekkefjord	Fredrikstad	Førde	Hammerfest	Tromsø	Trondheim
Langhus	11 970	35 659	5 781	1 565	4 630	7 922
Askim	0	1 277	0	0	0	0
Aukra	0	0	0	0	0	420
Bergen	0	0	1 687	0	0	0
Bærum	0	328	0	0	0	0
Drammen	0	3 917	0	0	0	0
Finnsnes	0	0	0	0	2 324	0
Flekkefjord	1 144	0	0	0	0	0
Fredrikstad	0	4 182	0	0	0	0
Førde	0	0	1 943	0	0	0
Gjøvik	0	2 614	0	0	0	0
Hamar	0	5 707	0	0	0	0
Hammerfest	0	0	0	753	0	0
Haugesund	1 046	0	0	0	0	0
Jessheim	0	2 382	0	0	0	0
Kirkenes	0	0	0	812	0	0
Kongsberg	0	2 172	0	0	0	0
Kristiansand	2 220	0	0	0	0	0
Larvik	0	3 727	0	0	0	0
Mandal	3 973	0	0	0	0	0
Molde	0	0	0	0	0	2 412
Moss	0	3 076	0	0	0	0
Narvik	0	0	0	0	1 059	0
Oslo	0	1 700	0	0	0	0
Raufoss	0	1 400	0	0	0	0
Sandefjord	0	3 177	0	0	0	0
Stavanger	1 436	0	0	0	0	0
Stord	1 437	0	0	0	0	0
Tromsø	0	0	0	0	1 247	0
Trondheim	0	0	0	0	0	2 816
Tynset	0	0	0	0	0	1 537
Verdal	0	0	0	0	0	737
Ålesund	0	0	2 151	0	0	0
Åsen	714	0	0	0	0	0

Table 5: Solution for Scenario 3 when distributing themselves. The facilities used is Flekkefjord, Fredrikstad, Førde, Hammerfest, Tromsø and Trondheim. The table displays the total orders sent from Langhus to each facility and from each facility to each location.

We see that the natural clusters mentioned in section 5.5.1, is somewhat kept by the model. Fredrikstad serves the whole of eastern Norway. Not surprisingly, Fredrikstad is turned into the biggest warehouse with 35 659 orders served in total. This makes sense since this is the closest location to the warehouses in Sweden. Flekkefjord serves the southern and southwestern region of the country, while Førde serves the mid-western part. Trondheim serves the two most northwestern locations and the locations in the middle of Norway. As specified in the model, Hammerfest and Tromsø serves the northern cluster.

When we investigate the total demand at each facility, we see a broad variation. Thinking back to the SRL and the assumption of that the demand should be evenly spread among the centralized facilities, we cannot apply Evers and Beier (1993) SRL at this solution. Because of that, we use the SRL provided by Maister (1976) and get the following estimated reduction in safety stock with 6 centralized regional warehouses:

$$1 - \frac{\sqrt{6}}{\sqrt{33}} = 57{,}36\ \% \qquad (26)$$

We keep in mind that this result might be optimistic, as propose by Ballou. See appendix B for solutions from the facility location analysis.

6. Simulation Analysis

This chapter describes how we perform the simulation analysis. As in chapter five, we start by explaining the assumptions. Then the model and the description of it follows, and the data collection. We finish of by analyzing the results.

6.1 Assumptions

Also in the simulation model, a series of assumptions have to be made in order to be able to simulate the situation. Some assumptions is the same as in the facility location analysis, and some are new. We have also been forced to take some assumptions in order to decrease the run-time of the model, so that we get a result within reasonable time. The list below presents the assumptions:

- When calculating the input data, one year is 250 days working 7,5 hours a day.
- The arrival rate for the customer orders is the same as in 2014 for every location.
- The time it takes to drive from point a to b is normally distributed, where the quickest way according to google maps is used as a mean with a 10 % standard deviation.
- The process time at Langhus is normally distributed with an expected value of five hours and a standard deviation of one hour.
- The receiving time at a warehouse is exponentially distributed with a mean of 20 minutes. We uses the exponential distribution because of the real life variation in the delivery sizes.
- The opening hours at the warehouse is randomly set to be from 7 am to 6 pm.
- The delivery sizes are usually pre-determined and fixed, and there are little or no room for human determination.
- The demand for A-, B- and C-products are the same when they are ordered, meaning that the customers demand A-products on an order position 16 times as often as C-products (A = 80%, C = 5 %), and they have the same average demand.
- The number of positions at a customer order is exponentially distributed with last year’s average as a mean.
- The facilities serves the incoming customer orders by sending the orders to the locations. We never serves the incoming orders from the corresponding location.
- The vehicles do only delivery to one warehouse per trip.

- The reorder point is the demand in lead-time.

Section 6.3 further elaborates and explains the assumptions.

6.2 Model Description

The simulation models uses a series of logical queries and different statistical elements, in order to best give a view of the new situation. Three main models are used:

- The current situation
- The new situation using a (R, s, S) system
- The new situation using an (s, Q) system

In addition to the two new situations and the current situation, we model both with and without using PostNord as a distribution partner. In this section, we explain the different queries and logical aspects of the models. Since all the models has much of the same phases and logical aspects, the current situation is explained in depth and only the changes and new logics is explained in the (R, s, S) and (s, Q)-model.

6.2.1 Current situation

There are three different phases in the model, plus a separate transportation logic. The first phase determines the location, the number of positions on the customer order, the demand for each position, and the product type at each position. The model checks if there is a sufficient inventory to fulfill the order in the second phase, and controls the reorder point in the third.

6.2.1.1 Phase I

From figure 7, we see that the model initially creates a customer order. They arrive according to a pre specified arrival schedule, which is calculated using historical data. The arrival process is distributed according to a Poisson process, where the time between arrivals is exponentially distributed. The first sub-model assigns each order a location. This works in a way that when an order arrives, each location have a given probability of getting the order. Each order gets an attribute that represents the location.

Following this, the model assigns the number of positions on the order. This happens according to an exponential distribution, due to the randomness of the number of positions. The model rounds the order positions to the nearest integer, so it is able to handle it later on. The order continues into an if-logic, which has the assignment of controlling whether the number of order positions is zero or more than zero. If the number of positions is zero, the model reassigns it to one, and if it is larger than zero, it skips the logic.

The model continues by splitting the orders into the different order positions, in order to assign each position a demand and product type. A new if-logic whether if the demand is zero or not, before it moves on to gather different statistics such as the average demand and product types.

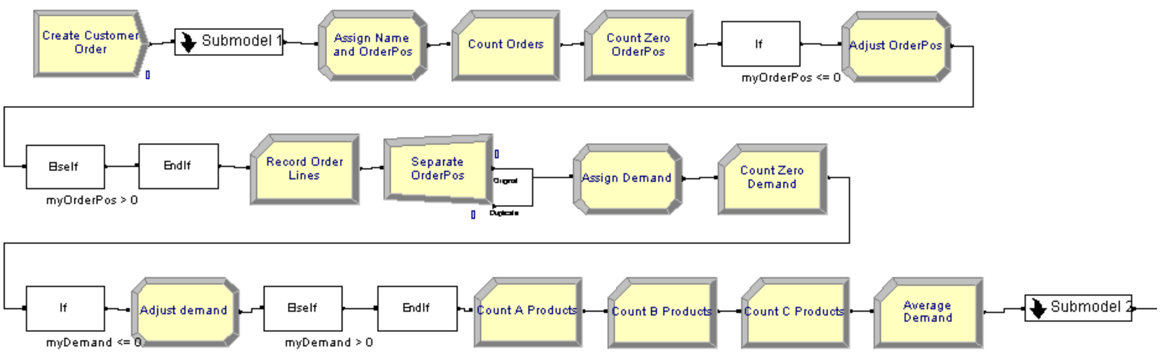

Figure 7: First phase in the model for the current situation, where the model assigns and controls the demand, location and order positions.

6.2.1.2 Phase II

In Phase 2, illustrated in figure 8, the model checks if there is a sufficient inventory at the corresponding location to fulfill the order position. If we have a sufficient inventory, the logic sends the order position straight forward and updates the inventory. The order then waits for all the other order positions on that unique order to be fulfilled, so that the customer gets the entire order delivered at the same time. If the inventory is not sufficient to fulfill the required demand, the model check if what is on order and the remaining inventory is enough. If this minus the total demand that is already waiting for the next delivery is still not enough, the logic goes on to make an extra delivery. If on the other hand what is on order is enough, it continues and holds until the inventory is sufficient.

When placing an extra delivery, the order position goes into a hold module and waits there for a sufficient inventory. While the order position waits, the model creates a new entity, which represents the extra delivery. The entity starts by holding for transportation, before the model sends it for processing at the PostNord terminal in Langhus. After processing, the logic continues by transporting the delivery to the corresponding location. If the transportation arrives at the location outside its opening hours, the transportation has to wait before delivering. After the location has received the delivery, the model updates the inventory and the order position is automatically released from the hold module.

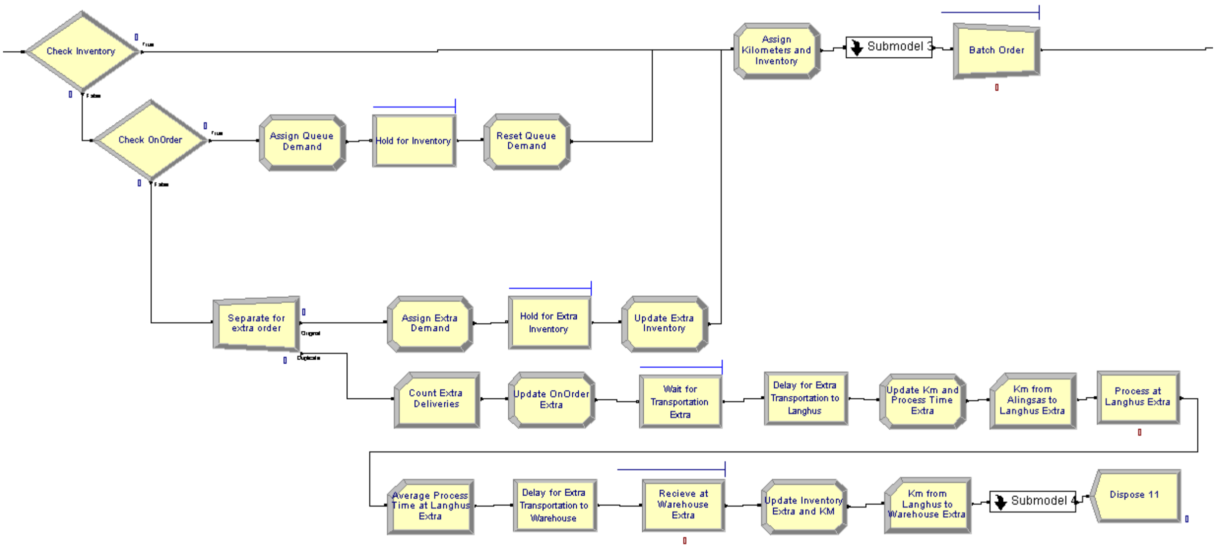

Figure 8: Second phase in the current situation model where the inventory is controlled and updated for the customer order.

When the model has fulfilled all the positions on an order, it is batched together and ready for Phase 3. Sub-model 3 and 4 is there to update the inventory at each location. Different statistical measurements such as counting the extra orders and average processing time, is tactically placed to get the desired output.

6.2.1.3 Phase III

In Phase 3, illustrated in figure 9, the model deliver the order to the customer, and the inventory level is check to see whether it has reached the reorder point. If the reorder point is reached, or the inventory level plus what is already on order is less than or equal to the reorder point, a delivery is requested. The delivery of the order and transportation works in the same way as the delivery and transportation for an extra delivery.

Immediately after a location has received the customer order, we record the order time. The two following decide modules is there to decide whether the total order time is more than 18 hours, and in that case if the order is for the northern locations. We do not include the northern locations in the number of orders over 18 hour's statistic, since the distances is naturally large.

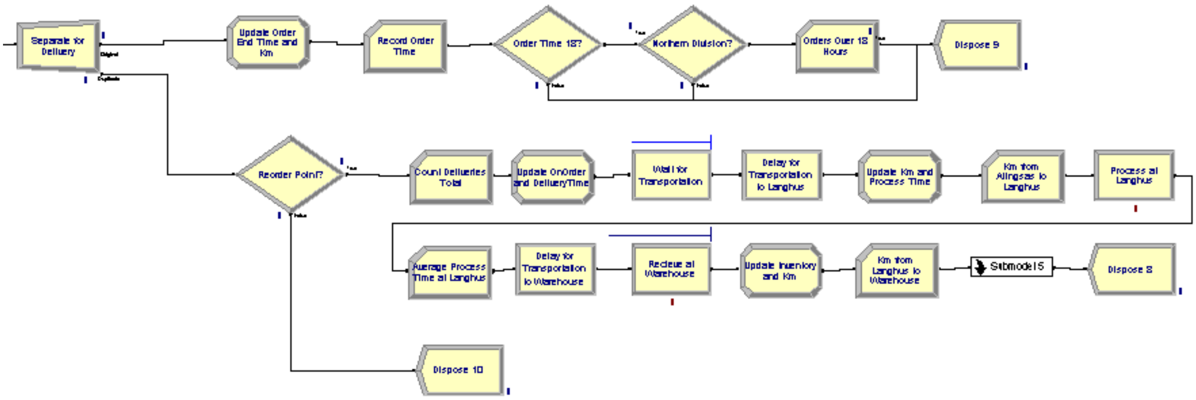

Figure 9: Third phase in the current situation where we deliver the customer order, control the inventory level up against the reorder point, and request a delivery if needed.

6.2.1.4 Transportation logic

The additional transportation logic illustrated in figure 10, is there to give a signal for when the transportation from Sweden departures. As previously mentioned, a delivery order has to hold for a signal before the transportation from Sweden can start. The model initiates the logic by creating an entity, which goes straight into a delay module and waits there for eight hours (from 00.00 am to 08.00 am). From there, it moves on and gives a signal that initiates the first of two transportations that day. After the initiation of the first transportation, the entity holds for five more hours (from 08.00 am to 01.00 pm). After five hours, a new signal that initiates the second transportation is given. The entity continues into a new hold where it stays for eleven hours (from 01.00 pm to 00.00 am). This logic represents 24 hours, and it continues in a loop for the whole simulation.

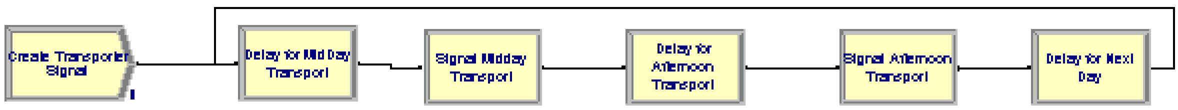

Figure 10: Transportation logic that initializes the transportations from Sweden throughout the simulation.

The model uses different variables, attributes, and expressions, in order for the different logics to work and to get enough and relevant output from the simulation analysis. The model runs in 270 days, with a warm-up time of 20 days. This represents the assumed working year of 250 days. In order to get accurate statistics, the model does 15 replications. The (R, s, S) and (s, Q) models, uses the same number of replications and run time parameters.

6.2.2 (R, s, S) system

In the (R, s, S) model, there are much of the same logics and phases as in the current situation. We divide the main logic into four different phases, and there are two additional ones. The first phase is the same as in the previous model. The second phase is a new logic where the corresponding regional warehouse is assigned to each the order. The third phase is the same as Phase 2 in the previous model, only that the model updates the inventory at the regional warehouses instead of at the locations. The fourth phase is similar to Phase 3, only that the logic of checking the reorder point is now a separate one. In addition, we have to transport the customer orders to the corresponding locations, before it can be delivered to the customer. The first additional logic is the same as the transportation logic in the above model, and the second is the new separate delivery logic.

6.2.2.1 New phase II

In the second phase, the model assigns the regional warehouses. This happens by using the location attribute defined in Phase 1, and routing it through a decide module that sends each order to the corresponding regional warehouse. In addition to the different statistics gathered, we assign an attribute that symbolizes the regional warehouse for later usage in the model. A figurative illustration of the new Phase 2 is in figure 11.

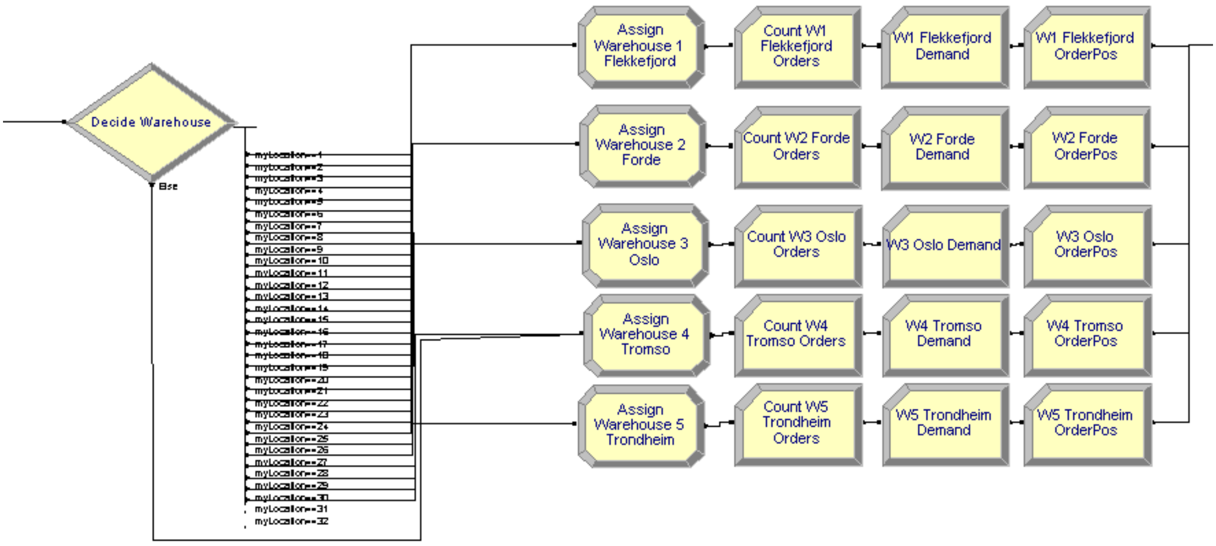

Figure 11: Phase 2 in the (R, s, S) and (s, Q) system models where the correct warehouse is assigned to each order position.

6.2.2.2 Delivery logic

The delivery logic consist of two phases. The model assign the corresponding regional warehouse attribute and the delivery sizes in Phase 1, before it controls the delivery size and deliver it if the size is significantly big in Phase 2. Figure 12 and 13 presents the two phases described in this section.

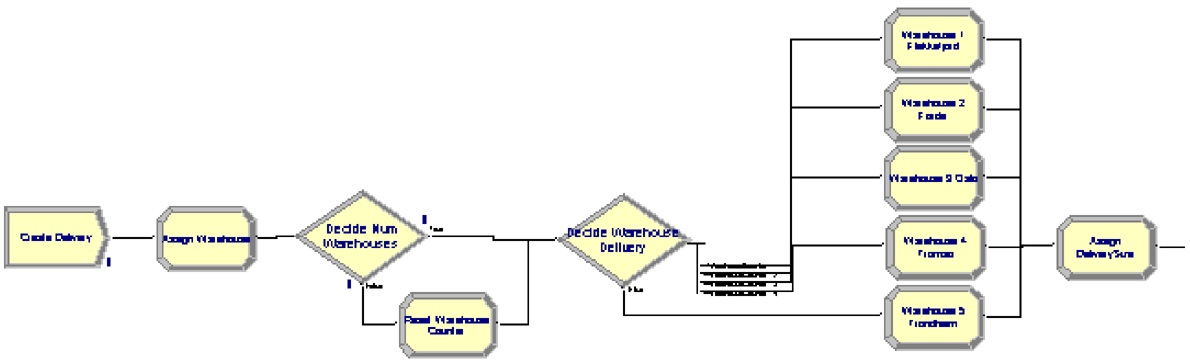

Figure 12: First phase in the delivery logic where the model creates an inventory controller for each warehouse and assign the correct regional warehouse to each controller.

Every day at 4 pm, the model creates a fixed number of entities. The total number of entities created, is controlled through a variable that represents the total number of regional warehouses used. The model assigns each entity a warehouse attribute, so it can deliver to the correct warehouse.

