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Centralization of inventory management for spare parts

- *A case study on its performance compared to the current inventory control system at Arriva DK*

Master's thesis project

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Preface

This master's thesis is the final part of the Master of Science programs Mechanical Engineering, and Industrial Engineering and Management at Lund University, Faculty of Engineering. The thesis corresponds to 30 ECT points and was conducted during the summer and fall of 2013 on initiatives from Arriva DK.

We would like to thank our supervisor Sven Axsäter at Lund University and Stefan Vidgren, Arriva DK for making this thesis possible.

We would like to thank Sven Axsäter for his help with our thesis. We would also like to thank Stefan for all his support and feedback he has given us during the thesis. We would also like to thank Lars Bonke at Arriva DK for his support and help during our study visit. Finally, we would like to thank everyone we met during our visits to Arriva.

Lund, January 2014

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Abstract

Title

Centralization of inventory management for spare parts - A case study on its performance compared to the current inventory control system at Arriva DK

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Background

Arriva DK currently has a decentralized organization where each depot is responsible for the inventory control of their spare parts. This type of organization often presents challenges when it comes to control and management. Arriva DK suffers from high order costs due to lack of coordination between the depots and the suppliers. To address these issues Arriva wants to introduce a central warehouse.

Purpose

The aim of the thesis is to optimize inventory management by creating simulation models that from a cost perspective explore the effects of introducing a central warehouse for spare parts.

To provide Arriva DK with simulation models of the supply chain and inventory management, both with – and without a central warehouse.

Method

The thesis is built on Hillier and Lieberman's Operations research method. Data used in the thesis consist of both primary and secondary quantitative and qualitative data. Literature studies have also been done and are the basis for the theory. Two simulation models were built. The first model represents an optimized decentralized situation that uses joint replenishment. The second model represents a system with a central warehouse, which also uses joint replenishment. Thereafter the models were compared to determine if an investment in a centralized system is profitable.

Conclusions

The results from the simulation study showed that the total cost for the CW-model is higher than the DC-model in all scenarios. Both the holding- and order cost will be higher with a central warehouse.

The major advantage of using a central warehouse is that the number of orders to the suppliers will be reduced by more than 50%. This along with the suppliers only have to deliver to one location will result in price reductions on the products. Even with small discounts, will a central warehouse be profitable since the procurement cost represents such a large part of the total cost.

Keywords: Central Warehouse, Joint replenishment, Multi-echelon, Simulation

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1. Introduction

In this chapter the background, purpose, delimitations, problem formulation and target group are discussed. This chapter will also provide a brief company description of Arriva Dk. Finally a report outline is discussed.

1.1 Background

Supply Chain Management, the control of the flow of goods, is recognised as a central activity in most enterprises. Inventory control is a very important component in a supply chain. Investments in inventories are enormous which means that the inventory levels should be kept at a minimum. High inventory levels, however, avoids shortages and large order costs. Finding a balance between these goals offers an important potential for improvement.

Arriva DK currently has a decentralized organization where each depot is responsible for the inventory control of their spare parts. This type of organization often presents challenges when it comes to control and management. Arriva DK suffers from high order costs due to lack of coordination between the depots and the suppliers. As a first step, Arriva DK has implemented a joint replenishment policy at the depots. This means that when a depot places an order with a supplier; all products from that supplier are ordered at the same time to reduce the order cost.

Arriva DK feels, however, that there are more room for improvement. With a central warehouse, which functions as a bundling and distribution centre between the suppliers and the depots, even more products can be jointly replenished. The depots can then order a group of products, from the central warehouse; independent of which suppliers they originate from.

At the same time, new costs, such as transportation cost, will arise. The possible benefits and drawbacks, of a central warehouse, will be impossible to scale and quantify without further analysis.

This master thesis focuses on the effects of introducing a central warehouse and centralizing the inventory management. Due to the complexity of the system, simulation will be used as the tool for evaluation. The simulation models and the overall insights, of this project, will then serve as an underlying foundation for similar projects.

1.2 Company Description

Arriva is public transport company and is since 2010 owned by Deutsche Bahn (DB). It was founded in Sunderland, United Kingdom in 1938 and has since the start grown to where it is today with bus, train, waterbus, tram and coach operations in over 12 countries in Europe and currently employs around 55,900 people (Arriva, 2013).

Arriva DK has been part of Denmark's public transport since 1997 after buying the Danish bus company Unibus. Today, after acquiring several different bus companies, Arriva is Denmark's largest bus company with a market share of about 50 % and traffics most parts of Denmark with approximately 1300 buses.

The buses are serviced and repaired in different depots across Denmark that also functions as warehouses. A bus only belongs to one depot at a time. All spare parts used are bought from suppliers and delivered to the depots.

1.3 Purpose

The purpose of this project has two parts:

1. The aim of the thesis is to optimize inventory management by creating simulation models that from a cost perspective explore the effects of introducing a central warehouse for spare parts.
2. To provide Arriva DK with simulation models of the supply chain and inventory management, both with – and without a central warehouse.

This project will result in a cost oriented decision support for Arriva DKs management for operating a supply chain with a central warehouse. It will also make it easier to carry out similar projects in other regions or markets thanks to the simulation models created for this project.

1.4 Delimitations

For practical reasons and due to limitations of the simulation software, used in this project, some delimitations have to be made.

Delimitations to the demand:

- The demand for every product is assumed to follow a Poisson process.
- Trends in the demand will not be taken into account.
- The suppliers always deliver complete orders on time.

Delimitations to the simulation models:

- The simulation models can handle a maximum of four depots at the same time.
- Each depot can carry up to ten different products.
- The maximum number of suppliers is eight.
- The suppliers can carry up to five different products each.

1.5 Problem Formulation

This project aims to answer two questions:

1. How will Arriva DKs spare parts inventory system perform with a central warehouse compared to without a central warehouse regarding order -, holding - and transportation costs?
2. Under what conditions will a centralized system outperform a decentralized system, from a cost perspective?

1.6 Target Group

The main target group for this master thesis is Arriva DKs management and operations research team. This project has, however, been carried out in a way that it with minor modifications can be applied on other geographical regions with different conditions. This means that the study is also relevant for other companies that are thinking of introducing a central warehouse and wants to use simulation as a tool for analysis. Finally, this thesis can act as an inspiration to students who are interested in inventory control in combination with simulation.

1.7 Report outline

The report is divided into the following sections.

- **Chapter 1, *Introduction*:** In this chapter the background, purpose, delimitations, problem formulation and target group are discussed. This chapter will also provide a brief company description of Arriva Dk. Finally a report outline is presented.
- **Chapter 2, *Methodology*:** In this chapter the methodology used in the thesis is presented. Initially, the general operations study approach is discussed. Secondly, the approach used in this study is explained and finally, the validity, reliability and objectivity of this study are discussed.
- **Chapter 3, *Theoretical Framework*:** The theoretical framework is presented in this chapter. Initially, a brief introduction to inventory control is presented. Then the ordering policy and the costs connected to the models are discussed. Finally, the theory behind a central warehouse and joint replenishment are presented.
- **Chapter 4, *The Supply Chain Set-Up*:** This chapter aims to give a background to the real world set-up for the flow of spare parts at Arriva DK and describe the two set-ups used in the simulation study.
- **Chapter 5, *Simulation scenarios*:** In this chapter the results from the different simulation scenarios are presented. In order to see if a central warehouse is better than a decentralized model; different scenarios have been created to get different views and outputs.
- **Chapter 6, *Analysis*:** In this chapter the analysis of the costs are presented. A trend analysis is also presented as well as an analysis of the organization.
- **Chapter 7, *Conclusions and discussion*:** In this chapter the conclusions are presented and discussed.

2. Methodology

In this chapter the methodology used in the thesis is presented. Initially, the general operations study approach is discussed. Secondly, the approach used in this study is explained. Finally, the validity, reliability and objectivity of this study are discussed.

2.1 General Operations Research Study

The approach of this thesis belongs to the field of Operations Research. An operations research study is generally divided into six phases, which usually are overlapping (Hillier & Lieberman, 2005):

1. Define the problem and gather data.
2. Formulate a mathematical model to represent the problem.
3. Develop a computer-based procedure for deriving solutions to the problem from the model.
4. Test the model and refine it as needed.
5. Prepare the ongoing application of the model assigned by management.
6. Implement.