Over at Phase 2, the model starts by controlling the delivery size. For the delivery to go through, the delivery size must be bigger than a pre-specified quantity. If the delivery size is larger than or equal to the minimum delivery size, the delivery goes through to the next checkpoint.

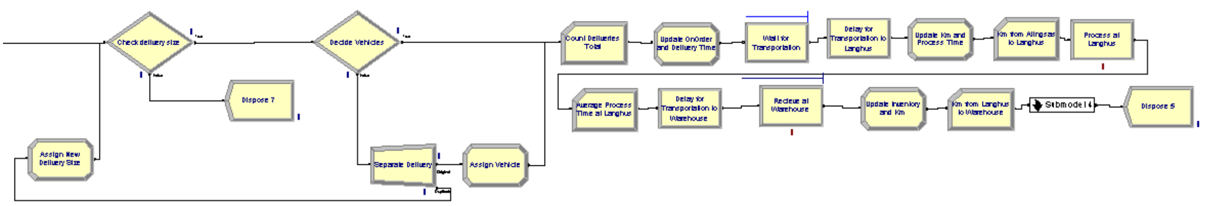

Figure 13: The second phase in the delivery logic where the model controls the delivery size and deliver the order to the corresponding regional warehouse.

At the next checkpoint, the model checks the delivery size again. If the size is smaller than the capacity of a full vehicle, it goes on with a normal delivery. If the size is larger than one full truckload, the model splits the order in two pieces. The first piece delivers one full truckload to the corresponding warehouse, and the second piece subtracts the products delivered by piece one from the remaining delivery size. It does this in order to account for the amount already delivered by piece one, so it can repeat the checkpoint logic. The second piece starts Phase 2 over again, and checks if the remaining delivery size is significantly big. If the size is larger than the minimum delivery size, the checkpoint logic is repeated, and if not we dispose of the remaining order. The transportation and delivery logic that follows is the same as in the previous model, only that we gather statistics and deliver to the regional warehouses and not the locations.

6.2.3 (s, Q) system

In the (s, Q) model, there are different variations of the phases and logics that is already explained. We divide the model into four phases, in addition to the separate transportation logic used in the two models above. Phase 1 is the same as in the two previous models. Phase 2 and 3 are the same as in the (R, s, S) model, where the model assigns the corresponding warehouse to each entity and the inventory is checked. The reorder point logic is inserted back into Phase 4, in the same way that it is in the current situation. The process of transporting the goods from the warehouse to the location is also here included in the delivery of the customer order.

6.2.4 Changes when distributing themselves

When changing from distributing through PostNord to distributing themselves, there are only minor changes. We remove the transportation to and processing at Langhus, since we now transport directly to the warehouses. The distance and time matrixes is adapted and changed, so they represents the new times and distances from Alingsås to the regional warehouses. In addition to this, there are some change in how and what kind of statistics that is collected, in order to be able to compare the alternatives.

6.3 Data Collection

We have used many variables, parameters, expressions and different inputs in the simulation models. This section contains an explanation and accounts for how we got, them and/or calculated them.

6.3.1 Locations and products

We need to find a way of distributing the incoming orders to the different locations. We do this so the model contains a certain amount of a stochastic environment, so it will be the best possible representation of reality. A simple and straightforward way of doing this is to sum up the total number of orders in one year, and find the probability for each location compared to the total number of orders.

In order to split the demand into different product groups (A-, B- and C-products), we uses a discrete distribution. The discrete distribution works by returning a value that has a certain probability. Each value is paired with an accumulated probability, and attributes represents the values. The probability for product A is 80 % probability with attribute one, B is 15 % with attribute two, and C is 5 % with attribute three.

6.3.2 Inventory variables, reorder point and order quantity

The different models uses different values and methods for calculating the inventory and ordering variables. The following sections describes them.

6.3.2.1 (s, Q) system

The (s, Q) model is built up with a fixed order size *Q*, and a fixed reorder point *s*. In order to best utilize the capacity of a vehicle, we have set the order size *Q* equal to the estimated vehicle capacity. The method used to calculate the approximate capacity of a vehicle, is to divide the total units delivered by the total trucks driven in one year. From historical data, we get that the total units delivered from their three biggest suppliers is 8 229 425. Keeping in mind that this is only 52 % of the total products, the total unit count is approximately 15 825 817. Dividing this by the total trucks driven per year and rounding it up to the nearest 100, we get:

$$\frac{15\ 825\ 817}{1000} = 15\ 825{,}817 \approx 15\ 900 \tag{27}$$

We now have an estimate for the vehicle capacity, and the order quantity *Q*.

The reorder point *s* is estimated to be the demand in lead-time. In order to calculate this, we have extracted the time it takes to drive from google maps, and multiplied it by the demand per minute. We have calculated the demand per minute for each location by finding the total units sold using historical data obtained from Tools. We also need to calculate the total minutes worked in one year, in order to get the demand per minute. The calculation follows: 250 days with 7,5 working hours per day = 112 500 working minutes per year. After this, it is easy to calculate the demand per minute with and without PostNord as a distribution partner. We assume that the demand is the same whether we distribute with or without PostNord, so the reorder point is only dependable on the lead-time.

When doing a test run with the numbers calculated above, we obtained a very high stock out probability in the eastern warehouse (Oslo/Fredrikstad). This is because of the high demand and high density of locations in this area, in addition to the short lead-time. These results indicates there is a need for a higher buffer at this regional warehouse. In order to cope with this, we double the demand inn lead-time and uses this as a reorder point for that warehouse in particular. The warehouse is now able to handle more fluctuations in the demand, without having a stock out situation. After further test runs, we get that the stock out probability is about the same as in the other warehouses.

The initial inventory level is set to be equal to the reorder point plus the order quantity, namely $I = s + Q$.

6.3.2.2 (R, s, S) system

The (R, s, S) system is built up using an order-up-to variable. The model controls the inventory level at time *R* and check if it is below point *s*. If it is below point *s*, we order the quantity needed for the inventory level to be *S*. In this way, we do not have to monitor the inventory on a continuous basis, and we do not risk driving virtually empty trucks.

The time *R* is set to be every day after work. This means that every day at 4 pm when the customer order stops coming in, we control the inventory level. This is the extra delivery logic explained in section 6.2.2.2. The reorder point *s* is set to be two thirds of a full vehicle. This means that since we have calculated a full vehicle to be 15 900 units, the reorder point *s* is: 15 900 * (2/3) = 10 600. So we do not deliver, unless the delivery size is larger than or equal to 10 600 units.

We calculate the order-up-to level to be the reorder point *s* plus the capacity of a vehicle. This also works as the initial inventory, except for the warehouse in the east. As explained in the previous section, we need a higher buffer to avoid a stock out situation in the eastern part of the country. So also here, we double the demand in lead-time and use it as inputs for the initial inventory and order-up-to point.

6.3.3 Distances and driving times

The input data for the driving times and distances, is inserted through expressions. The distances is the same as they were in the facility location analysis, and extracted using google maps. The new thing here is that we uses the time it takes to travel instead of the kilometers travelled as a measurement, and record the distance travelled instead. This is to get a clearer and more realistic review of the solution when implemented. Since time is not constant and the time it takes to drive from one place to another depends on many factors such as weather, time of day and traffic, we must apply some statistical factors that represents the stochastic environment we live in. The suggested distribution to use is a normal distribution with a 10 % standard deviation of the expected value (Rømo and Sætermo, 2003).

In addition to the time it takes to travel, there are strict driving policies in Norway. These regulations and obligated resting times is directly included in the calculations of the driving times in the following way (VEGVESEN.no):

- For every 4,5 hours of driving the driver is obligated to take a 45 minutes break. The first break is taken after 4,5 hours of driving.
- There should at least be 11 hours of cohesive break in one day (24 hrs.).
- If the driving time is more than 13 hours (24-11 = 13), we replace one 45-minute break with an 11-hour daily break.

The time matrixes is presented in appendix A. The departure times for a truck that leaves from Alingsås is set in cooperation with Tools, and already pointed out in section 6.2.1.4.

6.3.4 Demand, schedules and processing times

Each order consists of a certain number of order positions, and each positions have an estimated average demand. The model calculates these numbers by using expressions implemented by the user. We calculate these averages as averages for each location, and distribute them exponentially. We have chosen the exponential distribution so that we have a random demand, with an expected value. It is very unlikely that the demand is extremely high compared with the expected value, but not theoretically impossible. The model automatically round both parameters to the closest integer, as explained in section 6.2.1.1.

We use schedules, in order to get a random approach for the arrival rate of the customer orders. They are calculated using historical data, and inserted in a schedule. The orders is assumed to arrive between 8 am and 4 pm, and the average number of orders per day is the total number of incoming orders divided by the total number of days in one year:

$$\frac{308\ 790{,}5}{250} = 1\ 235{,}162 \tag{28}$$

This means that the average orders that arrive each day, is 1 235,162. This arrival rate is exponentially distributed, as proposed by Rossetti (2009). We use the historical data from 2014 as input.

The resources limits when a warehouse is open to receive a delivery, and is set to be active from 7 am to 6 pm. This means that if a delivery arrives outside the opening hours, it has to wait with the delivery until the warehouse is open.

The processing time at Langhus is randomly set to be five hours, while the unloading and receiving time at the warehouse is set to be 20 minutes. Due to the stochastic reality, both numbers are exponentially distributed.

6.3.5 Statistics and Welch plot

When we simulate and uses estimated values for the variables, we get some initialization bias. This means that the systems performs in a way that is not representative for a long-time run. In order to cope with this, we introduce a warm-up time. The warm-up time represents the time it takes for the system to reach a state where the performance of the system no longer depends on time, and the system has reached a state where the observations is adequately similar to a desired steady-state distribution (Rossetti, 2009). To find out when the system has reached this state, a Welch-plot is applied (Welch, 1983).

A Welch-plot is the cumulative moving average of a given statistic output from the simulation model. By visually studying the moving average, we can see when the system stabilizes. The statistics used to measure the steady state in this thesis, is the average order-time. We perform this procedure for every model, and all systems reaches a state where the cumulative average stabilizes within 20 days. We insert this in Arena, and the model automatically resets all statistics at day 20, and deletes all the bad data.

In figure 14, we see the Welch-plot from Scenario 2 when distributing through PostNord. In the beginning of the plot, we see that the line fluctuates some and is not stable. This indicates that the performance is not representative for a long run condition. By visually studying this line, we see that approximately at time 70, the system looks stabilized. We can study the Welch-plot with a broader time horizon, which might make it easier to see when the system reaches the desired state.

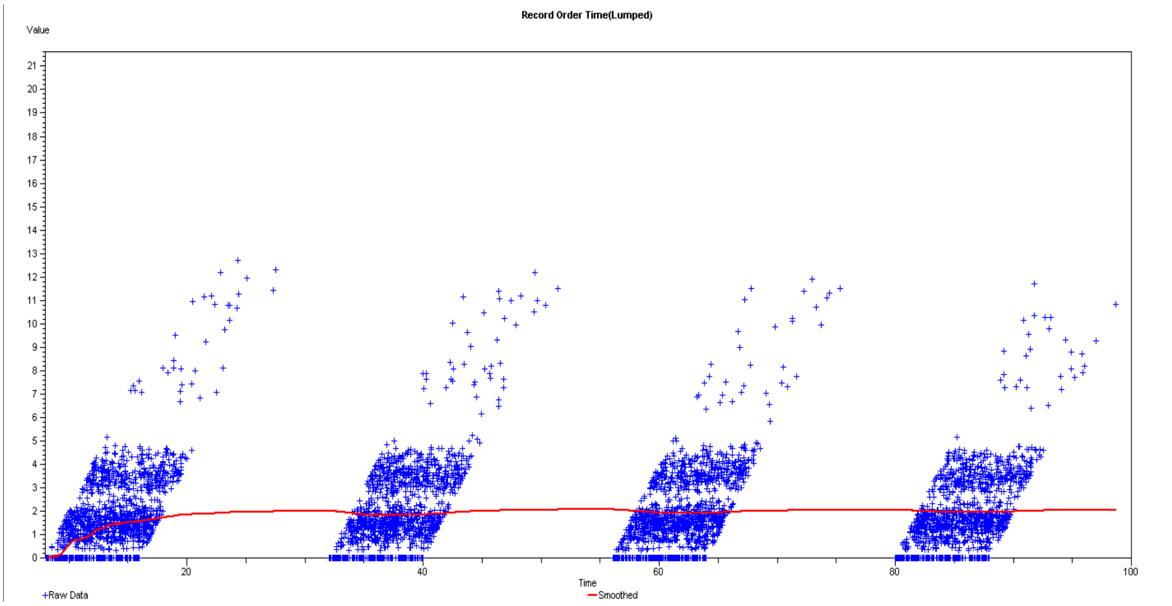

Figure 14: Welch plot for the first 100 hours from the Scenario 2 using PostNord and a (R, s, S) system.

It is not easy to decide the length of a replication. A rule of thumb is that the replication length should at least be ten times as long as the data deleted (Banks et al., 2005). In this way, we assure that the statistics gathered is sufficient and accurate. The replication length used is 250 days. This represents one full year, and it is more than ten times as long as the warm-up time, which represents the deleted data.

In order to get accurate statistics, we would like to minimize the half-widths in the output report from the simulation. These half-widths represents a 95 % confidence interval, and describes how accurate the statistics are. After some test-runs, we end up with using 15 replications. The half-widths for the most important statistics as the average order time, the stock out probability and the queue statistics are zero or close to zero, so we say that the model gives accurate output. Optimally the models would have been ran longer, but since each replication takes quite a long time to run, and there are many models, 15 replications is concluded to be sufficient.

6.4 Results

The different simulation models are simulated using version 13.0 – CPR 9 of Arena, provided by Rockwell Automation. We initially built the models with 2-dimensional variables for the inventory and demand, where we divided the columns into A-, B- and C-products and the rows into the different warehouses. Due to a very long run time, the model was simplified and the variables turned into 1-dimensional with only one product and multiple warehouses as described in section 6.2 and 6.3.

The run time differed between approximately 9,5 and 17,5 minutes as figure 15 illustrates.

Figure 15: Total run time for each simulation model divided into scenarios and sorted by distribution method and inventory system.

All the numbers and results in this section are averages for all the 15 replications, with a yearly basis.

6.4.1 Average Order time

The average order time, is the average time it takes before a location have received the order and delivered it to the customer. We see that the average order times increases when we have fewer warehouses. This corresponds well with the theories explained by Brandimarte and Zotteri (2007), of that we may see an increase in lead-time when centralizing the warehouse operations. We see that by using only one warehouse in the southern cluster, we get a high average order time. On the other hand, we get no orders over 18 hours. Since it is important for Tools to deliver the next day, the objective of minimizing the number of orders over 18 hours might be an appropriate measurement.

From table 6, we see that the best solution when minimizing the number of orders over 18 hours, is Scenario 4 with an (s, Q) system and using PostNord as a distribution partner. We note that Scenario 2, using an (R, s, S) system and distributing themselves, has only 0,4 more deliveries over 18 hours and approximately 2 hours shorter average lead time.

Order policy and distribution	Scenario	Average Order Time	Orders Over 18 hours
(s, Q) PostNord	Scenario 1	**0,0633**	234,20
(R, s, S) PostNord	Scenario 2	2,0212	23,00
(R, s, S) Themselves	Scenario 2	2,1659	0,40
(s, Q) PostNord	Scenario 2	2,0224	30,53
(s, Q) Themselves	Scenario 2	2,1671	13,67
(R, s, S) PostNord	Scenario 3	1,8617	19,60
(R, s, S) Themselves	Scenario 3	2,0068	7,53
(s, Q) PostNord	Scenario 3	1,8641	4,13
(s, Q) Themselves	Scenario 3	2,0068	8,60
(R, s, S) PostNord	Scenario 4	4,4102	**0,00**
(R, s, S) Themselves	Scenario 4	4,4103	**0,00**
(s, Q) PostNord	Scenario 4	4,4094	**0,00**
(s, Q) Themselves	Scenario 4	4,4101	**0,00**

Table 6: Average order time and number of orders over 18 hours from each simulation model, where the numbers marked in green and red represents the best alternatives depending on the objective.

The number of order over 18 hours is without the five northern locations. This is because there are very large distances in the north and by including these locations, we would not get a statistic that is representative for the whole system. We get an indication of the distances by studying the average delivery times in section 6.4.3.

We see that by using the situation they have today they have a very low average order time, but very many orders over 18 hours. This might be bad for business, since the customers might not get important goods delivered in time. The reason why might be that they usually have enough on stock to supply the incoming orders, but when they first run out it is a long lead time. The current situation do not have the safety of having a consolidated safety stock that keeps a buffer in case of a stock out situation, as there is in the other scenarios. In order to decrease the number of orders over 18 hours we must increase the reorder point, which leads to a higher average inventory shown in appendix G, Situation 4.

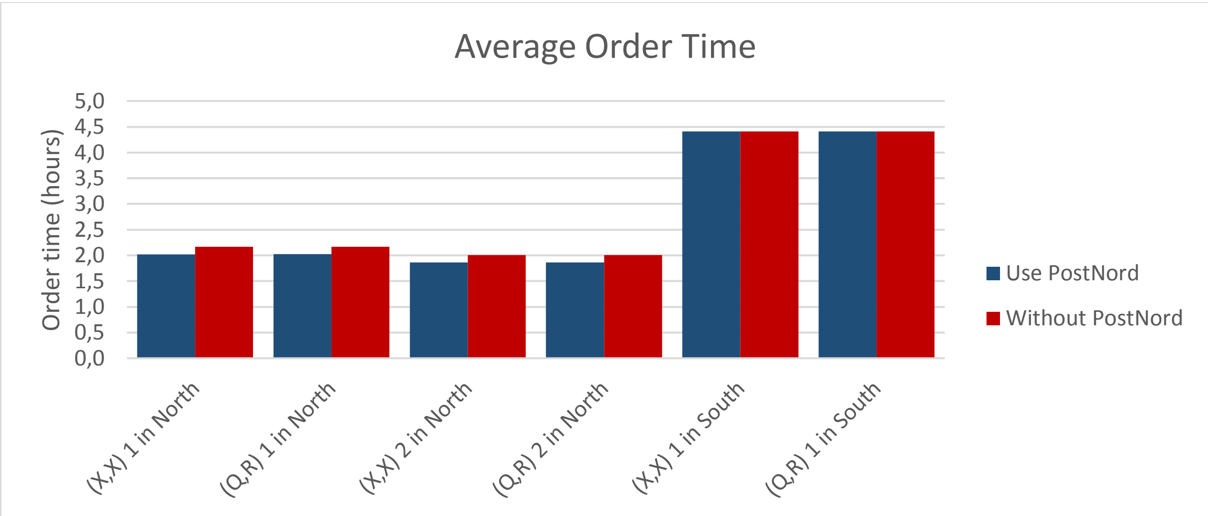

Figure 16: Average order time graphically displayed divided into scenarios and sorted by distribution method.

Figure 16 graphically displays the average order times for each scenario alternative. It is easy to see that when we use PostNord, the total distances is shorter. The only scenario who differ from this is Scenario 4, where it looks approximately the same.

6.4.2 Number of deliveries and kilometers travelled

From table 7, we see that the number of deliveries does not vary that much within the same system, but that there are some variations between them. Using an (s, Q) system clearly gives fewer total deliveries. The average deviation between the two systems is approximately 45 deliveries, which is slightly less than one delivery per week. Note that the smallest deviation between the two systems is in Scenario 4, when using PostNord, where the deviation is approximately 33.

In this analysis, the lowest total distance driven is found in Scenario 3, when they use PostNord and an (s, Q) system. The lowest total deliveries is in Scenario 4 when they distribute themselves, and uses an (s, Q) system. However, note that the number of deliveries is only 0,53 less than in Scenario 3, and since the number of total deliveries is approximately the same, we say that Scenario 3, with an (s, Q) system and using PostNord, is the best solution when using the total kilometers and deliveries made as an objective.

Order policy and distribution	Scenario	Warehouses	Distance travelled	Deliveries	Delivery deviation
(s, Q) PostNord	Scenario 1	33	460 768,67	543,67	543,67
(R, s, S) PostNord	Scenario 2	5	43 078 269	589,80	46,47
(s, Q) PostNord	Scenario 2	5	43 048 385	543,33	
(R, s, S) Themselves	Scenario 2	5	45 076 700	590,47	47,07
(s, Q) Themselves	Scenario 2	5	45 029 062	543,40	
(R, s, S) PostNord	Scenario 3	6	39 459 707	595,33	51,93
(s, Q) PostNord	Scenario 3	6	**39 396 673**	543,40	
(R, s, S) Themselves	Scenario 3	6	41 434 450	594,27	51,07
(s, Q) Themselves	Scenario 3	6	41 384 098	543,20	
(R, s, S) PostNord	Scenario 4	3	100 938 138	576,60	**33,47**
(s, Q) PostNord	Scenario 4	3	100 890 373	543,13	
(R, s, S) Themselves	Scenario 4	3	100 882 396	583,53	40,66
(s, Q) Themselves	Scenario 4	3	100 887 777	**542,87**	
Average			**57 074 369**	**564,08**	**45,11**

Table 7: Total deliveries made and the total distance travelled where the alternatives marked in green and red represents the desired alternative depending on what objective we have.

If we study the total distance driven a bit further, we notice that the results show a higher total distance driven in Scenario 2 and 3 when distributing themselves. This contradict with the results found in the facility analysis, and it is an unexpected result. One would think that when we rule out PostNord, we would drive a shorter distance, but this is clearly not the case according to the simulation analysis.

A possible reason for this might be that google maps choses roads that are longer in kilometers but with higher speed limits, so that the average speed is higher. Another reason why we see these results is that we have included resting time when driving so that the driving time is no longer proportionally correct with the number of kilometers. If we would have used time instead of distances in the facility location analysis, the results might have been different. This tells us that it is not the same whether we use the distance or time as the measurement, and that using time is a more appropriate and accurate measurement.

6.4.3 Average delivery time

Shifting the focus over to the average delivery time presented in table 8, we see a different result. The average delivery time is the time it takes from an order is requested in Sweden, to it has arrived and been delivered to the correct regional warehouse. For each scenario alternative, the average delivery time is shorter when they distribute themselves. This makes more sense than when we studied the results from a distance perspective. The average deviation is approximately six hours, which means that an average delivery when distributing themselves is six hour faster than when they distributes through PostNord. A complete overview of the total kilometers, the number of trips made and the average delivery time for each scenario alternative, is presented in appendix D.

Scenario	Order policy and distribution	Average delivery time	Highest distance	Name highest	Deviation
Scenario 1	(s, Q) PostNord	30,27	33,03	Narvik	
Scenario 2	(s, Q) PostNord	32,81	55,50	Tromsø	4,74
Scenario 2	(s, Q) Themselves	28,06	50,15	Tromsø	
Scenario 2	(R, s, S) PostNord	41,46	64,11	Tromsø	7,29
Scenario 2	(R, s, S) Themselves	34,17	57,47	Tromsø	
Scenario 3	(s, Q) PostNord	36,67	56,61	Hammerfest	4,78
Scenario 3	(s, Q) Themselves	31,89	51,33	Hammerfest	
Scenario 3	(R, s, S) PostNord	45,33	64,54	Hammerfest	6,74
Scenario 3	(R, s, S) Themselves	38,58	60,66	Hammerfest	
Scenario 4	(s, Q) PostNord	44,68	56,26	Hammerfest	7,13
Scenario 4	(s, Q) Themselves	37,55	50,64	Hammerfest	
Scenario 4	(R, s, S) PostNord	51,32	64,73	Hammerfest	5,15
Scenario 4	(R, s, S) Themselves	46,17	60,27	Hammerfest	
Average			**55,79**		**5,97**

Table 8: Average delivery time, highest delivery time and name of warehouse. The deviation between using PostNord or not for each scenario alternative is also included. The numbers marked in green and red represents the desired alternative depending on the objective.

6.4.4 Inventory

When reviewing the inventory, we want it to be as low as possible but still keep a sufficient service level. The theory says that the fewer inventories we have, the lower the safety stock. The results from the simulation analysis also gives quite the significant reduction in average inventory, which corresponds well with the theory. Off course, the results is just indications off what we can expect if we try to implement the solutions in real life, but it is as close as we can get without actually doing it.

Comparing the different scenarios, we can investigate the differences in the average inventory, presented in table 9. Also here, the (s, Q) system gives the best results. When comparing the (s, Q) with the (R, s, S) system, we see that the (s, Q) system achieves an average of 16,15 percentage points lower average inventory than the (R, s, S) system does. Another interesting result is that almost every solution have a percentage reduction in average inventory on more than 60 %. These results indicates that a centralization of the warehouses, will give a lower average inventory.

Scenario	Order policy and distribution	Sum average inventory	Ratio	Reduction	System difference
Scenario 1	(s, Q) PostNord	294 667	100,00 %	0 %	
Scenario 2	(s, Q) PostNord	**61 754**	**20,96 %**	**79,04 %**	16,74 %
Scenario 2	(R, s, S) PostNord	111 076	37,70 %	62,30 %	
Scenario 2	(s, Q) Themselves	64 470	21,88 %	78,12 %	14,53 %
Scenario 2	(R, s, S) Themselves	107 274	36,40 %	63,60 %	
Scenario 3	(s, Q) PostNord	69 963	23,74 %	76,26 %	21,21 %
Scenario 3	(R, s, S) PostNord	132 470	44,96 %	55,04 %	
Scenario 3	(s, Q) Themselves	72 457	24,59 %	75,41 %	19,14 %
Scenario 3	(R, s, S) Themselves	128 869	43,73 %	56,27 %	
Scenario 4	(s, Q) PostNord	83 051	28,18 %	71,82 %	17,84 %
Scenario 4	(R, s, S) PostNord	135 611	46,02 %	53,98 %	
Scenario 4	(s, Q) Themselves	91 638	31,10 %	68,90 %	7,46 %
Scenario 4	(R, s, S) Themselves	113 624	38,56 %	61,44 %	
Average		**97 688**	**33,15 %**	**66,85 %**	**16,15 %**

Table 9: The average inventory and reduction compared to the initial solution (Scenario 1).

We see that we obtain the lowest average inventory in Scenario 2. To be more precise, if we use Scenario 2 with an (s, Q) system, and distributing through PostNord. More elaborating tables of the inventory results is presented in appendix E.

6.4.5 Stock out probability

We obtain the stock out probabilities by recording the percentage time each inventory level is zero. In order to compare them, we find the averages and the highest one for all the warehouses in each scenario. Table 10 presents the results.

We see that we find the lowest probability of a stock out situation in Scenario 4, namely using an (R, s, S) system and PostNord. This alternative also has the lowest highest stock out probability, so it is definitively the desired alternative when considering this as an objective. None if the probabilities are significantly high, so there is in general a low probability of a stock out situation. A complete overview of the stock out probabilities for each scenario alternative, is displayed in appendix F.

Scenario	Order policy and distribution	Average stock out probability	Highest probability	Name Highest
Scenario 1	(s, Q) PostNord	0,1499 %	0,1831 %	Stavanger
Scenario 2	(s, Q) PostNord	0,4011 %	0,5352 %	Trondheim
Scenario 2	(R, s, S) PostNord	0,2443 %	0,4074 %	Flekkefjord
Scenario 2	(s, Q) Themselves	0,2296 %	0,2935 %	Forde
Scenario 2	(R, s, S) Themselves	0,1586 %	0,2301 %	Flekkefjord
Scenario 3	(s, Q) PostNord	0,4032 %	0,6360 %	Forde
Scenario 3	(R, s, S) PostNord	0,2259 %	0,4787 %	Oslo
Scenario 3	(s, Q) Themselves	0,2078 %	0,2896 %	Forde
Scenario 3	(R, s, S) Themselves	0,1571 %	0,2691 %	Flekkefjord
Scenario 4	(s, Q) PostNord	0,1326 %	0,1368 %	Hammerfest
Scenario 4	(R, s, S) PostNord	**0,1315 %**	**0,1353 %**	Hammerfest
Scenario 4	(s, Q) Themselves	0,1350 %	0,1386 %	Hammerfest
Scenario 4	(R, s, S) Themselves	0,1341 %	0,1378 %	Hammerfest

Table 10: Average and highest stock out probability for each scenario where Scenario 4.

6.4.6 Queues

The queue statistics indicates how much traffic there is in a system, and it could point out potential bottlenecks. From table 11, we see a summary of the queue statistics from each simulation.

Order policy and distribution	Scenario	Time in queue			Number in Queue		
		Hold for Inventory	Receive at Warehouse	Wait for Transport	Hold for Inventory	Receive at Warehouse	Wait for Transport
(s, Q) PostNord	Scenario 1	11,73	4,39	8,01	8,71	0,40	0,73
(R, s, S) PostNord	Scenario 2	4,09	5,23	16,00	0,55	0,51	1,57
(R, s, S) Themselves	Scenario 2	1,91	3,14	16,00	0,12	0,31	1,57
(s, Q) PostNord	Scenario 2	4,84	4,65	8,16	0,81	0,42	0,74
(s, Q) Themselves	Scenario 2	3,85	5,20	8,17	0,36	0,47	0,74
(R, s, S) PostNord	Scenario 3	3,24	5,20	16,00	0,49	0,52	1,59
(R, s, S) Themselves	Scenario 3	2,17	3,07	16,00	0,21	0,30	1,59
(s, Q) PostNord	Scenario 3	6,37	4,62	8,14	1,03	0,42	0,74
(s, Q) Themselves	Scenario 3	2,81	5,22	8,16	0,26	0,47	0,74
(R, s, S) PostNord	Scenario 4	0,00	0,44	16,00	0,00	0,04	1,54
(R, s, S) Themselves	Scenario 4	0,00	1,01	16,00	0,00	0,10	1,56
(s, Q) PostNord	Scenario 4	0,00	4,81	8,07	0,00	0,44	0,73
(s, Q) Themselves	Scenario 4	0,00	0,85	8,06	0,00	0,08	0,73

Table 11: Queue statistics from each simulation with desired alternatives marked in green and red.

The results we find when analyzing the statistics, corresponds well with the number of orders over 18 hours we found in section 6.4.1. Looking at Scenario 1 there is an average of 8,71 orders in the queue, and the average waiting time is 11,73 hours. Looking at Scenario 4, we see that the average orders that holds for inventory is zero. Neither the receive at warehouse or the wait for transportation queues should get to much attention when we analyze the queues because they are both mostly for modeling purposes, and they do not have much effect on the overall system performance. The system performs best when we use Scenario 4, and we see a clear improvement from Scenario 1.

6.4.7 Discussion

The different scenarios and distribution alternatives, gives quite different result. It is hard to pick out one favorite, and we should do a deeper analyzes with representative from Tools. However, in order to be able to make a conclusion on which scenarios we should investigate further and which statistics to use, we can briefly discuss the results.

We have used nine different statistics in the analysis. As mentioned above, we have pointed out the most important ones. In general, we want the average order time to be as low as possible. On the other hand, we also want our logistical costs to be as low as possible, but without hurting the customer satisfaction. When investigating the number of orders above 18 hours and the average order time, we see a clear trend in the current situation. The number of orders over 18 hours is high, which might lead to many unsatisfied customers, and the total inventory is high, which leads to high logistical costs. It is therefore not a very good alternative.

By changing the strategy to an alternative that gives higher average order times, but fewer orders over 18 hours and a lower average inventory, we might be able to increase the performance without hurting the customer satisfaction.

We can investigate two different objectives:

1. Minimizing the number of orders over 18 hours, and
2. Minimizing the average inventory

When minimizing the number of orders over 18 hours, we end up with using Scenario 4 with an (s, Q) system. Whether or not they distribute themselves depends on the preferences of the company. If they want the lowest possible inventory they distribute using PostNord, and if they want the lowest average delivery time and total kilometers driven they distribute themselves. It is hard to say what is best, but both results gives approximately a 70 % reduction in inventory. The results for the two distribution alternatives is presented in table 12.

Scenario 4 (s, Q)		
Parameter	**PostNord**	**Themselves**
Average order time	**4,4094**	4,4101
Orders over 18 hours	**0**	**0**
Number of warehouses	**3**	**3**
Deliveries	543,13	**542,87**
Kilometers travelled	100 890 373	**100 887 777**
Average delivery time	44,68	**37,55**
Highest delivery time	56,26	**50,64**
Average inventory	**83 051**	91 638
Percentage reduction	**71,82 %**	68,90 %
Average stock out probabilities	**0,1326 %**	0,1350 %
Highest stock out probabilities	**0,1368 %**	0,1386 %
Time in hold for inventory queue	**0**	**0**
Number in hold for inventory queue	**0**	**0**

Table 12: Results using an (s, Q) system in Scenario 4.

Looking back at the SRL, we can make an estimate of the reduction in safety stock. The demand is unevenly spread at the regional warehouses, so we cannot use Evers and Beiers SRL. With three centralized warehouse, Maister (1976) suggests that the reduction in safety stock will be:

$$1 - \frac{\sqrt{3}}{\sqrt{33}} = 69{,}85\ \% \tag{29}$$

This is pretty close to what we got from the simulation model, which indicate that there is a high probability that we would see a reduction in safety stock.

When the goal is to minimize the average inventory, we end up with Scenario 2 with an (s, Q) system and distributing through PostNord. The total reduction in inventory is 79,04 %. A downside with this alternative is that there are some orders over 18 hours. If they want to decrease this number but keep the ordering system, an alternative is to distribute themselves. The average inventory is then reduced to 78,12 % instead, which is only one percentage point worse than when using PostNord, and the number of orders over 18 hours is approximately cut in half to 13,67. Table 13 presents both distribution alternatives.

Scenario 2 (s, Q)		
Parameter	**PostNord**	**Themselves**
Average order time	**2,0224**	2,1671
Orders over 18 hours	30,53	**13,67**
Number of warehouses	**5**	**5**
Deliveries	**543,33**	543,4
Kilometers travelled	**43 048 385**	45 029 062
Average delivery time	32,81	**28,06**
Highest delivery time	55,5	**50,15**
Average inventory	**61 754**	64 470
Percentage reduction	**79,04 %**	78,12 %
Average stock out probabilities	0,4011 %	**0,2296 %**
Highest stock out probabilities	0,5352 %	**0,2935 %**
Time in hold for inventory queue	4,84	**3,85**
Number in hold for inventory queue	0,81	**0,36**

Table 13: Results using (s, Q) system in Scenario 2.

The estimated reduction in safety stock is:

$$1 - \frac{\sqrt{5}}{\sqrt{33}} = 61{,}08\ \% \tag{30}$$

We see that when applying Maisters SRL, we estimate a 61 % reduction in safety stock. Since the simulation model estimates a 79 % reduction in total average inventory, the results points towards a reduction in the total average inventory.

We notice that the estimates for the average inventory from the simulation models gives a higher reduction when using five warehouses than when using three, and that the SRL estimates a lower safety stock with fewer warehouse. These results underpins the research done by Evers and Beier (1993), which concluded with that it is not always better to consolidate to one facility.

7. Sensitivity Analysis

This chapter presents the sensitivity analysis used to test the solution further and to see how a change in capacities and order sizes effect the performance. We briefly explain the data used, and analyze the results.

7.1 Model and data collection

We implement the different situations in version 13.0 of Process Analyzer, provided by Rockwell Automation. After a test run, we decide to use a 15 % increase/decrease in the different variables. This is high enough to get result significant enough to see a considerable change, and still low enough for it to be realistic.

7.2 Results

The results from the sensitivity analysis is presented below, where the headlines indicates which variable that has been increased or decreased. There are allot of numbers presented so in order to make the section readable, we have included a small summary at the end of each section in addition to the discussion at the end. The results from the sensitivity analysis is in appendix G, where the results discussed below is marked in green and red.

7.2.1 Order-up-to point

In general, we see that the effect is larger when we decrease the order-up-to point than when we increase. When we decrease, we see several increases in their stock out probabilities, where Førde is most affected. Scenario 2, when distributing through PostNord, gives Førde the highest increase from 0,15 % to 2,62 %.

When looking at the hold for inventory queue, we see that the number in queue decreases to zero in both Scenario 2 and 3. The same goes for the number of orders over 18 hours. When we decrease the variable, both the number in queue, time in queue and orders over 18 hours increase. Number of orders over 18 hours increases most drastically to 492 and 520,4 in Scenario 2 and 3. For the same scenarios the time in queue increases with 1,83 and 2,85 hours, and number in queue increases with 13,91 and 14,39.

When studying the change in the average inventory, we see quite big changes. At each different scenario alternative, we see a minimum of about 15 % increase or decrease in the average inventory, whereas Scenario 2 have more than +/- 20 % change. There are little or no difference whether we increase or decrease the order-up-to point, other than that when we increase we get an increase in inventory and a reduction when we decrease.

Summary

A quick overview, tells us that Scenario 4 is not affected by the change, other than the average inventory. We can eliminate the hold for inventory queues and the number of orders over 18 hours for Scenario 2 and 3 when increasing the order-up-to point, but this will increase the average inventory. In addition, we see that the system is sensitive for decreases. Whenever decreasing, we see a high number of orders over 18 hours and more orders in queue.

7.2.2 Minimum delivery size

The results shows that changing the minimum delivery size has small effect on the stock out probabilities. The only change that is higher than one percentage point is in Scenario 3, when using PostNord. The stock out probability increases from 0,29 % to 1,42 %.

When increasing the minimum delivery size, we see some changes in Scenario 2 and 3 when using PostNord. The time in queue increases from 4,09/3,24 to 6,09/6,51, and the average number in queue from 0,55/0,49 to 3,54/4,26. When decreasing the minimum delivery size, we eliminate the time in queue in Scenario 3.

When investigating how an increase or decrease effects the number of orders over 18 hours we see some changes, but mostly when they distribute using PostNord. Scenario 2 and 3 changes from 23/19,6 to 153/192,4.

The total deliveries made, are also changed quite allot. When we increase the minimum the total deliveries decrease with an average of 24,17, whereas 20,6 is the minimum. When we decrease the minimum, the average increase in deliveries is 30,5 whereas 11,47 is the smallest increase.

Summary

By studying the results, we see that Scenario 4 is not particularly affected. We see no clear improvement, without negatively effecting another factor. We can almost eliminate the number of orders over 18 hours, but it gives a higher average inventory. The inventory change varies around 5 %, except for in Scenario 4 where the variation is between 0,5 to 2 percentage.

7.2.3 Capacity

The changes in the hold for inventory queue are small except for two cases: when we increase in Scenario 2 and 3 using PostNord, the time in queue increases from 4,09 and 3,24 to 12,28 and 7,62. There are in average still less than one order in queue, but the orders are there for a longer time.

When we increase the capacity, the number of orders over 18 hours in Scenario 2 and 3, when using PostNord, increases from 23/19,6 to 57/57. There are also some smaller decreases, but we are not able to eliminate the orders. We do not see a big reduction in average inventory either.

When we investigate the number of deliveries made, we see a clear trend. When we increase the capacity of a vehicle, the total trips goes down with a minimum of 42 trips, and an average of 49. When we decrease the capacity the minimum increase in trips is 64, and the average is 68.

Summary

There are no big changes in the system when we change the capacity, other than the total trips made. We might be able to accept a slightly higher average inventory if we can use fewer vehicles, but this depends on factors like whether or not they have to expand the warehouses or if they have unused capacity.

7.2.4 Reorder Point

When we change the reorder point, we see several effects in the stock out probability. As it was when we changed the order-up-to point, there are most effects when we decrease the reorder point. The highest change is at Flekkefjord in Scenario 2 and 3 when distributing with PostNord. The change is from 0,37/0,58 % to 5,85/5,46 %. We can also see small changes at Førde, Oslo and Trondheim in Scenario 2 and 3. When they distribute themselves, there are smaller changes. A reduction in Scenario 2, gives higher stock out probabilities for Flekkefjord, Oslo and Trondheim from 0,29/0,29/0,29 % to 1,45 %, 2,56 % and 1,58 %.

The average time and number in the hold for inventory queue changes in both Scenario 2 and 3. Both distribution alternatives is affected, but most when we distribute using PostNord. When we increase the reorder point the average time and number in queue goes down, and vice versa when we decrease. The highest increase in time in queue and number in queue is in Scenario 2, where the change is from 4,84 to 9,74, and from 0,81 to 14,72.

In Scenario 2 and 3, we are able to eliminate or almost eliminate all the orders over 18 hours when we increase the reorder point, whatever the distribution. However, when we decrease the reorder point, we see some big increases in Scenario 2 and 3. When distributing themselves the number of orders over 18 hours increases to 694 and 677, and 197 and 164 when using PostNord.