2.1.1 Define the Problem and Gather Data

The first step of an operations research study is to study the relevant system and develop a well-defined statement of the problem. Setting objectives, constraints on what can be done as well as time limits. It is important to involve all partners and make them understand what the problem is (Hillier & Lieberman, 2005). After this step, data is gathered to better understand the problem and to obtain the inputs that are required for the simulation models.

There are two methods to choose from when gathering data. The first one is quantitative data, which is data that can be measured numerically. Mathematical models are generally quantitative. The second one is qualitative data, which is data that aims at providing a comprehensive picture of the situation. Interviews are usually useful for qualitative studies.

The collected data can be collected both as primary – and secondary data. Primary data is data that has been collected or created during the projects run. Secondary data is data that already exists and are collected for other purposes than the project.

2.1.2 Represent the Problem by Formulating a Mathematical Model

After the problem is defined, the next phase is to reformulate the problem in a form that is convenient for analysis (Hillier & Lieberman, 2005). A mathematical model is constructed and it is important to start with a simple version and then gradually improve it until it represents the problem.

2.1.3 Deriving Solutions From the Model

The third step is to develop a procedure that is usually computer-based that derives solutions to the problem. It is common to search for an optimal solution by applying a standard algorithm or using software to model the problem. However, these solutions are only optimal with respect to the model being used. Since the model is an idealized version there is no guarantee that the solution is an optimal solution for the real problem. If the model is well formulated and tested, the solution should tend to be a good approximation to the problem (Hillier & Lieberman, 2005).

2.1.4 Testing the Model and Refining it as Needed

This step involves testing the model in order to find bugs. Early versions of a model usually contain many bugs that need to be eliminated. This process is commonly referred to as model validation or verification. Verification of the model should be done continuously and not after the entire model is finished. It is important to note that a verified model does not necessarily describe the system accurately. It only means that the model is free from bugs and behaves in the way it should (Hillier & Lieberman, 2005).

2.1.5 Preparing to Apply the Model

The fifth step is to install a well-documented system to prepare for implementing the model as prescribed by management. The system includes the model, solution procedure and operating procedures for implementation (Hillier & Lieberman, 2005).

2.1.6 Implementation

The final step is to implement the solution in the system. For best result it is important that the team that worked with the model is involved with the implementation, since they know the model best. The success of the implementation also depends on the support of top management and operating management (Hillier & Lieberman, 2005).

2.2 The Approach of This Thesis

Hillier and Lieberman's approach for operations research, described above, is relatively broad and intended to be used to any operations research study. This thesis will not cover step 5 "*Prepare the ongoing application of the model assigned by management*" and step 6 "*Implement*" since they fall outside the scope of the thesis. This general method will be used as a framework, and modified to fit this thesis.

2.2.1 Define the Problem and Gather Data.

The problem given to the authors was to evaluate the effects of centralizing the inventory management for spare parts by introducing a central warehouse. After discussions with Arriva DK, it was decided to create two models. The first model represents an optimized decentralized situation that uses joint replenishment. The second model represents a system with a central warehouse, which also uses joint replenishment. Thereafter the models will be compared to determine if an investment in a centralized system is profitable.

Interviews at the initial phase of the thesis were held with stock managers at two different warehouses. The interviews with the managers helped to understand the current situation and what the impact of introducing a central warehouse would be. Study visits to the warehouses were also made to get an overall view of the order processing and the inventory management. Furthermore an interview was also made with a supplier to better understand their situation and what problems they have today with the current setup.

After the problem formulation was done the objectives of the study could be set. It was important to get a structure of what was needed and expected from the authors. After discussions with Arriva DK all objectives were set and a project plan with a timeline was made which describes how the work would be conducted.

Data Collection

Data used in the thesis consist of both primary and secondary quantitative and qualitative data. The data gathered from Arriva DK's ERP-system such as product prices, the total product demand in a year are considered secondary data since it was not created for this project.

Visits to Arriva DK's warehouses were done in order to interview the stakeholders and collect raw data. Questions were prepared before the

interviews. The costs connected to when an order is made such as handling cost and billing cost were obtained from interviews with Arriva DK's supply chain manager. This is considered primary data since it was created for this project.