Summary

To sum up, we see little or no changes in Scenario 4 and higher effect when we decrease the reorder point, than when we increase. We have the opportunity to eliminate the number of orders over 18 hours, the average time, and the average number in the hold for inventory queue. The downside by doing this is that we see a significant increase in the average inventory that varies between a 12 and 16 percentage.

7.2.5 Order quantity

There are not that many changes in the hold for inventory queue. The time in queue change varies between -0,85 % and 2,43 %, and the number in queue from -0,09 to 0,30.

There are some changes in the number of orders over 18 hours, but not as much as we have seen in some of the other situations. The max increase is when we decrease the order quantity in Scenario 3 and using PostNord. The increase is from 4,13 to 49, and from 4,13 to 35 when we increase the order quantity.

The total delivery count fluctuates a bit more. When we increase the order quantity, the number of deliveries goes down and vice versa. Max reduction is 71,4 with an average of 71,22, and the max increase is 95,13 with an average of 94,78.

Summary

There are not many changes in Situation 5, other than the total deliveries. As it was in Situation 3, we can decrease the total number of deliveries but we would have to accept an increase in the total inventory. The change in inventory varies between 6,53 and 10,69 percentage.

7.2.6 Discussion

To sum up, we see that the different systems reacts differently to the different changes and situations. One thing we can say in general is that the average order time is not effected that much and therefore not very sensitive to changes. The biggest increase/decrease is only about five minutes, which is not that much when we review the system as a whole. The reason why the average order time is not affected that much might be that there are so many orders so even if a small percentage of the orders have a high order time, the average is not affected that much.

The number of total deliveries is a bit varied. We see no clear difference between the different scenarios, but quite a big difference from situation to situation. The variables that have a significant effect on the total deliveries is the minimum delivery size and the capacity in the (R, s, S) system, and the order quantity in the (s, Q) system. We say that the total deliveries is sensitive to changes in these variables in all scenarios, which is not very surprising considering that they in some way represents the delivery frequency.

By changing the order-up-to and the reorder point, we have the opportunity to eliminate both the number of orders over 18 hours and the average number and time in the hold for inventory queue in Scenario 2 and 3. The consequence of doing this is an increase in the average inventory. We need to conduct a deeper analysis before we can give a conclusion of whether or not to change. Do we have unused capacity at the regional warehouses? What is the consequences of expanding the average inventory? Do we have to expand some of the regional warehouses? For now, we conclude with that the number of orders over 18 hours and the hold for inventory queue in Scenario 2 and 3 is sensitive to changes.

We can also see some changes in the stock out probabilities when changing the order-up-to and reorder point. The biggest increase is when they distribute through PostNord, and when we decrease the variables in Scenario 2 and 3. There are some variations from warehouse to warehouse, and Flekkefjord, Førde, Oslo and Trondheim is the only ones that see a significant increase. We say that the stock out probability for the warehouses in the southern cluster, except Fredrikstad, is sensitive to decreases in the order-up-to and reorder point, but only in Scenario 2 and 3 when distributing through PostNord.

We see that Scenario 4 is not very sensitive to changes in the different variables. None of the statistics shows much increase or decrease, other than the total trips made and average inventory. When we look at the variables and see how they have affected the system, we see that in some cases they have a very high impact on the total trips and the average inventory. This is not very surprising, due to the fact the variables changed in some way controls the delivery frequency and size. We conclude with that Scenario 4 is not very sensitive to changes, and the most robust solution of the scenarios tested.

8. Conclusion and Further Research

Three analyses have been used in order to investigate the effect of introducing regional warehouses to Tools value chain. We have used a facility location analysis to find out where to setup the facilities, and how to distribute. Two mathematical models have been used and compared, in order to obtain the optimal solution. We have investigated three different scenarios, in addition to two different distribution alternatives. The facility location analysis have suggested where to place the facilities in the different scenarios, and implies that by setting up six regional warehouses, and distributing without using PostNord, we obtain the shortest total distance traveled.

In order to get an idea of how the solutions obtained from the facility analysis behave in real life, we have analyzed them further through a simulation analysis. We implemented each solution in a simulation model, and compared them to each other and to the current situation. The simulation model indicates that by centralizing the warehouses, we will improve the performance on several areas. The results varies some from scenario to scenario, but they all show a significant decrease in the average inventory. We obtain the highest decrease in inventory, when setting up one warehouse in the northern cluster, and four in the southern. If we switch the objective to minimizing the number of orders that has a service time on more than 18 hours, the simulation analysis suggests that we set up one warehouse in the southern cluster and two in the northern.

Compared to the current situation, we see a significant improvement in the performance by choosing either one of these strategies. By applying theories as the Square Root Law, we see a significantly high estimated reduction in the aggregated safety stock that underpins the results found in the simulation analysis. When investigating how to distribute, we see no clear improvement when ruling out PostNord. Even though the average delivery time is shorter, other factors such as the average order time and the total distance travelled is longer. Since the facility location analysis gave a shorter total distance travelled, it is difficult to interpret these results. Since more factors is included in the simulation analysis and it should give a more thorough answer, we choose to rely on this. Because of that, we say that the analysis suggests that we keep PostNord as a distribution partner.

We should keep in mind that the results obtained from these analyses is based on a set of assumptions, and that we have not included the setup cost of a regional warehouse. This implies that there is need for a deeper and more thorough analysis, in order to say with certainty whether it would benefit the company or not. Nevertheless, by investigating the results obtained from the analyses we can say that by centralizing their warehouses, they might improve their performance and they will get a lower average inventory.

To test the solutions further, we have used a sensitivity analysis to test the robustness of the solutions. In addition, we have looked for possible improvements to the system performance, by making small changes in the system variables. The analysis shows that we might be able to improve certain factors, but not without weakening others. This gives us an indication of which areas to improve, once we decide what statistics from the simulation analysis to use as an objective.

8.1 Further research

Several modifications and additional research can be made to further improve the solutions and better reflect the real life situation. Firstly, we could make some improvements to the mathematical models and the facility analysis. As the analyses have pointed out, the usage of time instead of distances would be a better representation of the reality than the distances used in this thesis. In addition to changing the data used, we could include the setup cost for a facility. A deeper and more thorough analysis of the possible locations for a facility should be performed, in order to get a more realistic model. Thirdly, the usage of transshipments could be included. By eliminating the assumption of that each vehicle only delivers to one regional warehouse at the time, we would get an even better understanding of how the solutions would behave when implemented.

A natural extension from this thesis is to review the problem from a more detailed perspective. A way of doing this could be to include products. Which product is more profitable than others are? Where should the different products be located? Should any products have a higher priority than others should? An analysis that answered questions like this would probably be of value for the company, and have a good basis from the analyses performed her.

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10. Appendix

Appendix A. Distance and time matrixes

Distance from facility to location (kilometers)

Facility/Location	Haugesund	Bergen	Stord	Flekkefjord	Stavanger	Åsen	Tynset	Hamar	Gjøvik	Raufoss	Jessheim	Bærum	Oslo	Fredrikstad	Moss	Askim	Kongsberg	Drammen	Larvik	Sandefjord	Kristiansand	Mandal	Trondheim	Verdal	Molde	Aukra	Ålesund	Førde	Tromsø	Narvik	Finnsnes	Kirkenes	Hammerfest
Haugesund	0	153	59,2	203	69,9	77,9	685	518	470	480	480	424	447	510	471	471	351	393	389	399	311	267	817	903	630	652	588	317	1967	1712	1875	2281	2314
Bergen	151	0	93,5	342	209	217	651	484	436	446	489	455	483	573	534	524	416	451	502	510	476	407	708	794	462	484	420	184	1859	1604	1766	2249	2281
Stord	58,7	94,8	0	250	117	125	714	547	499	508	508	452	476	539	499	499	380	421	417	428	358	314	845	931	537	559	495	259	1996	1740	1903	2309	2342
Flekkefjord	202	343	249	0	133	125	758	552	563	519	472	415	439	403	360	401	380	385	298	309	110	66,3	923	1009	923	957	977	507	2074	1818	1981	2273	2306
Stavanger	69,8	211	117	134	0	9,5	890	685	528	652	604	548	572	536	492	534	512	518	430	441	242	199	1056	1141	653	675	611	375	2206	1951	2114	2405	2438
Åsen	77,9	219	125	125	9,4	0	881	675	686	642	594	538	562	526	483	524	503	508	421	431	233	189	1046	1132	661	683	655	383	2197	1941	2104	2396	2428
Tynset	685	651	714	758	889	880	0	218	249	264	290	349	320	428	388	379	419	374	464	452	651	693	171	257	251	284	336	450	1503	1067	1229	1609	1637
Hamar	519	484	547	551	683	675	218	0	50,9	65,9	84	141	114	222	183	173	212	167	257	245	444	486	383	469	372	407	427	417	1534	1278	1441	1766	1799
Gjøvik	471	436	499	561	529	685	249	50,4	0	18	94,3	132	125	232	193	184	178	177	267	255	454	496	381	467	358	393	413	369	1532	1276	1439	1816	1848
Raufoss	479	445	508	517	648	639	264	64,5	16,4	0	92,8	115	98,8	208	169	159	162	133	224	211	410	452	395	481	373	407	427	377	1546	1290	1453	1829	1862
Jessheim	478	490	506	470	603	594	289	83,8	94,1	93	0	60,6	33,6	141	102	92,5	131	86	176	164	363	405	454	540	454	489	509	437	1605	1350	1512	1809	1842
Bærum	423	454	452	415	547	538	347	142	130	115	65	0	31	121	81,4	71,9	76,4	31,6	122	110	309	351	513	598	512	547	567	401	1666	1408	1571	1865	1898
Oslo	446	482	457	438	570	561	321	115	126	98,7	34,5	29,1	0	110	70,5	61	99,3	54,5	145	132	332	374	486	572	486	520	540	429	1637	1381	1544	1836	1869
Fredrikstad	502	565	531	398	530	521	419	213	224	200	132	112	102	0	35,6	55,9	155	110	105	92,4	292	333	584	670	584	618	638	512	1735	1479	1642	1981	2014
Moss	471	534	500	360	492	483	388	183	193	169	102	81,1	70,9	44,1	0	45,7	124	79	66,9	54,4	254	296	553	639	553	587	607	481	1704	1449	1611	1903	1936
Askim	471	524	499	401	532	524	378	173	183	159	91,9	71,3	61,1	55,6	45,8	0	124	78,63	108	95,2	294	336	543	629	543	578	598	471	1694	1439	1601	1942	1974
Kongsberg	352	416	380	380	512	503	413	208	174	158	131	72,8	96,4	160	120	120	0	42	86,2	94,7	274	316	579	664	530	564	584	403	1731	1474	1637	1930	1963
Drammen	393	450	421	385	516	508	372	167	177	136	90	31,7	55,3	118	78,9	78,6	45,7	0	91,8	79,3	278	320	538	623	537	571	592	419	1690	1433	1596	1889	1922
Larvik	388	501	417	298	429	420	463	257	267	226	180	122	145	110	66,3	108	86,2	91,5	0	15,1	191	233	628	714	628	662	682	513	1780	1523	1686	1979	2012
Sandefjord	399	510	428	309	440	431	450	245	255	214	168	110	133	97,6	53,9	95,4	94,8	79,2	15,5	0	202	244	615	701	615	650	670	500	1768	1511	1673	1967	2000
Kristiansand	309	476	356	109	240	231	651	445	456	413	365	309	332	297	253	294	273	278	191	202	0	44,2	816	902	816	850	870	699	1967	1711	1874	2166	2199
Mandal	266	407	313	66,2	198	189	693	488	498	455	407	351	374	339	295	336	315	320	233	244	44,8	0	858	944	858	892	912	741	2009	1754	1916	2208	2241
Trondheim	817	709	846	924	1055	1046	172	384	381	396	455	514	486	594	554	545	585	540	630	618	817	859	0	86,6	216	242	290	525	1151	896	1059	1514	1542
Verdal	903	795	931	1009	1140	1131	257	469	467	482	541	600	571	679	640	630	670	625	716	703	902	944	87,2	0	301	327	375	611	1067	811	974	1444	1445
Molde	594	462	537	923	688	696	251	372	359	374	455	514	485	593	553	544	534	539	629	617	816	858	215	301	0	34,4	74,2	278	1366	1110	1273	1729	1757
Aukra	652	484	559	955	710	718	284	401	388	403	484	543	514	622	583	573	563	568	659	646	845	887	241	327	34,2	0	96	300	1392	1136	1299	1755	1783
Ålesund	589	420	495	977	611	655	337	427	413	428	509	568	539	647	608	598	588	593	684	671	871	912	289	375	74,3	96,4	0	236	1440	1184	1347	1803	1831
Førde	317	184	259	508	375	383	450	417	369	378	437	402	430	521	482	472	403	419	511	498	697	739	525	611	278	300	236	0	1675	1420	1583	2038	2066
Tromsø	1969	1861	1997	2075	2206	2198	1504	1535	1533	1548	1607	1666	1637	1745	1706	1819	1736	1691	1782	1769	1968	2010	1153	1068	1367	1393	1441	1677	0	255	160	812	537
Narvik	1713	1605	1742	1820	1951	1942	1068	1280	1278	1293	1352	1410	1382	1490	1450	1441	1481	1436	1526	1514	1713	1755	898	812	1112	1138	1186	1421	255	0	163	856	641
Finnsnes	1876	1768	1904	1982	2114	2105	1231	1442	1440	1455	1514	1573	1545	1652	1613	1603	1643	1599	1689	1676	1876	1918	1061	975	1275	1301	1348	1584	160	163	0	821	546
Kirkenes	2281	2250	2309	2272	2404	2395	1609	1767	1817	1832	1809	1863	1835	1981	1903	1868	1933	1889	1979	1967	2166	2208	1514	1443	1729	1754	1802	2038	812	896	821	0	477
Hammerfest	2313	2283	2342	2305	2437	2428	1638	1800	1850	1864	1842	1896	1867	2014	1936	1974	1966	1922	2012	1999	2199	2241	1543	1445	1758	1783	1831	2067	538	641	546	477	0

Table A1: The distances in kilometers from a potential facility to a location. The table is read by travelling from the facility in the row, to the location in the column.

Time from facility to location (minutes)

Facility/Location	Haugesund	Bergen	Stord	Flekkefjord	Stavanger	Åsen	Tynset	Hamar	Gjøvik	Raufoss	Jessheim	Bærum	Oslo	Fredrikstad	Moss	Askim	Kongsberg	Drammen	Larvik	Sandefjord	Kristiansand	Mandal	Trondheim	Verdal	Molde	Aukra	Ålesund	Førde	Tromsø	Narvik	Finnsnes	Kirkenes	Hammerfest
Haugesund	0	199	52	202	97	107	629	483	447	453	447	408	426	473	449	454	353	387	376	380	272	254	734	802	698	745	616	368	1680	1500	1620	1740	1860
Bergen	200	0	151	389	283	294	552	405	369	375	416	389	412	467	443	442	369	394	441	437	465	440	632	700	515	562	434	190	1620	1384	1500	1800	1800
Stord	51	150	0	240	134	144	651	505	469	475	469	430	448	495	471	476	375	409	398	402	330	291	756	824	645	692	563	319	1740	1500	1620	1800	1740
Flekkefjord	201	387	240	0	108	97	549	389	407	393	335	296	314	343	312	344	296	276	231	235	95	56	677	745	719	776	731	556	1620	1420	1560	1620	1620
Stavanger	97	282	135	109	0	14	653	493	590	497	439	400	418	447	416	448	400	380	335	340	199	160	781	849	777	824	695	451	1740	1500	1680	1740	1740
Åsen	107	292	145	98	13	0	642	482	500	486	428	389	407	436	404	437	389	369	324	328	188	149	770	838	787	832	710	461	1740	1500	1680	1740	1740
Tynset	629	550	652	551	653	643	0	173	207	217	221	261	239	307	283	283	313	276	328	321	461	497	137	205	212	268	276	389	1049	880	1022	1230	1155
Hamar	482	403	505	389	493	482	172	0	41	52	61	99	78	147	123	122	151	114	167	159	299	335	300	368	334	391	346	380	1255	1043	1186	1325	1315
Gjøvik	448	369	470	408	531	501	208	42	0	17	80	115	97	166	142	141	157	133	185	178	318	354	313	380	327	384	339	345	1267	1056	1198	1364	1354
Raufoss	453	374	476	394	497	486	220	53	17	0	80	103	88	158	134	133	145	120	172	164	304	341	324	332	338	395	350	350	1278	1067	1209	1375	1365
Jessheim	444	415	467	336	439	429	221	62	79	79	0	46	25	94	70	69	98	61	113	106	246	282	349	417	391	448	403	391	1303	1092	1234	1319	1309
Bærum	405	387	428	297	400	389	260	101	114	102	47	0	28	82	58	58	60	23	75	67	208	244	388	456	430	487	442	363	1345	1131	1273	1356	1346
Oslo	422	409	445	314	417	407	239	80	97	88	26	25	0	73	49	48	77	40	92	85	225	261	367	435	409	466	421	385	1321	1110	1252	1332	1322
Fredrikstad	474	467	497	346	448	438	308	149	166	159	95	84	76	0	35	51	128	90	123	116	256	292	436	504	478	535	490	443	1390	1179	1321	1392	1382
Moss	448	442	471	313	415	405	282	123	140	133	69	58	50	33	0	38	102	64	91	83	223	259	410	478	453	509	464	418	1365	1153	1296	1375	1365
Askim	452	440	475	344	446	436	281	121	139	132	67	56	49	50	37	0	107	68	121	114	254	290	409	477	451	508	463	416	1363	1152	1294	1352	1342
Kongsberg	351	368	374	299	401	391	312	152	157	144	98	60	79	125	101	107	0	40	76	72	209	245	440	508	478	535	490	394	1396	1183	1325	1406	1396
Drammen	385	392	408	278	380	370	274	115	132	120	61	23	42	87	63	69	40	0	56	48	188	224	403	470	445	509	456	379	1358	1145	1308	1369	1359
Larvik	375	439	398	232	335	324	326	167	184	172	113	75	94	122	91	124	74	55	0	15	142	179	455	522	497	553	508	433	1410	1197	1340	1421	1411
Sandefjord	380	436	403	237	340	330	319	160	177	165	106	68	86	115	84	116	71	48	15	0	148	184	447	515	490	546	501	426	1403	1190	1333	1414	1404
Kristiansand	272	463	331	96	199	188	460	300	318	304	246	207	225	253	222	255	206	187	142	146	0	43	588	656	630	687	641	565	1560	1331	1500	1560	1560
Mandal	253	439	292	57	160	149	496	336	354	339	282	242	261	289	258	291	242	223	178	182	42	0	624	692	666	722	677	600	1560	1367	1500	1560	1560
Trondheim	736	635	758	681	783	773	139	303	313	324	351	391	369	437	413	412	443	406	458	451	591	627	0	69	210	261	315	448	956	745	887	1145	1069
Verdal	803	702	825	748	850	840	206	369	380	391	418	458	436	504	480	479	510	473	525	518	658	694	70	0	277	328	382	515	890	679	821	1103	1042
Molde	697	516	645	722	782	793	205	336	329	339	393	433	410	479	455	454	479	448	500	492	632	669	210	278	0	59	108	329	1164	953	1095	1353	1278
Aukra	745	561	690	777	827	838	271	391	384	394	448	488	465	534	510	509	534	503	555	547	687	724	261	329	59	0	153	374	1215	1004	1146	1404	1329
Ålesund	615	432	561	731	692	709	274	345	337	348	401	441	418	487	463	462	487	456	508	501	641	677	313	381	107	154	0	245	1267	1056	1198	1440	1381
Førde	365	187	316	553	448	458	388	381	345	350	391	363	387	442	418	417	393	378	432	424	564	601	445	513	328	375	247	0	1399	1188	1330	1560	1500
Tromsø	1680	1620	1740	1620	1740	1740	1058	1260	1271	1281	1309	1349	1326	1395	1371	1254	1401	1364	1416	1408	1560	1560	961	894	1167	1209	1272	1406	0	213	131	647	451
Narvik	1500	1380	1500	1426	1500	1500	885	1048	1059	1069	1097	1137	1114	1183	1159	1158	1188	1152	1204	1196	1336	1372	749	682	955	1007	1060	1194	212	0	143	679	538
Finnsnes	1620	1500	1620	1560	1680	1680	1028	1191	1202	1212	1240	1280	1257	1326	1302	1301	1331	1295	1347	1339	1500	1500	892	825	1098	1150	1203	1336	132	144	0	654	458
Kirkenes	1740	1740	1800	1620	1740	1740	1231	1331	1369	1379	1323	1359	1336	1396	1381	1363	1411	1374	1426	1419	1560	1620	1145	1106	1352	1403	1440	1620	645	685	653	0	396
Hammerfest	1740	1740	1800	1620	1740	1740	1166	1324	1362	1372	1316	1352	1329	1389	1374	1347	1404	1367	1419	1412	1560	1560	1080	1048	1287	1338	1392	1500	450	540	458	394	0

Table A2: The time it takes to drive from a potential facility, to a location. The table is read by travelling from the facility in the row, to the location in the column.

Langhus to Facility

Langhus - Facility			
Location	**Km**	**Hours**	**Minutes**
Haugesund	446	8,30	498,0
Bergen	489	8,05	483,0
Stord	475	8,68	521,0
Flekkefjord	447	6,42	385,0
Stavanger	479	8,32	499,0
Åsen	470	8,47	508,0
Tynset	343	4,33	260,0
Hamar	138	1,63	98,0
Gjøvik	148	2,05	123,0
Raufoss	124	1,87	112,0
Jessheim	57	0,75	45,0
Bærum	36	0,52	31,0
Oslo	27	0,42	25,0
Fredrikstad	89	1,03	62,0
Moss	49	0,60	36,0
Askim	34	0,60	36,0
Kongsberg	107	1,43	86,0
Drammen	62	0,82	49,0
Larvik	153	1,85	111,0
Sandefjord	141	1,72	103,0
Kristiansand	340	4,15	249,0
Mandal	382	5,50	330,0
Trondheim	509	7,33	440,0
Verdal	594	8,48	509,0
Molde	508	8,02	481,0
Aukra	535	8,92	535,0
Ålesund	562	7,60	456,0
Førde	437	7,60	456,0
Tromsø	1756	37,13	2228,0
Narvik	1402	32,73	1964,0
Finnsnes	1562	35,20	2112,0
Kirkenes	1856	37,83	2270,0
Hammerfest	1889	38,28	2297,0

Table A3: Distances in kilometers and driving times from the PostNord terminal at Langhus to the potential facilities.

Alingsås to Facility

Alingsås - Facility			
Location	**Distance**	**Hours**	**Minutes**
Haugesund	705	12,07	724
Bergen	775	11,93	716
Stord	735	12,43	746
Flekkefjord	609	8,87	532
Stavanger	738	11,42	685
Åsen	729	11,23	674
Tynset	629	8,20	492
Hamar	424	5,50	330
Gjøvik	434	5,88	353
Raufoss	410	5,73	344
Jessheim	343	3,85	231
Bærum	322	3,63	218
Oslo	313	3,52	211
Fredrikstad	220	2,62	157
Moss	246	2,80	168
Askim	258	3,15	189
Kongsberg	366	4,42	265
Drammen	321	3,77	226
Larvik	315	4,30	258
Sandefjord	303	4,17	250
Kristiansand	502	7,35	441
Mandal	544	7,95	477
Trondheim	794	11,18	671
Verdal	880	12,35	741
Molde	794	11,88	713
Aukra	821	12,80	768
Ålesund	848	12,07	724
Førde	723	11,45	687
Tromsø	1873	35,63	2138
Narvik	1712	33,02	1981
Finnsnes	1831	34,77	2086
Kirkenes	1899	37,08	2225
Hammerfest	1931	37,18	2231

Table A4: Distance in kilometers and time it takes to drive from Alingsås to the potential facilities.

Appendix B. Facility location analysis solutions

Scenario 2, distributing using PostNord

Scenario 2, using PostNord, P-median					
Location/Facility	**Flekkefjord**	**Førde**	**Oslo**	**Tromsø**	**Trondheim**
Langhus	11 970	5 781	35 659	6 195	7 922
Askim	0	0	1 277	0	0
Aukra	0	0	0	0	420
Bergen	0	1 687	0	0	0
Bærum	0	0	328	0	0
Drammen	0	0	3 917	0	0
Finnsnes	0	0	0	2 324	0
Flekkefjord	1 144	0	0	0	0
Fredrikstad	0	0	4 182	0	0
Førde	0	1 943	0	0	0
Gjøvik	0	0	2 614	0	0
Hamar	0	0	5 707	0	0
Hammerfest	0	0	0	753	0
Haugesund	1 046	0	0	0	0
Jessheim	0	0	2 382	0	0
Kirkenes	0	0	0	812	0
Kongsberg	0	0	2 172	0	0
Kristiansand	2 220	0	0	0	0
Larvik	0	0	3 727	0	0
Mandal	3 973	0	0	0	0
Molde	0	0	0	0	2 412
Moss	0	0	3 076	0	0
Narvik	0	0	0	1 059	0
Oslo	0	0	1 700	0	0
Raufoss	0	0	1 400	0	0
Sandefjord	0	0	3 177	0	0
Stavanger	1 436	0	0	0	0
Stord	1 437	0	0	0	0
Tromsø	0	0	0	1 247	0
Trondheim	0	0	0	0	2 816
Tynset	0	0	0	0	1 537
Verdal	0	0	0	0	737
Ålesund	0	2 151	0	0	0
Åsen	714	0	0	0	0

Table B1: Scenario 2 solution when distributing through PostNord from the facility analysis with the p-median objective.

Scenario 2, using PostNord, P-center					
Location/Facility	**Førde**	**Jessheim**	**Stavanger**	**Tromsø**	**Trondheim**
Langhus	4 094	35 659	13 657	6 195	7 922
Askim	0	1 277	0	0	0
Aukra	0	0	0	0	420
Bergen	0	0	1 687	0	0
Bærum	0	328	0	0	0
Drammen	0	3 917	0	0	0
Finnsnes	0	0	0	2 324	0
Flekkefjord	0	0	1 144	0	0
Fredrikstad	0	4 182	0	0	0
Førde	1 943	0	0	0	0
Gjøvik	0	2 614	0	0	0
Hamar	0	5 707	0	0	0
Hammerfest	0	0	0	753	0
Haugesund	0	0	1 046	0	0
Jessheim	0	2 382	0	0	0
Kirkenes	0	0	0	812	0
Kongsberg	0	2 172	0	0	0
Kristiansand	0	0	2 220	0	0
Larvik	0	3 727	0	0	0
Mandal	0	0	3 973	0	0
Molde	0	0	0	0	2 412
Moss	0	3 076	0	0	0
Narvik	0	0	0	1 059	0
Oslo	0	1 700	0	0	0
Raufoss	0	1 400	0	0	0
Sandefjord	0	3 177	0	0	0
Stavanger	0	0	1 436	0	0
Stord	0	0	1 437	0	0
Tromsø	0	0	0	1 247	0
Trondheim	0	0	0	0	2 816
Tynset	0	0	0	0	1 537
Verdal	0	0	0	0	737
Ålesund	2 151	0	0	0	0
Åsen	0	0	714	0	0

Table B2: Scenario 2 solution when distributing through PostNord from the facility analysis with the p-center objective.

Scenario 2, distributing themselves

Scenario 2, distributing themselves, P-median					
Location/Facility	Flekkefjord	Fredrikstad	Førde	Tromsø	Trondheim
Langhus	11 970	35 659	5 781	6 195	7 922
Askim	0	1 277	0	0	0
Aukra	0	0	0	0	420
Bergen	0	0	1 687	0	0
Bærum	0	328	0	0	0
Drammen	0	3 917	0	0	0
Finnsnes	0	0	0	2 324	0
Flekkefjord	1 144	0	0	0	0
Fredrikstad	0	4 182	0	0	0
Førde	0	0	1 943	0	0
Gjøvik	0	2 614	0	0	0
Hamar	0	5 707	0	0	0
Hammerfest	0	0	0	753	0
Haugesund	1 046	0	0	0	0
Jessheim	0	2 382	0	0	0
Kirkenes	0	0	0	812	0
Kongsberg	0	2 172	0	0	0
Kristiansand	2 220	0	0	0	0
Larvik	0	3 727	0	0	0
Mandal	3 973	0	0	0	0
Molde	0	0	0	0	2 412
Moss	0	3 076	0	0	0
Narvik	0	0	0	1 059	0
Oslo	0	1 700	0	0	0
Raufoss	0	1 400	0	0	0
Sandefjord	0	3 177	0	0	0
Stavanger	1 436	0	0	0	0
Stord	1 437	0	0	0	0
Tromsø	0	0	0	1 247	0
Trondheim	0	0	0	0	2 816
Tynset	0	0	0	0	1 537
Verdal	0	0	0	0	737
Ålesund	0	0	2 151	0	0
Åsen	714	0	0	0	0

Table B3: Scenario 2 solution when distributing without PostNord from the facility analysis with the p-median objective.

Scenario 2, distributing themselves, P-center					
Location/Facility	Flekkefjord	Førde	Moss	Tromsø	Trondheim
Langhus	11 970	5 781	35 659	6 195	7 922
Askim	0	0	1 277	0	0
Aukra	0	0	0	0	420
Bergen	0	1 687	0	0	0
Bærum	0	0	328	0	0
Drammen	0	0	3 917	0	0
Finnsnes	0	0	0	2 324	0
Flekkefjord	1 144	0	0	0	0
Fredrikstad	0	0	4 182	0	0
Førde	0	1 943	0	0	0
Gjøvik	0	0	2 614	0	0
Hamar	0	0	5 707	0	0
Hammerfest	0	0	0	753	0
Haugesund	1 046	0	0	0	0
Jessheim	0	0	2 382	0	0
Kirkenes	0	0	0	812	0
Kongsberg	0	0	2 172	0	0
Kristiansand	2 220	0	0	0	0
Larvik	0	0	3 727	0	0
Mandal	3 973	0	0	0	0
Molde	0	0	0	0	2 412
Moss	0	0	3 076	0	0
Narvik	0	0	0	1 059	0
Oslo	0	0	1 700	0	0
Raufoss	0	0	1 400	0	0
Sandefjord	0	0	3 177	0	0
Stavanger	1 436	0	0	0	0
Stord	1 437	0	0	0	0
Tromsø	0	0	0	1 247	0
Trondheim	0	0	0	0	2 816
Tynset	0	0	0	0	1 537
Verdal	0	0	0	0	737
Ålesund	0	2 151	0	0	0
Åsen	714	0	0	0	0

Table B4: Scenario 2 solution when distributing without PostNord from the facility analysis with the p-center objective.

Scenario 3, distributing using PostNord

Scenario 3, using PostNord, P-median						
Location/Facility	Flekkefjord	Førde	Hammerfest	Oslo	Tromsø	Trondheim
Langhus	11 970	5 781	1 565	35 659	4 630	7 922
Askim	0	0	0	1 277	0	0
Aukra	0	0	0	0	0	420
Bergen	0	1 687	0	0	0	0
Bærum	0	0	0	328	0	0
Drammen	0	0	0	3 917	0	0
Finnsnes	0	0	0	0	2 324	0
Flekkefjord	1 144	0	0	0	0	0
Fredrikstad	0	0	0	4 182	0	0
Førde	0	1 943	0	0	0	0
Gjøvik	0	0	0	2 614	0	0
Hamar	0	0	0	5 707	0	0
Hammerfest	0	0	753	0	0	0
Haugesund	1 046	0	0	0	0	0
Jessheim	0	0	0	2 382	0	0
Kirkenes	0	0	812	0	0	0
Kongsberg	0	0	0	2 172	0	0
Kristiansand	2 220	0	0	0	0	0
Larvik	0	0	0	3 727	0	0
Mandal	3 973	0	0	0	0	0
Molde	0	0	0	0	0	2 412
Moss	0	0	0	3 076	0	0
Narvik	0	0	0	0	1 059	0
Oslo	0	0	0	1 700	0	0
Raufoss	0	0	0	1 400	0	0
Sandefjord	0	0	0	3 177	0	0
Stavanger	1 436	0	0	0	0	0
Stord	1 437	0	0	0	0	0
Tromsø	0	0	0	0	1 247	0
Trondheim	0	0	0	0	0	2 816
Tynset	0	0	0	0	0	1 537
Verdal	0	0	0	0	0	737
Ålesund	0	2 151	0	0	0	0
Åsen	714	0	0	0	0	0

Table B5: Scenario 3 solution when distributing through PostNord from the facility analysis with the p-median objective.

Scenario 3, using PostNord, P-center						
Location/Facility	Askim	Hammerfest	Tromsø	Trondheim	Ålesund	Åsen
Langhus	35 659	1 565	4 630	5 090	6 926	13 657
Askim	1 277	0	0	0	0	0
Aukra	0	0	0	0	420	0
Bergen	0	0	0	0	0	1 687
Bærum	328	0	0	0	0	0
Drammen	3 917	0	0	0	0	0
Finnsnes	0	0	2 324	0	0	0
Flekkefjord	0	0	0	0	0	1 144
Fredrikstad	4 182	0	0	0	0	0
Førde	0	0	0	0	1 943	0
Gjøvik	2 614	0	0	0	0	0
Hamar	5 707	0	0	0	0	0
Hammerfest	0	753	0	0	0	0
Haugesund	0	0	0	0	0	1 046
Jessheim	2 382	0	0	0	0	0
Kirkenes	0	812	0	0	0	0
Kongsberg	2 172	0	0	0	0	0
Kristiansand	0	0	0	0	0	2 220
Larvik	3 727	0	0	0	0	0
Mandal	0	0	0	0	0	3 973
Molde	0	0	0	0	2 412	0
Moss	3 076	0	0	0	0	0
Narvik	0	0	1 059	0	0	0
Oslo	1 700	0	0	0	0	0
Raufoss	1 400	0	0	0	0	0
Sandefjord	3 177	0	0	0	0	0
Stavanger	0	0	0	0	0	1 436
Stord	0	0	0	0	0	1 437
Tromsø	0	0	1 247	0	0	0
Trondheim	0	0	0	2 816	0	0
Tynset	0	0	0	1 537	0	0
Verdal	0	0	0	737	0	0
Ålesund	0	0	0	0	2 151	0
Åsen	0	0	0	0	0	714

Table B6: Scenario 3 solution when distributing through PostNord from the facility analysis with the p-center objective.

Scenario 3, distributing themselves

Scenario 3, distributing themselves, P-median						
Location/Facility	Flekkefjord	Fredrikstad	Førde	Hammerfest	Tromsø	Trondheim
Langhus	11 970	35 659	5 781	1 565	4 630	7 922
Askim	0	1 277	0	0	0	0
Aukra	0	0	0	0	0	420
Bergen	0	0	1 687	0	0	0
Bærum	0	328	0	0	0	0
Drammen	0	3 917	0	0	0	0
Finnsnes	0	0	0	0	2 324	0
Flekkefjord	1 144	0	0	0	0	0
Fredrikstad	0	4 182	0	0	0	0
Førde	0	0	1 943	0	0	0
Gjøvik	0	2 614	0	0	0	0
Hamar	0	5 707	0	0	0	0
Hammerfest	0	0	0	753	0	0
Haugesund	1 046	0	0	0	0	0
Jessheim	0	2 382	0	0	0	0
Kirkenes	0	0	0	812	0	0
Kongsberg	0	2 172	0	0	0	0
Kristiansand	2 220	0	0	0	0	0
Larvik	0	3 727	0	0	0	0
Mandal	3 973	0	0	0	0	0
Molde	0	0	0	0	0	2 412
Moss	0	3 076	0	0	0	0
Narvik	0	0	0	0	1 059	0
Oslo	0	1 700	0	0	0	0
Raufoss	0	1 400	0	0	0	0
Sandefjord	0	3 177	0	0	0	0
Stavanger	1 436	0	0	0	0	0
Stord	1 437	0	0	0	0	0
Tromsø	0	0	0	0	1 247	0
Trondheim	0	0	0	0	0	2 816
Tynset	0	0	0	0	0	1 537
Verdal	0	0	0	0	0	737
Ålesund	0	0	2 151	0	0	0
Åsen	714	0	0	0	0	0

Table B7: Scenario 3 solution when distributing without PostNord from the facility analysis with the p-median objective.

Scenario 3, distributing themselves, P-center						
Location/Facility	Askim	Hammerfest	Tromsø	Trondheim	Ålesund	Åsen
Langhus	35 659	1 565	4 630	5 090	6 926	13 657
Askim	1 277	0	0	0	0	0
Aukra	0	0	0	0	420	0
Bergen	0	0	0	0	0	1 687
Bærum	328	0	0	0	0	0
Drammen	3 917	0	0	0	0	0
Finnsnes	0	0	2 324	0	0	0
Flekkefjord	0	0	0	0	0	1 144
Fredrikstad	4 182	0	0	0	0	0
Førde	0	0	0	0	1 943	0
Gjøvik	2 614	0	0	0	0	0
Hamar	5 707	0	0	0	0	0
Hammerfest	0	753	0	0	0	0
Haugesund	0	0	0	0	0	1 046
Jessheim	2 382	0	0	0	0	0
Kirkenes	0	812	0	0	0	0
Kongsberg	2 172	0	0	0	0	0
Kristiansand	0	0	0	0	0	2 220
Larvik	3 727	0	0	0	0	0
Mandal	0	0	0	0	0	3 973
Molde	0	0	0	0	2 412	0
Moss	3 076	0	0	0	0	0
Narvik	0	0	1 059	0	0	0
Oslo	1 700	0	0	0	0	0
Raufoss	1 400	0	0	0	0	0
Sandefjord	3 177	0	0	0	0	0
Stavanger	0	0	0	0	0	1 436
Stord	0	0	0	0	0	1 437
Tromsø	0	0	1 247	0	0	0
Trondheim	0	0	0	2 816	0	0
Tynset	0	0	0	1 537	0	0
Verdal	0	0	0	737	0	0
Ålesund	0	0	0	0	2 151	0
Åsen	0	0	0	0	0	714

Table B8: Scenario 3 solution when distributing without PostNord from the facility analysis with the p-center objective.

Scenario 4, distributing using PostNord

Scenario 4, using PostNord, P-median			
Location/Facility	**Hammerfest**	**Oslo**	**Tromsø**
Langhus	1 565	61 332	4 630
Askim	0	1 277	0
Aukra	0	420	0
Bergen	0	1 687	0
Bærum	0	328	0
Drammen	0	3 917	0
Finnsnes	0	0	2 324
Flekkefjord	0	1 144	0
Fredrikstad	0	4 182	0
Førde	0	1 943	0
Gjøvik	0	2 614	0
Hamar	0	5 707	0
Hammerfest	753	0	0
Haugesund	0	1 046	0
Jessheim	0	2 382	0
Kirkenes	812	0	0
Kongsberg	0	2 172	0
Kristiansand	0	2 220	0
Larvik	0	3 727	0
Mandal	0	3 973	0
Molde	0	2 412	0
Moss	0	3 076	0
Narvik	0	0	1 059
Oslo	0	1 700	0
Raufoss	0	1 400	0
Sandefjord	0	3 177	0
Stavanger	0	1 436	0
Stord	0	1 437	0
Tromsø	0	0	1 247
Trondheim	0	2 816	0
Tynset	0	1 537	0
Verdal	0	737	0
Ålesund	0	2 151	0
Åsen	0	714	0

Table B9: Scenario 4 solution when distributing through PostNord from the facility analysis with the p-median objective.

Scenario 4, using PostNord, P-center			
Location/Facility	**Hammerfest**	**Oslo**	**Tromsø**
Langhus	753	61 332	5 442
Askim	0	1 277	0
Aukra	0	420	0
Bergen	0	1 687	0
Bærum	0	328	0
Drammen	0	3 917	0
Finnsnes	0	0	2 324
Flekkefjord	0	1 144	0
Fredrikstad	0	4 182	0
Førde	0	1 943	0
Gjøvik	0	2 614	0
Hamar	0	5 707	0
Hammerfest	753	0	0
Haugesund	0	1 046	0
Jessheim	0	2 382	0
Kirkenes	0	0	812
Kongsberg	0	2 172	0
Kristiansand	0	2 220	0
Larvik	0	3 727	0
Mandal	0	3 973	0
Molde	0	2 412	0
Moss	0	3 076	0
Narvik	0	0	1 059
Oslo	0	1 700	0
Raufoss	0	1 400	0
Sandefjord	0	3 177	0
Stavanger	0	1 436	0
Stord	0	1 437	0
Tromsø	0	0	1 247
Trondheim	0	2 816	0
Tynset	0	1 537	0
Verdal	0	737	0
Ålesund	0	2 151	0
Åsen	0	714	0

Table B10: Scenario 3 solution when distributing through PostNord from the facility analysis with the p-center objective.

Scenario 4, distributing themselves

Scenario 4, distributing themselves, P-median			
Location/Facility	**Hammerfest**	**Oslo**	**Tromsø**
Langhus	1 565	61 332	4 630
Askim	0	1 277	0
Aukra	0	420	0
Bergen	0	1 687	0
Bærum	0	328	0
Drammen	0	3 917	0
Finnsnes	0	0	2 324
Flekkefjord	0	1 144	0
Fredrikstad	0	4 182	0
Førde	0	1 943	0
Gjøvik	0	2 614	0
Hamar	0	5 707	0
Hammerfest	753	0	0
Haugesund	0	1 046	0
Jessheim	0	2 382	0
Kirkenes	812	0	0
Kongsberg	0	2 172	0
Kristiansand	0	2 220	0
Larvik	0	3 727	0
Mandal	0	3 973	0
Molde	0	2 412	0
Moss	0	3 076	0
Narvik	0	0	1 059
Oslo	0	1 700	0
Raufoss	0	1 400	0
Sandefjord	0	3 177	0
Stavanger	0	1 436	0
Stord	0	1 437	0
Tromsø	0	0	1 247
Trondheim	0	2 816	0
Tynset	0	1 537	0
Verdal	0	737	0
Ålesund	0	2 151	0
Åsen	0	714	0

Table B11: Scenario 3 solution when distributing without PostNord from the facility analysis with the p-median objective.

Scenario 4, distributing themselves, P-center			
Location/Facility	**Hammerfest**	**Oslo**	**Tromsø**
Langhus	753	61 332	5 442
Askim	0	1 277	0
Aukra	0	420	0
Bergen	0	1 687	0
Bærum	0	328	0
Drammen	0	3 917	0
Finnsnes	0	0	2 324
Flekkefjord	0	1 144	0
Fredrikstad	0	4 182	0
Førde	0	1 943	0
Gjøvik	0	2 614	0
Hamar	0	5 707	0
Hammerfest	753	0	0
Haugesund	0	1 046	0
Jessheim	0	2 382	0
Kirkenes	0	0	812
Kongsberg	0	2 172	0
Kristiansand	0	2 220	0
Larvik	0	3 727	0
Mandal	0	3 973	0
Molde	0	2 412	0
Moss	0	3 076	0
Narvik	0	0	1 059
Oslo	0	1 700	0
Raufoss	0	1 400	0
Sandefjord	0	3 177	0
Stavanger	0	1 436	0
Stord	0	1 437	0
Tromsø	0	0	1 247
Trondheim	0	2 816	0
Tynset	0	1 537	0
Verdal	0	737	0
Ålesund	0	2 151	0
Åsen	0	714	0

Table B12: Scenario 3 solution when distributing without PostNord from the facility analysis with the p-center objective.

Appendix C. Solution statistics for Scenario 1 from simulation analysis

Scenario 1	Delivery Time	Scenario 1	Stock out Probability	Scenario 1	Average Inventory
Askim	29,59	**Askim**	0,1441 %	**Askim**	8 787,97
Aukra	29,17	**Aukra**	0,1569 %	**Aukra**	8 792,89
Bærum	7,64	**Bærum**	0,1682 %	**Bærum**	8 870,08
Bergen	31,16	**Bergen**	0,1522 %	**Bergen**	9 099,62
Drammen	31,03	**Drammen**	0,1336 %	**Drammen**	9 002,18
Finnsnes	31,43	**Finnsnes**	0,1347 %	**Finnsnes**	8 863,26
Flekkefjord	32,91	**Flekkefjord**	0,1575 %	**Flekkefjord**	8 868,39
Forde	31,42	**Forde**	0,1324 %	**Forde**	9 023,37
Fredrikstad	30,40	**Fredrikstad**	0,1711 %	**Fredrikstad**	8 942,71
Gjøvik	32,22	**Gjøvik**	0,1334 %	**Gjøvik**	8 906,44
Hamar	31,28	**Hamar**	0,1482 %	**Hamar**	9 066,07
Hammerfest	31,61	**Hammerfest**	0,1722 %	**Hammerfest**	8 858,18
Haugesund	30,66	**Haugesund**	0,1623 %	**Haugesund**	9 062,36
Jessheim	30,61	**Jessheim**	0,1360 %	**Jessheim**	8 962,55
Kirkenes	30,42	**Kirkenes**	0,1363 %	**Kirkenes**	8 870,53
Kongsberg	31,26	**Kongsberg**	0,1544 %	**Kongsberg**	8 768,63
Kristiansand	31,14	**Kristiansand**	0,1331 %	**Kristiansand**	8 909,44
Larvik	31,71	**Larvik**	0,1347 %	**Larvik**	9 030,02
Mandal	31,25	**Mandal**	0,1336 %	**Mandal**	9 045,63
Molde	31,93	**Molde**	0,1335 %	**Molde**	9 029,88
Moss	30,34	**Moss**	0,1591 %	**Moss**	8 898,51
Narvik	33,03	**Narvik**	0,1363 %	**Narvik**	8 753,86
Oslo	30,26	**Oslo**	0,1327 %	**Oslo**	8 891,15
Raufoss	31,16	**Raufoss**	0,1749 %	**Raufoss**	8 891,83
Sandefjord	31,50	**Sandefjord**	0,1692 %	**Sandefjord**	8 918,96
Stavanger	31,72	**Stavanger**	0,1831 %	**Stavanger**	9 097,44
Stord	31,63	**Stord**	0,1310 %	**Stord**	8 995,07
Tromsø	31,53	**Tromsø**	0,1536 %	**Tromsø**	8 982,46
Trondheim	29,62	**Trondheim**	0,1562 %	**Trondheim**	8 933,88
Tynset	29,26	**Tynset**	0,1561 %	**Tynset**	8 799,79
Verdal	31,06	**Verdal**	0,1532 %	**Verdal**	8 880,97
Ålesund	32,04	**Ålesund**	0,1544 %	**Ålesund**	9 072,14
Åsen	26,98	**Åsen**	0,1583 %	**Åsen**	8 790,97
	30,27		**0,1499 %**		**294 667,23**

Table C1: Solution for Scenario 1 in the simulation analysis. Delivery time, stock out probability and average inventory level for each of the locations with the corresponding total/average for each statistics is displayed.

Appendix D. Average delivery time from the simulation analysis

Delivery Time				
Scenario 2	(s, Q) PostNord	(R, s, S) PostNord	(s, Q) Themselves	(R, s, S) Themselves
Flekkefjord	28,49	39,35	23,55	25,37
Forde	28,26	39,32	27,56	34,56
Fredrikstad			11,26	18,94
Oslo	23,36	25,23		
Tromsø	55,50	64,11	50,15	57,47
Trondheim	28,42	39,32	27,81	34,51
Average	32,81	41,46	28,06	34,17

Scenario 3	(s, Q) PostNord	(R, s, S) PostNord	(s, Q) Themselves	(R, s, S) Themselves
Flekkefjord	28,36	39,35	23,67	25,33
Forde	28,52	39,34	27,81	33,27
Fredrikstad			11,33	18,96
Oslo	23,32	25,28		
Hammerfest	56,61	64,54	51,33	60,66
Tromsø	54,56	64,14	50,08	58,38
Trondheim	28,63	39,32	27,11	34,91
Average	36,67	45,33	31,89	38,58

Scenario 4	(s, Q) PostNord	(R, s, S) PostNord	(s, Q) Themselves	(R, s, S) Themselves
Hammerfest	56,26	64,73	50,64	60,27
Oslo	22,40	25,06	11,98	19,92
Tromsø	55,37	64,18	50,02	58,33
Average	44,68	51,32	37,55	46,17

Table D1: Delivery time for each of the new scenario alternatives from the simulation analysis.

Appendix E. Average inventory from the simulation analysis

Average Inventory				
Scenario 2	(s, Q) PostNord	(R, s, S) PostNord	(s, Q) Themselves	(R, s, S) Themselves
Flekkefjord	10 771,91	18 743,50	12 155,74	23 153,88
Forde	10 134,64	18 262,81	10 584,95	19 855,19
Fredrikstad			13 135,63	12 324,04
Oslo	10 711,27	20 129,69		
Tromsø	20 829,51	38 140,21	19 099,76	35 261,95
Trondheim	9 306,76	15 799,57	9 493,50	16 678,46
Average	61 754,09	111 075,78	64 469,58	107 273,52

Scenario 3	(s, Q) PostNord	(R, s, S) PostNord	(s, Q) Themselves	(R, s, S) Themselves
Flekkefjord	10 769,31	18 680,10	12 106,11	23 089,63
Forde	10 149,28	18 183,47	10 573,61	20 221,17
Fredrikstad			13 117,33	12 328,95
Oslo	10 794,57	20 160,03		
Hammerfest	11 031,66	25 187,89	10 650,01	24 426,56
Tromsø	17 890,60	34 488,24	16 454,71	32 219,07
Trondheim	9 327,18	15 770,67	9 555,37	16 583,14
Average	69 962,60	132 470,40	72 457,14	128 868,52

Scenario 4	(s, Q) PostNord	(R, s, S) PostNord	(s, Q) Themselves	(R, s, S) Themselves
Hammerfest	11 014,64	25 071,14	10 642,21	24 237,03
Oslo	54 338,22	76 040,20	64 555,17	57 182,87
Tromsø	17 698,63	34 499,68	16 440,84	32 203,82
Average	83 051,49	135 611,02	91 638,22	113 623,72

Table E1: Average inventory for each of the new scenario alternatives from the simulation analysis.

Appendix F. Stock out probabilities from the simulation analysis

Stock out Probability				
Scenario 2	**(s, Q) PostNord**	**(R, s, S) PostNord**	**(s, Q) Themselves**	**(R, s, S) Themselves**
Flekkefjord	0,3709 %	0,4074 %	0,2888 %	0,2301 %
Forde	0,4651 %	0,1524 %	0,2935 %	0,1651 %
Fredrikstad			0,1402 %	0,1336 %
Oslo	0,5015 %	0,4037 %		
Tromsø	0,1330 %	0,1237 %	0,1339 %	0,1302 %
Trondheim	0,5352 %	0,1342 %	0,2918 %	0,1343 %
Average	**0,4011 %**	**0,2443 %**	**0,2296 %**	**0,1586 %**

Scenario 3	(s, Q) PostNord	(R, s, S) PostNord	(s, Q) Themselves	(R, s, S) Themselves
Flekkefjord	0,5794 %	0,2881 %	0,2729 %	0,2691 %
Forde	0,6360 %	0,1891 %	0,2896 %	0,1399 %
Fredrikstad			0,1363 %	0,1337 %
Oslo	0,5241 %	0,4787 %		
Hammerfest	0,1351 %	0,1367 %	0,1352 %	0,1379 %
Tromsø	0,1341 %	0,1302 %	0,1351 %	0,1292 %
Trondheim	0,4103 %	0,1329 %	0,2778 %	0,1330 %
Average	**0,4032 %**	**0,2259 %**	**0,2078 %**	**0,1571 %**

Scenario 4	(s, Q) PostNord	(R, s, S) PostNord	(s, Q) Themselves	(R, s, S) Themselves
Hammerfest	0,1368 %	0,1353 %	0,1386 %	0,1378 %
Oslo	0,1261 %	0,1335 %	0,1335 %	0,1335 %
Tromsø	0,1350 %	0,1257 %	0,1330 %	0,1311 %
Average	**0,1326 %**	**0,1315 %**	**0,1350 %**	**0,1341 %**

Table F1: Stock out probabilities for each of the new scenario alternatives from the simulation analysis.

Appendix G. Results from the sensitivity analysis

Situation 1, order-up-to point

Situation 1: Increase or decrease the order-up-to point																							
			Stock out probabilities																				
Scenario	Order policy and distribution	Increase or decrease	Flekkefjord			Fredrikstad			Forde			Hammerfest			Oslo			Tromsø			Trondheim		
			Old	New	Diff	Old	New	Diff	Old	New	Diff	Old	New	Diff	Old	New	Diff	Old	New	Diff	Old	New	Diff
Scenario 2	(R, s, S) PostNord	Increase	0,41 %	0,13 %	-0,28 %				0,15 %	0,13 %	-0,02 %			0,00 %	0,40 %	0,13 %	-0,27 %	0,12 %	0,13 %	0,01 %	0,13 %	0,13 %	0,00 %
Scenario 2	(R, s, S) PostNord	Decrease	0,41 %	1,58 %	1,17 %				0,15 %	2,62 %	2,47 %			0,00 %	0,40 %	2,55 %	2,15 %	0,12 %	0,12 %	0,00 %	0,13 %	1,36 %	1,23 %
Scenario 3	(R, s, S) PostNord	Increase	0,29 %	0,12 %	-0,17 %				0,19 %	0,13 %	-0,06 %	0,14 %	0,14 %	0,00 %	0,48 %	0,13 %	-0,35 %	0,13 %	0,12 %	-0,01 %	0,13 %	0,13 %	0,00 %
Scenario 3	(R, s, S) PostNord	Decrease	0,29 %	1,63 %	1,34 %				0,19 %	2,64 %	2,45 %	0,14 %	0,14 %	0,00 %	0,48 %	2,51 %	2,03 %	0,13 %	0,13 %	0,00 %	0,13 %	0,13 %	0,00 %
Scenario 4	(R, s, S) PostNord	Increase										0,14 %	0,14 %	0,00 %	0,13 %	0,13 %	0,00 %	0,13 %	0,13 %	0,00 %			
Scenario 4	(R, s, S) PostNord	Decrease										0,14 %	0,14 %	0,00 %	0,13 %	0,13 %	0,00 %	0,13 %	0,13 %	0,00 %			
Scenario 2	(R, s, S) Themselves	Increase	0,23 %	0,13 %	-0,10 %	0,13 %	0,13 %	0,00 %	0,17 %	0,13 %	-0,04 %							0,13 %	0,13 %	0,00 %	0,13 %	0,13 %	0,00 %
Scenario 2	(R, s, S) Themselves	Decrease	0,23 %	0,93 %	0,70 %	0,13 %	0,50 %	0,37 %	0,17 %	1,35 %	1,18 %							0,13 %	0,13 %	0,00 %	0,13 %	0,86 %	0,73 %
Scenario 3	(R, s, S) Themselves	Increase	0,27 %	0,13 %	-0,14 %	0,13 %	0,13 %	0,00 %	0,14 %	0,13 %	-0,01 %	0,14 %	0,14 %	0,00 %				0,13 %	0,13 %	0,00 %	0,13 %	0,13 %	0,00 %
Scenario 3	(R, s, S) Themselves	Decrease	0,27 %	0,86 %	0,59 %	0,13 %	0,52 %	0,39 %	0,14 %	1,89 %	1,75 %	0,14 %	0,14 %	0,00 %				0,13 %	0,13 %	0,00 %	0,13 %	0,99 %	0,86 %
Scenario 4	(R, s, S) Themselves	Increase									0,00 %	0,14 %	0,14 %	0,00 %	0,13 %	0,13 %	0,00 %	0,13 %	0,13 %	0,00 %			
Scenario 4	(R, s, S) Themselves	Decrease									0,00 %	0,14 %	0,14 %	0,00 %	0,13 %	0,13 %	0,00 %	0,13 %	0,13 %	0,00 %			

			Average Inventory																					
Scenario	Order policy and distribution	Increase or decrease	Flekkefjord			Fredrikstad			Forde			Hammerfest			Oslo			Tromsø			Trondheim			Average change
			Old	New	Change	Old	New	Change	Old	New	Change	Old	New	Change	Old	New	Change	Old	New	Change	Old	New	Change	
Scenario 2	(R, s, S) PostNord	Increase	18 744	23 348	24,56 %				18 263	22 256	21,86 %				20 130	24 194	20,19 %	38 140	43 961	15,26 %	15 800	19 140	21,14 %	20,60 %
Scenario 2	(R, s, S) PostNord	Decrease	18 744	13 877	-25,97 %				18 263	14 371	-21,31 %				20 130	15 413	-23,43 %	38 140	32 171	-15,65 %	15 800	12 429	-21,34 %	-21,54 %
Scenario 3	(R, s, S) PostNord	Increase	18 680	23 285	24,65 %				18 183	22 197	22,08 %	25 188	28 448	12,94 %	20 160	24 261	20,34 %	34 488	39 619	14,88 %	15 771	19 127	21,28 %	19,36 %
Scenario 3	(R, s, S) PostNord	Decrease	18 680	13 838	-25,92 %				18 183	14 374	-20,95 %	25 188	22 065	-12,40 %	20 160	15 561	-22,81 %	34 488	29 126	-15,55 %	15 771	12 463	-20,98 %	-19,77 %
Scenario 4	(R, s, S) PostNord	Increase										25 071	28 316	12,94 %	76 040	89 751	18,03 %	34 500	39 643	14,91 %				15,29 %
Scenario 4	(R, s, S) PostNord	Decrease										25 071	22 087	-11,90 %	76 040	62 496	-17,81 %	34 500	29 243	-15,24 %				-14,98 %
Scenario 2	(R, s, S) Themselves	Increase	23 154	27 526	18,88 %	12 324	16 109	30,71 %	19 855	23 895	20,35 %							35 262	40 869	15,90 %	16 678	20 020	20,04 %	21,18 %
Scenario 2	(R, s, S) Themselves	Decrease	23 154	18 174	-21,51 %	12 324	8 575	-30,42 %	19 855	16 436	-17,22 %							35 262	29 882	-15,26 %	16 678	13 488	-19,13 %	-20,71 %
Scenario 3	(R, s, S) Themselves	Increase	23 090	27 548	19,31 %	12 329	16 046	30,15 %	20 211	23 622	16,88 %	24 427	27 406	12,20 %				32 219	37 113	15,19 %	16 583	20 055	20,94 %	19,11 %
Scenario 3	(R, s, S) Themselves	Decrease	23 090	18 163	-21,34 %	12 329	8 575	-30,45 %	20 211	16 068	-20,50 %	24 427	21 432	-12,26 %				32 219	27 353	-15,10 %	16 583	13 221	-20,27 %	-19,99 %
Scenario 4	(R, s, S) Themselves	Increase										24 237	27 307	12,67 %	57 183	70 381	23,08 %	32 204	36 915	14,63 %				16,79 %
Scenario 4	(R, s, S) Themselves	Decrease										24 237	21 481	-11,37 %	57 183	44 174	-22,75 %	32 204	27 445	-14,78 %				-16,30 %

Scenario	Order policy and distribution	Increase or decrease	Total deliveries made			Orders over 18 hours			Hold for inventory						Average order time			
									Time in queue			Number in queue						
			Old	New	Diff	Old	New	Diff	Old	New	Diff	Old	New	Diff	Old	New	Diff	Minutes
Scenario 2	(R, s, S) PostNord	Increase	589,8	590	-0,2	23	0	-23	4,09	0,00	-4,09	0,55	0,00	-0,55	2,0212	2,0178	-0,0034	-0,2040
Scenario 2	(R, s, S) PostNord	Decrease	589,8	587	2,8	23	515	492	4,09	5,92	1,83	0,55	14,46	13,91	2,0212	2,1054	0,0842	5,0520
Scenario 3	(R, s, S) PostNord	Increase	595,33	594	1,33	19,6	0	-19,6	3,24	0,00	-3,24	0,49	0,00	-0,49	1,8617	1,8581	-0,0036	-0,2160
Scenario 3	(R, s, S) PostNord	Decrease	595,33	595	0,33	19,6	540	520,4	3,24	6,09	2,85	0,49	14,88	14,39	1,8617	1,9466	0,0849	5,0940
Scenario 4	(R, s, S) PostNord	Increase	576,6	577	-0,4	0	0	0	0,00	0,00	0,00	0,00	0,00	0,00	4,4102	4,4099	-0,0003	-0,0180
Scenario 4	(R, s, S) PostNord	Decrease	576,6	575	1,6	0	0	0	0,00	0,00	0,00	0,00	0,00	0,00	4,4102	4,4095	-0,0007	-0,0420
Scenario 2	(R, s, S) Themselves	Increase	590,47	590	0,47	0,4	0	-0,4	1,91	0,00	-1,91	0,12	0,00	-0,12	2,1659	2,1653	-0,0006	-0,0360
Scenario 2	(R, s, S) Themselves	Decrease	590,47	588	2,47	0,4	105	104,6	1,91	3,35	1,44	0,12	5,15	5,03	2,1659	2,1908	0,0249	1,4940
Scenario 3	(R, s, S) Themselves	Increase	594,27	595	-0,73	7,53	0	-7,53	2,17	0,00	-2,17	0,21	0,00	-0,21	2,0068	2,0050	-0,0018	-0,1080
Scenario 3	(R, s, S) Themselves	Decrease	594,27	595	-0,73	7,53	192	184,47	2,17	4,07	1,90	0,21	6,36	6,15	2,0068	2,0355	0,0287	1,7220
Scenario 4	(R, s, S) Themselves	Increase	583,53	584	-0,47	0	0	0	0,00	0,00	0,00	0,00	0,00	0,00	4,4103	4,4097	-0,0006	-0,0360
Scenario 4	(R, s, S) Themselves	Decrease	583,53	584	-0,47	0	0	0	0,00	0,00	0,00	0,00	0,00	0,00	4,4103	4,4093	-0,0010	-0,0600

Table G1: Results from the sensitivity analysis when changing the order-up-to point. Numbers marked in green and red are discussed in section 7.2.1.

Situation 2, delivery size

Situation 2: Increase or decrease the delivery size																							
Scenario	Order policy and distribution	Increase or decrease	Stock out probabilities																				
			Flekkefjord			Fredrikstad			Forde			Hammerfest			Oslo			Tromsø			Trondheim		
			Old	New	Diff	Old	New	Diff	Old	New	Diff	Old	New	Diff	Old	New	Diff	Old	New	Diff	Old	New	Diff
Scenario 2	(R, s, S) PostNord	Increase	0,41 %	1,12 %	0,71 %				0,15 %	0,90 %	0,75 %				0,40 %	0,87 %	0,47 %	0,12 %	0,13 %	0,01 %	0,13 %	0,15 %	0,02 %
Scenario 2	(R, s, S) PostNord	Decrease	0,41 %	0,23 %	-0,18 %				0,15 %	0,13 %	-0,02 %				0,40 %	0,16 %	-0,24 %	0,12 %	0,13 %	0,01 %	0,13 %	0,13 %	0,00 %
Scenario 3	(R, s, S) PostNord	Increase	0,29 %	1,42 %	**1,13 %**				0,19 %	0,94 %	0,75 %	0,14 %	0,14 %	0,00 %	0,48 %	0,93 %	0,45 %	0,13 %	0,13 %	0,00 %	0,13 %	0,15 %	0,02 %
Scenario 3	(R, s, S) PostNord	Decrease	0,29 %	0,18 %	-0,11 %				0,19 %	0,13 %	-0,06 %	0,14 %	0,14 %	0,00 %	0,48 %	0,14 %	-0,34 %	0,13 %	0,13 %	0,00 %	0,13 %	0,13 %	0,00 %
Scenario 4	(R, s, S) PostNord	Increase										0,14 %	0,14 %	0,00 %	0,13 %	0,13 %	0,00 %	0,13 %	0,13 %	0,00 %			
Scenario 4	(R, s, S) PostNord	Decrease										0,14 %	0,14 %	0,00 %	0,13 %	0,13 %	0,00 %	0,13 %	0,13 %	0,00 %			
Scenario 2	(R, s, S) Themselves	Increase	0,23 %	0,43 %	0,20 %	0,13 %	0,14 %	0,01 %	0,17 %	0,38 %	0,28 %							0,13 %	0,13 %	0,00 %	0,13 %	0,13 %	0,00 %
Scenario 2	(R, s, S) Themselves	Decrease	0,23 %	0,16 %	-0,07 %	0,13 %	0,13 %	0,00 %	0,17 %	0,13 %	-0,04 %							0,13 %	0,13 %	0,00 %	0,13 %	0,13 %	0,00 %
Scenario 3	(R, s, S) Themselves	Increase	0,27 %	0,49 %	0,22 %	0,13 %	0,45 %	0,32 %	0,14 %	0,45 %	-0,14 %	0,14 %	0,14 %	0,00 %				0,13 %	0,13 %	0,00 %	0,13 %	0,13 %	0,00 %
Scenario 3	(R, s, S) Themselves	Decrease	0,27 %	0,17 %	-0,10 %	0,13 %	0,13 %	0,00 %	0,14 %	0,13 %	-0,14 %	0,14 %	0,14 %	0,00 %				0,13 %	0,13 %	0,00 %	0,13 %	0,13 %	0,00 %
Scenario 4	(R, s, S) Themselves	Increase										0,14 %	0,14 %	0,00 %	0,13 %	0,13 %	0,00 %	0,13 %	0,13 %	0,00 %			
Scenario 4	(R, s, S) Themselves	Decrease										0,14 %	0,14 %	0,00 %	0,13 %	0,13 %	0,00 %	0,13 %	0,13 %	0,00 %			

Scenario	Order policy and distribution	Increase or decrease	Average Inventory																					Average change
			Flekkefjord			Fredrikstad			Forde			Hammerfest			Oslo			Tromsø			Trondheim			
			Old	New	Change	Old	New	Change	Old	New	Change	Old	New	Change	Old	New	Change	Old	New	Change	Old	New	Change	
Scenario 2	(R, s, S) PostNord	Increase	18 744	18 053	-3,69 %				18 263	17 054	-6,62 %				20 130	18 416	-8,51 %	38 140	37 361	-2,04 %	15 800	15 066	-4,65 %	**-5,10 %**
Scenario 2	(R, s, S) PostNord	Decrease	18 744	19 469	3,87 %				18 263	18 834	3,13 %				20 130	21 693	7,76 %	38 140	38 223	0,22 %	15 800	17 490	10,70 %	**5,13 %**
Scenario 3	(R, s, S) PostNord	Increase	18 680	17 919	-4,07 %				18 183	16 969	-6,68 %	25 188	26 286	4,36 %	20 160	18 268	-9,38 %	34 488	31 842	-7,67 %	15 771	15 042	-4,62 %	**-4,68 %**
Scenario 3	(R, s, S) PostNord	Decrease	18 680	19 477	4,27 %				18 183	18 845	3,64 %	25 188	24 296	-3,54 %	20 160	21 854	8,40 %	34 488	35 307	2,37 %	15 771	17 563	11,36 %	**4,42 %**
Scenario 4	(R, s, S) PostNord	Increase										25 071	26 187	4,45 %	76 040	74 245	-2,36 %	34 500	31 893	-7,56 %				**-1,82 %**
Scenario 4	(R, s, S) PostNord	Decrease										25 071	24 434	-2,54 %	76 040	77 433	1,83 %	34 500	35 357	2,48 %				**0,59 %**
Scenario 2	(R, s, S) Themselves	Increase	23 154	22 389	-3,30 %	12 324	11 338	-8,00 %	19 855	18 381	-7,42 %							35 262	34 574	-1,95 %	16 678	15 932	-4,47 %	**-5,03 %**
Scenario 2	(R, s, S) Themselves	Decrease	23 154	23 895	3,20 %	12 324	13 588	10,26 %	19 855	20 408	2,79 %							35 262	35 730	1,33 %	16 678	18 473	10,76 %	**5,67 %**
Scenario 3	(R, s, S) Themselves	Increase	23 090	22 359	-3,17 %	12 329	11 412	-7,44 %	20 211	18 492	-8,51 %	24 427	25 427	4,09 %				32 219	29 921	-7,13 %	16 583	16 073	-3,08 %	**-4,20 %**
Scenario 3	(R, s, S) Themselves	Decrease	23 090	23 997	3,93 %	12 329	13 570	10,07 %	20 211	20 582	1,84 %	24 427	23 607	-3,36 %				32 219	33 122	2,80 %	16 583	18 317	10,46 %	**4,29 %**
Scenario 4	(R, s, S) Themselves	Increase										24 237	25 501	5,22 %	57 183	54 926	-3,95 %	32 204	29 794	-7,48 %				**-2,07 %**
Scenario 4	(R, s, S) Themselves	Decrease										24 237	23 423	-3,36 %	57 183	57 645	0,81 %	32 204	33 008	2,50 %				**-0,02 %**

Scenario	Order policy and distribution	Increase or decrease	Total deliveries made			Orders over 18 hours			Hold for inventory						Average order time			
									Time in queue			Number in queue						
			Old	New	Diff	Old	New	Diff	Old	New	Diff	Old	New	Diff	Old	New	Diff	Minutes
Scenario 2	(R, s, S) PostNord	Increase	589,8	565	**-24,8**	23	176	**153**	4,09	6,09	**2,00**	0,55	3,54	**2,99**	2,0212	2,0395	0,0183	1,0980
Scenario 2	(R, s, S) PostNord	Decrease	589,8	622	**32,2**	23	4	**-19**	4,09	3,94	**-0,15**	0,55	0,07	**-0,48**	2,0212	2,0183	-0,0029	-0,1740
Scenario 3	(R, s, S) PostNord	Increase	595,33	567	**-28,33**	19,6	212	**192,4**	3,24	6,51	**3,27**	0,49	4,26	**3,77**	1,8617	1,8644	0,0027	0,1620
Scenario 3	(R, s, S) PostNord	Decrease	595,33	634	**38,67**	19,6	4	**-15,6**	3,24	0,00	**-3,24**	0,49	0,06	**-0,43**	1,8617	1,8487	-0,0130	-0,7800
Scenario 4	(R, s, S) PostNord	Increase	576,6	556	**-20,6**	0	0	0	0,00	0,00	0,00	0,00	0,00	0,00	4,4102	4,4094	-0,0008	-0,0480
Scenario 4	(R, s, S) PostNord	Decrease	576,6	592	**15,4**	0	0	0	0,00	0,00	0,00	0,00	0,00	0,00	4,4102	4,4094	-0,0008	-0,0480
Scenario 2	(R, s, S) Themselves	Increase	590,47	567	**-23,47**	0,4	12	**11,6**	1,91	3,14	**1,23**	0,12	0,74	**0,62**	2,1659	2,1693	0,0034	0,2040
Scenario 2	(R, s, S) Themselves	Decrease	590,47	630	**39,53**	0,4	0	**-0,4**	1,91	0,84	**-1,08**	0,12	0,02	**-0,10**	2,1659	2,1650	-0,0009	-0,0540
Scenario 3	(R, s, S) Themselves	Increase	594,27	568	**-26,27**	7,53	21	**13,47**	2,17	2,99	**0,82**	0,21	0,98	**0,77**	2,0068	2,0103	0,0035	0,2100
Scenario 3	(R, s, S) Themselves	Decrease	594,27	640	**45,73**	7,53	2	**-5,53**	2,17	0,00	**-2,17**	0,21	0,05	**-0,16**	2,0068	2,0055	-0,0013	-0,0780
Scenario 4	(R, s, S) Themselves	Increase	583,53	562	**-21,53**	0	0	0	0,00	0,00	0,00	0,00	0,00	0,00	4,4103	4,4091	-0,0012	-0,0720
Scenario 4	(R, s, S) Themselves	Decrease	583,53	595	**11,47**	0	0	0	0,00	0,00	0,00	0,00	0,00	0,00	4,4103	4,4096	-0,0007	-0,0420

Table G2: Results from the sensitivity analysis when changing the minimum delivery size. Numbers marked in green and red are discussed in section 7.2.2.

Situation 3, capacity

Situation 3: Increase or decrease the capacity																							
Scenario	Order policy and distribution	Increase or decrease	Stock out probabilities																				
			Flekkefjord			Fredrikstad			Forde			Hammerfest			Oslo			Tromsø			Trondheim		
			Old	New	Diff	Old	New	Diff	Old	New	Diff	Old	New	Diff	Old	New	Diff	Old	New	Diff	Old	New	Diff
Scenario 2	(R, s, S) PostNord	Increase	0,41 %	0,68 %	0,27 %				0,15 %	0,24 %	0,09 %				0,40 %	0,17 %	-0,23 %	0,12 %	0,13 %	0,01 %	0,13 %	0,13 %	0,00 %
Scenario 2	(R, s, S) PostNord	Decrease	0,41 %	0,31 %	-0,10 %				0,15 %	0,19 %	0,04 %				0,40 %	0,21 %	-0,19 %	0,12 %	0,13 %	0,01 %	0,13 %	0,13 %	0,00 %
Scenario 3	(R, s, S) PostNord	Increase	0,29 %	0,76 %	0,47 %				0,19 %	0,21 %	0,02 %	0,14 %	0,14 %	0,00 %	0,48 %	0,17 %	-0,31 %	0,13 %	0,13 %	0,00 %	0,13 %	0,13 %	0,00 %
Scenario 3	(R, s, S) PostNord	Decrease	0,29 %	0,31 %	0,02 %				0,19 %	0,15 %	-0,04 %	0,14 %	0,14 %	0,00 %	0,48 %	0,22 %	-0,26 %	0,13 %	0,13 %	0,00 %	0,13 %	0,13 %	0,00 %
Scenario 4	(R, s, S) PostNord	Increase										0,14 %	0,14 %	0,00 %	0,13 %	0,13 %	0,00 %	0,13 %	0,13 %	0,00 %			
Scenario 4	(R, s, S) PostNord	Decrease										0,14 %	0,40 %	0,26 %	0,13 %	0,13 %	0,00 %	0,13 %	0,13 %	0,00 %			
Scenario 2	(R, s, S) Themselves	Increase	0,23 %	0,34 %	0,11 %	0,13 %	0,13 %	-2,69 %	0,17 %	0,14 %	-0,01 %							0,13 %	0,13 %	0,00 %	0,13 %	0,13 %	0,00 %
Scenario 2	(R, s, S) Themselves	Decrease	0,23 %	0,25 %	0,02 %	0,13 %	0,13 %	-2,69 %	0,17 %	0,15 %	-0,02 %							0,13 %	0,13 %	0,00 %	0,13 %	0,13 %	0,00 %
Scenario 3	(R, s, S) Themselves	Increase	0,27 %	0,35 %	0,08 %	0,13 %	0,13 %	-2,79 %	0,14 %	0,16 %	-0,14 %	0,14 %	0,14 %	0,00 %				0,13 %	0,13 %	0,00 %	0,13 %	0,13 %	0,00 %
Scenario 3	(R, s, S) Themselves	Decrease	0,27 %	0,22 %	-0,05 %	0,13 %	0,13 %	-2,79 %	0,14 %	0,15 %	-0,14 %	0,14 %	0,14 %	0,00 %				0,13 %	0,13 %	0,00 %	0,13 %	0,13 %	0,00 %
Scenario 4	(R, s, S) Themselves	Increase										0,14 %	0,14 %	0,00 %	0,13 %	0,13 %	0,00 %	0,13 %	0,13 %	0,00 %			
Scenario 4	(R, s, S) Themselves	Decrease										0,14 %	0,14 %	0,00 %	0,13 %	0,13 %	0,00 %	0,13 %	0,13 %	0,00 %			

Scenario	Order policy and distribution	Increase or decrease	Average Inventory																					Average change
			Flekkefjord			Fredrikstad			Forde			Hammerfest			Oslo			Tromsø			Trondheim			
			Old	New	Change	Old	New	Change	Old	New	Change	Old	New	Change	Old	New	Change	Old	New	Change	Old	New	Change	
Scenario 2	(R, s, S) PostNord	Increase	18 744	20 079	7,12 %				18 263	19 126	4,73 %				20 130	20 616	2,41 %	38 140	39 885	4,58 %	15 800	16 376	3,65 %	4,50 %
Scenario 2	(R, s, S) PostNord	Decrease	18 744	18 377	-1,96 %				18 263	16 670	-8,72 %				20 130	19 975	-0,77 %	38 140	36 104	-5,34 %	15 800	14 808	-6,28 %	-4,61 %
Scenario 3	(R, s, S) PostNord	Increase	18 680	20 067	7,43 %				18 183	19 093	5,00 %	25 188	25 205	0,07 %	20 160	20 790	3,13 %	34 488	36 062	4,56 %	15 771	16 298	3,34 %	3,92 %
Scenario 3	(R, s, S) PostNord	Decrease	18 680	18 391	-1,55 %				18 183	16 544	-9,01 %	25 188	25 091	-0,39 %	20 160	19 821	-1,68 %	34 488	32 391	-6,08 %	15 771	14 841	-5,90 %	-4,10 %
Scenario 4	(R, s, S) PostNord	Increase										25 071	25 172	0,40 %	76 040	75 130	-1,20 %	34 500	35 931	4,15 %				1,12 %
Scenario 4	(R, s, S) PostNord	Decrease										25 071	25 134	0,25 %	76 040	74 196	-2,43 %	34 500	32 399	-6,09 %				-2,75 %
Scenario 2	(R, s, S) Themselves	Increase	23 154	24 460	5,64 %	12 324	12 699	3,04 %	19 855	20 671	4,11 %							35 262	37 237	5,60 %	16 678	17 342	3,98 %	4,48 %
Scenario 2	(R, s, S) Themselves	Decrease	23 154	22 850	-1,31 %	12 324	12 627	2,46 %	19 855	18 212	-8,27 %							35 262	33 562	-4,82 %	16 678	15 818	-5,16 %	-3,42 %
Scenario 3	(R, s, S) Themselves	Increase	23 090	24 578	6,44 %	12 329	12 696	2,98 %	20 211	20 959	3,70 %	24 427	24 196	-0,95 %				32 219	33 583	4,23 %	16 583	17 089	3,05 %	3,24 %
Scenario 3	(R, s, S) Themselves	Decrease	23 090	22 833	-1,11 %	12 329	12 610	2,28 %	20 211	18 242	-9,74 %	24 427	24 326	-0,41 %				32 219	30 431	-5,55 %	16 583	15 728	-5,16 %	-3,28 %
Scenario 4	(R, s, S) Themselves	Increase										24 237	24 439	0,83 %	57 183	55 368	-3,17 %	32 204	33 621	4,40 %				0,69 %
Scenario 4	(R, s, S) Themselves	Decrease										24 237	24 497	1,07 %	57 183	53 153	-7,05 %	32 204	30 231	-6,13 %				-4,03 %

Scenario	Order policy and distribution	Increase or decrease	Total deliveries made			Orders over 18 hours			Hold for inventory						Average order time			
									Time in queue			Number in queue						
			Old	New	Diff	Old	New	Diff	Old	New	Diff	Old	New	Diff	Old	New	Diff	Minutes
Scenario 2	(R, s, S) PostNord	Increase	589,8	543	-46,8	23	57	34	4,09	12,28	8,19	0,55	0,94	0,39	2,0212	2,0231	0,0019	0,1140
Scenario 2	(R, s, S) PostNord	Decrease	589,8	659	69,2	23	12	-11	4,09	5,01	0,92	0,55	0,29	-0,26	2,0212	2,0195	-0,0017	-0,1020
Scenario 3	(R, s, S) PostNord	Increase	595,33	552	-43,33	19,6	57	37,4	3,24	10,86	7,62	0,49	0,93	0,44	1,8617	1,8634	0,0017	0,1020
Scenario 3	(R, s, S) PostNord	Decrease	595,33	661	65,67	19,6	14	-5,6	3,24	3,96	0,72	0,49	0,35	-0,14	1,8617	1,8603	-0,0014	-0,0840
Scenario 4	(R, s, S) PostNord	Increase	576,6	509	-67,6	0	0	0	0,00	0,00	0,00	0,00	0,00	0,00	4,4102	4,4102	0,0000	0,0000
Scenario 4	(R, s, S) PostNord	Decrease	576,6	649	72,4	0	0	0	0,00	0,00	0,00	0,00	0,00	0,00	4,4102	4,4091	-0,0011	-0,0660
Scenario 2	(R, s, S) Themselves	Increase	590,47	543	-47,47	0,4	2	1,6	1,91	2,08	0,17	0,12	0,27	0,15	2,1659	2,1668	0,0009	0,0540
Scenario 2	(R, s, S) Themselves	Decrease	590,47	660	69,53	0,4	6	5,6	1,91	2,76	0,85	0,12	0,19	0,07	2,1659	2,1663	0,0004	0,0240
Scenario 3	(R, s, S) Themselves	Increase	594,27	552	-42,27	7,53	6	-1,53	2,17	2,69	0,52	0,21	0,30	0,09	2,0068	2,007	0,0002	0,0120
Scenario 3	(R, s, S) Themselves	Decrease	594,27	662	67,73	7,53	3	-4,53	2,17	2,09	-0,08	0,21	0,14	-0,07	2,0068	2,0058	-0,001	-0,0600
Scenario 4	(R, s, S) Themselves	Increase	583,53	536	-47,53	0	0	0	0,00	0,00	0,00	0,00	0,00	0,00	4,4103	4,4092	-0,0011	-0,0660
Scenario 4	(R, s, S) Themselves	Decrease	583,53	648	64,47	0	0	0	0,00	0,00	0,00	0,00	0,00	0,00	4,4103	4,4097	-0,0006	-0,0360

Table G3: Results from the sensitivity analysis when changing the capacity of a vehicle. Numbers marked in green and red are discussed in section 7.2.3.

Situation 4, reorder point

Situation 4: Increase or decrease the reorder point																							
Scenario	Order policy and distribution	Increase or decrease	Stock out probabilities																				
			Flekkefjord			Fredrikstad			Forde			Hammerfest			Oslo			Tromsø			Trondheim		
			Old	New	Diff	Old	New	Diff	Old	New	Diff	Old	New	Diff	Old	New	Diff	Old	New	Diff	Old	New	Diff
Scenario 2	(s, Q) PostNord	Increase	0,37 %	0,13 %	-0,24 %				0,47 %	0,15 %	-0,32 %				0,50 %	0,21 %	-0,29 %	0,13 %	0,13 %	0,00 %	0,54 %	0,15 %	-0,39 %
Scenario 2	(s, Q) PostNord	Decrease	0,37 %	5,85 %	5,48 %				0,47 %	3,18 %	2,71 %				0,50 %	1,94 %	1,44 %	0,13 %	0,13 %	0,00 %	0,54 %	2,12 %	1,58 %
Scenario 3	(s, Q) PostNord	Increase	0,58 %	0,13 %	-0,45 %				0,64 %	0,15 %	-0,49 %	0,14 %	0,14 %	0,00 %	0,52 %	0,16 %	-0,36 %	0,13 %	0,14 %	0,01 %	0,41 %	0,13 %	-0,28 %
Scenario 3	(s, Q) PostNord	Decrease	0,58 %	5,46 %	4,88 %				0,64 %	3,24 %	2,60 %	0,14 %	0,14 %	0,00 %	0,52 %	2,18 %	1,66 %	0,13 %	0,13 %	0,00 %	0,41 %	0,18 %	-0,23 %
Scenario 4	(s, Q) PostNord	Increase										0,14 %	0,14 %	0,00 %	0,13 %	0,13 %	0,00 %	0,14 %	0,13 %	-0,01 %			
Scenario 4	(s, Q) PostNord	Decrease										0,14 %	0,14 %	0,00 %	0,13 %	0,12 %	-0,01 %	0,14 %	0,13 %	-0,01 %			
Scenario 2	(s, Q) Themselves	Increase	0,29 %	0,15 %	-0,14 %	0,14 %	0,13 %	-0,01 %	0,29 %	0,13 %	-0,16 %							0,13 %	0,13 %	0,00 %	0,29 %	0,13 %	-0,16 %
Scenario 2	(s, Q) Themselves	Decrease	0,29 %	1,45 %	1,16 %	0,14 %	0,23 %	0,09 %	0,29 %	2,56 %	2,27 %							0,13 %	0,13 %	0,00 %	0,29 %	1,58 %	1,29 %
Scenario 3	(s, Q) Themselves	Increase	0,27 %	0,13 %	-0,14 %	0,14 %	0,13 %	-0,01 %	0,29 %	0,13 %	-0,29 %	0,14 %	0,14 %	0,00 %				0,14 %	0,13 %	-0,01 %	0,28 %	0,13 %	-0,15 %
Scenario 3	(s, Q) Themselves	Decrease	0,27 %	1,20 %	0,93 %	0,14 %	0,23 %	0,09 %	0,29 %	2,56 %	-0,29 %	0,14 %	0,14 %	0,00 %				0,14 %	0,13 %	-0,01 %	0,28 %	1,68 %	1,40 %
Scenario 4	(s, Q) Themselves	Increase										0,13 %	0,14 %	0,01 %	0,13 %	0,13 %	0,00 %	0,13 %	0,13 %	0,00 %			
Scenario 4	(s, Q) Themselves	Decrease										0,13 %	0,14 %	0,01 %	0,13 %	0,13 %	0,00 %	0,13 %	0,13 %	0,00 %			

Scenario	Order policy and distribution	Increase or decrease	Average Inventory																					Average change
			Flekkefjord			Fredrikstad			Forde			Hammerfest			Oslo			Tromsø			Trondheim			
			Old	New	Change	Old	New	Change	Old	New	Change	Old	New	Change	Old	New	Change	Old	New	Change	Old	New	Change	
Scenario 2	(s, Q) PostNord	Increase	10 772	12 969	20,40 %				10 135	11 665	15,10 %				10 711	12 404	15,81 %	20 830	24 473	17,49 %	9 307	10 298	10,65 %	15,89 %
Scenario 2	(s, Q) PostNord	Decrease	10 772	8 657	-19,63 %				10 135	8 640	-14,75 %				10 711	9 050	-15,51 %	20 830	17 318	-16,86 %	9 307	8 384	-9,92 %	-15,33 %
Scenario 3	(s, Q) PostNord	Increase	10 769	12 996	20,68 %				10 149	11 807	16,34 %	11 032	11 850	7,41 %	10 795	12 364	14,53 %	17 891	20 539	14,80 %	9 327	10 244	9,83 %	13,93 %
Scenario 3	(s, Q) PostNord	Decrease	10 769	8 629	-19,87 %				10 149	8 635	-14,92 %	11 032	10 192	-7,61 %	10 795	9 077	-15,91 %	17 891	15 069	-15,77 %	9 327	8 358	-10,39 %	-14,08 %
Scenario 4	(s, Q) PostNord	Increase										11 015	11 776	6,91 %	54 338	64 956	19,54 %	17 699	20 502	15,84 %				14,10 %
Scenario 4	(s, Q) PostNord	Decrease										11 015	10 176	-7,62 %	54 338	42 551	-21,69 %	17 699	14 991	-15,30 %				-14,87 %
Scenario 2	(s, Q) Themselves	Increase	12 156	14 235	17,10 %	13 136	14 551	10,77 %	10 585	12 167	14,95 %							19 100	22 399	17,27 %	9 494	10 465	10,23 %	14,06 %
Scenario 2	(s, Q) Themselves	Decrease	12 156	9 985	-17,86 %	13 136	11 717	-10,80 %	10 585	9 022	-14,77 %							19 100	15 935	-16,57 %	9 494	8 590	-9,52 %	-13,90 %
Scenario 3	(s, Q) Themselves	Increase	12 106	14 215	17,42 %	13 117	14 522	10,71 %	10 574	12 203	15,41 %	10 650	11 275	5,87 %				16 455	18 974	15,31 %	9 555	10 483	9,71 %	12,40 %
Scenario 3	(s, Q) Themselves	Decrease	12 106	10 043	-17,04 %	13 117	11 799	-10,05 %	10 574	8 967	-15,20 %	10 650	9 927	-6,79 %				16 455	14 012	-14,85 %	9 555	8 567	-10,34 %	-12,38 %
Scenario 4	(s, Q) Themselves	Increase										10 642	11 371	6,85 %	64 555	75 226	16,53 %	16 441	18 870	14,77 %				12,72 %
Scenario 4	(s, Q) Themselves	Decrease										10 642	9 921	-6,78 %	64 555	53 740	-16,75 %	16 441	14 064	-14,46 %				-12,66 %

Scenario	Order policy and distribution	Increase or decrease	Total deliveries made			Orders over 18 hours			Hold for inventory						Average order time			
									Time in queue			Number in queue						
			Old	New	Diff	Old	New	Diff	Old	New	Diff	Old	New	Diff	Old	New	Diff	Minutes
Scenario 2	(s, Q) PostNord	Increase	543,33	544	0,67	30,53	0	-30,53	4,84	0,00	-4,84	0,81	0,03	-0,78	2,0224	2,0178	-0,0046	-0,2760
Scenario 2	(s, Q) PostNord	Decrease	543,33	543	-0,33	30,53	725	694,47	4,84	9,74	4,90	0,81	14,72	13,91	2,0224	2,1038	0,0814	4,8840
Scenario 3	(s, Q) PostNord	Increase	543,4	543	-0,4	4,13	1	-3,13	6,37	2,47	-3,90	1,03	0,02	-1,01	1,8641	1,8581	-0,0060	-0,3600
Scenario 3	(s, Q) PostNord	Decrease	543,4	543	-0,4	4,13	681	676,87	6,37	9,02	2,65	1,03	14,19	13,16	1,8641	1,9420	0,0779	4,6740
Scenario 4	(s, Q) PostNord	Increase	543,13	543	-0,13	0	0	0	0,00	0,00	0,00	0,00	0,00	0,00	4,4094	4,4104	0,0010	0,0600
Scenario 4	(s, Q) PostNord	Decrease	543,13	542	-1,13	0	0	0	0,00	0,00	0,00	0,00	0,00	0,00	4,4094	4,4100	0,0006	0,0360
Scenario 2	(s, Q) Themselves	Increase	543,4	544	0,6	13,67	1	-12,67	3,85	0,00	-3,85	0,36	0,02	-0,34	2,1671	2,1654	-0,0017	-0,1020
Scenario 2	(s, Q) Themselves	Decrease	543,4	543	-0,4	13,67	211	197,33	3,85	4,76	0,91	0,36	5,61	5,25	2,1671	2,1939	0,0268	1,6080
Scenario 3	(s, Q) Themselves	Increase	543,2	543	-0,2	8,6	0	-8,6	2,81	0,00	-2,81	0,26	0,00	-0,26	2,0068	2,0050	-0,0018	-0,1080
Scenario 3	(s, Q) Themselves	Decrease	543,2	543	-0,2	8,6	173	164,4	2,81	4,73	1,92	0,26	5,00	4,74	2,0068	2,0030	-0,0038	-0,2280
Scenario 4	(s, Q) Themselves	Increase	542,87	543	0,13	0	0	0	0,00	0,00	0,00	0,00	0,00	0,00	4,4101	4,4095	-0,0006	-0,0360
Scenario 4	(s, Q) Themselves	Decrease	542,87	542	-0,87	0	0	0	0,00	0,00	0,00	0,00	0,00	0,00	4,4101	4,4109	0,0008	0,0480

Table G4: Results from the sensitivity analysis when changing the reorder point. Numbers marked in green and red are discussed in section 7.2.4.

Situation 5, order quantity

Situation 5: Increase or decrease the order quantity																							
			Stock out probabilities																				
Scenario	Order policy and distribution	Increase or decrease	Flekkefjord			Fredrikstad			Forde			Hammerfest			Oslo			Tromsø			Trondheim		
			Old	New	Diff	Old	New	Diff	Old	New	Diff	Old	New	Diff	Old	New	Diff	Old	New	Diff	Old	New	Diff
Scenario 2	(s, Q) PostNord	Increase	0,37 %	0,61 %	0,24 %				0,47 %	0,36 %	-0,11 %				0,50 %	0,38 %	-0,12 %	0,13 %	0,13 %	0,00 %	0,54 %	0,32 %	-0,22 %
Scenario 2	(s, Q) PostNord	Decrease	0,37 %	0,64 %	0,27 %				0,47 %	0,56 %	0,09 %				0,50 %	0,62 %	0,12 %	0,13 %	0,13 %	0,00 %	0,54 %	0,32 %	-0,22 %
Scenario 3	(s, Q) PostNord	Increase	0,58 %	0,57 %	-0,01 %				0,64 %	0,45 %	-0,19 %	0,14 %	0,14 %	0,00 %	0,52 %	0,52 %	0,00 %	0,13 %	0,13 %	0,00 %	0,41 %	0,42 %	0,01 %
Scenario 3	(s, Q) PostNord	Decrease	0,58 %	0,53 %	-0,05 %				0,64 %	0,69 %	0,05 %	0,14 %	0,14 %	0,00 %	0,52 %	0,52 %	0,00 %	0,13 %	0,13 %	0,00 %	0,41 %	0,38 %	-0,03 %
Scenario 4	(s, Q) PostNord	Increase										0,14 %	0,14 %	0,00 %	0,13 %	0,12 %	-0,01 %	0,14 %	0,13 %	-0,01 %			
Scenario 4	(s, Q) PostNord	Decrease										0,14 %	0,14 %	0,00 %	0,13 %	0,13 %	0,00 %	0,14 %	0,13 %	-0,01 %			
Scenario 2	(s, Q) Themselves	Increase	0,29 %	0,24 %	-0,05 %	0,14 %	0,14 %	0,00 %	0,29 %	0,32 %	0,05 %							0,13 %	0,13 %	0,00 %	0,29 %	0,29 %	0,00 %
Scenario 2	(s, Q) Themselves	Decrease	0,29 %	0,26 %	-0,03 %	0,14 %	0,14 %	0,00 %	0,29 %	0,23 %	0,04 %							0,13 %	0,13 %	0,00 %	0,29 %	0,33 %	0,04 %
Scenario 3	(s, Q) Themselves	Increase	0,27 %	0,32 %	0,05 %	0,14 %	0,14 %	0,00 %	0,29 %	0,34 %	-0,29 %	0,14 %	0,14 %	0,00 %				0,14 %	0,13 %	-0,01 %	0,28 %	0,32 %	0,04 %
Scenario 3	(s, Q) Themselves	Decrease	0,27 %	0,34 %	0,07 %	0,14 %	0,13 %	-0,01 %	0,29 %	0,33 %	-0,29 %	0,14 %	0,14 %	0,00 %				0,14 %	0,13 %	-0,01 %	0,28 %	0,36 %	0,08 %
Scenario 4	(s, Q) Themselves	Increase										0,13 %	0,14 %	0,01 %	0,13 %	0,13 %	0,00 %	0,13 %	0,13 %	0,00 %			
Scenario 4	(s, Q) Themselves	Decrease										0,13 %	0,14 %	0,01 %	0,13 %	0,13 %	0,00 %	0,13 %	0,13 %	0,00 %			

Average Inventory																								
Scenario	Order policy and distribution	Increase or decrease	Flekkefjord			Fredrikstad			Forde			Hammerfest			Oslo			Tromsø			Trondheim			Average change
			Old	New	Change	Old	New	Change	Old	New	Change	Old	New	Change	Old	New	Change	Old	New	Change	Old	New	Change	
Scenario 2	(s, Q) PostNord	Increase	10 772	11 976	11,18 %				10 135	11 433	12,81 %				10 711	11 932	11,40 %	20 830	22 023	5,73 %	9 307	10 457	12,36 %	10,69 %
Scenario 2	(s, Q) PostNord	Decrease	10 772	9 631	-10,59 %				10 135	8 984	-11,36 %				10 711	9 591	-10,46 %	20 830	19 690	-5,47 %	9 307	8 184	-12,07 %	-9,99 %
Scenario 3	(s, Q) PostNord	Increase	10 769	12 026	11,67 %				10 149	11 421	12,53 %	11 032	12 252	11,06 %	10 795	11 902	10,25 %	17 891	18 961	5,98 %	9 327	10 456	12,10 %	10,60 %
Scenario 3	(s, Q) PostNord	Decrease	10 769	9 634	-10,54 %				10 149	9 013	-11,19 %	11 032	9 793	-11,23 %	10 795	9 605	-11,02 %	17 891	16 632	-7,04 %	9 327	8 162	-12,49 %	-10,59 %
Scenario 4	(s, Q) PostNord	Increase										11 015	12 255	11,26 %	54 338	55 582	2,29 %	17 699	18 995	7,32 %				6,96 %
Scenario 4	(s, Q) PostNord	Decrease										11 015	9 789	-11,13 %	54 338	53 129	-2,22 %	17 699	16 596	-6,23 %				-6,53 %
Scenario 2	(s, Q) Themselves	Increase	12 156	13 345	9,78 %	13 136	14 390	9,55 %	10 585	11 801	11,49 %							19 100	20 277	6,16 %	9 494	10 626	11,92 %	9,78 %
Scenario 2	(s, Q) Themselves	Decrease	12 156	10 934	-10,05 %	13 136	11 977	-8,82 %	10 585	9 415	-11,05 %							19 100	17 944	-6,05 %	9 494	8 392	-11,61 %	-9,52 %
Scenario 3	(s, Q) Themselves	Increase	12 106	13 299	9,85 %	13 117	14 368	9,54 %	10 574	11 767	11,28 %	10 650	11 874	11,49 %				16 455	17 664	7,35 %	9 555	10 732	12,32 %	10,31 %
Scenario 3	(s, Q) Themselves	Decrease	12 106	10 862	-10,28 %	13 117	11 923	-9,10 %	10 574	9 401	-11,09 %	10 650	9 427	-11,48 %				16 455	15 252	-7,31 %	9 555	9 300	-2,67 %	-8,66 %
Scenario 4	(s, Q) Themselves	Increase										10 642	11 910	11,92 %	64 555	65 712	1,79 %	16 441	17 721	7,79 %				7,16 %
Scenario 4	(s, Q) Themselves	Decrease										10 642	9 453	-11,17 %	64 555	63 317	-1,92 %	16 441	15 251	-7,24 %				-6,78 %

Scenario	Order policy and distribution	Increase or decrease	Total deliveries made			Orders over 18 hours			Hold for inventory						Average order time			
									Time in queue			Number in queue						
			Old	New	Diff	Old	New	Diff	Old	New	Diff	Old	New	Diff	Old	New	Diff	Minutes
Scenario 2	(s, Q) PostNord	Increase	543,33	472	**-71,33**	30,53	37	**6,47**	4,84	5,73	**0,89**	0,81	0,87	**0,06**	2,0224	2,0232	0,0008	0,0480
Scenario 2	(s, Q) PostNord	Decrease	543,33	638	**94,67**	30,53	40	**9,47**	4,84	6,32	**1,48**	0,81	1,11	**0,30**	2,0224	2,0243	0,0019	0,1140
Scenario 3	(s, Q) PostNord	Increase	543,4	472	**-71,4**	4,13	35	**30,87**	6,37	7,10	**0,73**	1,03	0,99	**-0,04**	1,8641	1,8641	0	0,0000
Scenario 3	(s, Q) PostNord	Decrease	543,4	638	**94,6**	4,13	49	**44,87**	6,37	6,17	**-0,20**	1,03	1,14	**0,11**	1,8641	1,865	0,0009	0,0540
Scenario 4	(s, Q) PostNord	Increase	543,13	472	**-71,13**	0	0	0	0,00	0,00	0,00	0,00	0,00	0,00	4,4094	4,4096	0,0002	0,0120
Scenario 4	(s, Q) PostNord	Decrease	543,13	638	**94,87**	0	0	0	0,00	0,00	0,00	0,00	0,00	0,00	4,4094	4,4098	0,0004	0,0240
Scenario 2	(s, Q) Themselves	Increase	543,4	472	**-71,4**	13,67	8	**-5,67**	3,85	4,21	**0,36**	0,36	0,24	**-0,12**	2,1671	2,1661	-0,001	-0,0600
Scenario 2	(s, Q) Themselves	Decrease	543,4	638	**94,6**	13,67	7	**-6,67**	3,85	3,00	**-0,85**	0,36	0,27	**-0,09**	2,1671	2,1661	-0,001	-0,0600
Scenario 3	(s, Q) Themselves	Increase	543,2	472	**-71,2**	8,6	19	**10,4**	2,81	5,24	**2,43**	0,26	0,38	**0,12**	2,0068	2,0075	0,0007	0,0420
Scenario 3	(s, Q) Themselves	Decrease	543,2	638	**94,8**	8,6	16	**7,4**	2,81	3,78	**0,97**	0,26	0,44	**0,18**	2,0068	2,007	0,0002	0,0120
Scenario 4	(s, Q) Themselves	Increase	542,87	472	**-70,87**	0	0	0	0,00	0,00	0,00	0,00	0,00	0,00	4,4101	4,4103	0,0002	0,0120
Scenario 4	(s, Q) Themselves	Decrease	542,87	638	**95,13**	0	0	0	0,00	0,00	0,00	0,00	0,00	0,00	4,4101	4,4093	-0,0008	-0,0480

Table G5: Results from the sensitivity analysis when changing the order quantity. Numbers marked in green and red are discussed in section 7.2.4.