Literature studies have also been done and are the basis for the theory presented in chapter 3. The articles used are from established and respected sources. The books used are from respected authors, which extensive knowledge in the subjects covered. The data obtained is considered secondary since it has been processed and used for other purposes than this thesis.

2.2.2 Analysing Data and Finding a Way to Describe a Product's Demand

Arriva DK carries a vast amount of items and an evaluation of all items through simulation would be impossible. Therefore it was necessary to select a sample of products from different suppliers to represent the inventory system. It was decided that products from eight suppliers were sufficient. The products were selected through ABC analysis, which is a technique to categorize inventory after importance.

An issue we encountered was to describe a product's demand satisfactory. The only data we could obtain was a product's total demand in a year. Therefore we have assumed that the customers arrive according to a Poisson process. This is a common assumption in stochastic inventory models (Axsäter, 2006). A Poisson process occurs when arrivals happen one at a time with given intensity λ , are completely at random and independent of one another. The number of customers in a time interval of length t has a Poisson distribution and the probability for k customer, according to Axsäter (2006).

$$P(k) = \frac{(\lambda t)^k}{k!} e^{-\lambda t}, \quad k = 0, 1, 2, \dots$$

The average and the variance of the number of customers are equal to λt . To obtain λ for our models we divide the total product demand for a year by the days of the year.

2.2.3 Formulate a Mathematical Model to Represent the Problem.

This project focuses on the economic gains of introducing a central warehouse. Hence, it is outside the scope of this thesis to derive a new mathematical model. Instead we performed a literature review in order to

find a model that corresponds with our requirements. It needs to use a (s, S)-policy with joint replenishment.

For the first part of the literature review we focused on the subject of inventory control and especially multi-echelon inventory control. The majority of the theoretical chapter is based on this. During the second part of the literature review we focused on finding mathematical models that describes the two systems. Recently published Master's theses as well as scientific papers were reviewed.

We were unable to find any published models that met all the requirements. However our supervisor at Arriva DK has a working paper that focuses on a single echelon inventory system that uses a (s, S)-policy with joint replenishment that we could use to describe our decentralized system.

2.2.4 Develop a Computer-based Procedure for Deriving Solutions to the Problem

We used ExtendSim v8 to build the simulation models. ExtendSim is powerful modelling software that can manage large systems. For more information about ExtendSim please visit www.extendsim.com or email info@extendsim.com. Discrete event was used as modelling technology. Discrete Event is where the system changes state only when an event occurs (ExtendSim, 2010). Passing of time has no direct effect on the model. The advantage of using discrete event simulation is that the simulation time is reduced.

We started by making simple flowcharts of the two systems. Then we started with building the decentralised model, which represents how it works today. After we finished the decentralized model and verified it we started with the centralized model. A large part of the project has been spent on building the models. See chapter 4 for more information about the models.

Optimization

Extendsim's built in optimizing feature will be used in all scenarios. The optimization works as goal seeking where the problem is stated as a cost function that ExtendSim tries to minimize. ExtendSim optimizer uses an initial population of solutions. Each solution is explored by running the model several times with different values for the selected variables and averaging the samples and sorting the solutions. The best solution is then used to derive slightly different but possibly better solutions until the Optimizer determines that there are probably no better solutions in sight.

The selected variables in this case are the reorder points (s) and the maximum inventory position (S) for each product and warehouse (ExtendSim, 2010).

One requirement for obtaining a performance measure is that the system reaches a steady state. A system in steady state is when the system performance is independent of the starting conditions (Howard, 2007). This can be described as the system is performing as usual. Because we have stochastic input data the output data is also stochastic. The mean is then also a stochastic variable and if the simulation was run for an infinite time then that stochastic variable would converge to its true value by the law of larger numbers.

However, this is not possible so the mean is taken when a steady state has been reached. An example of steady state can be seen if figure 1, where the blue line is the mean inventory level and the red line is the inventory level. A steady state is reached when the blue line has levelled out. The decentralized model was run for 100,000 days and the centralized model was run for 10,000 days. The reason the centralized model was run a shorter time is that it is a more advanced model which takes a longer time to simulate. The optimization would take too long to finish.

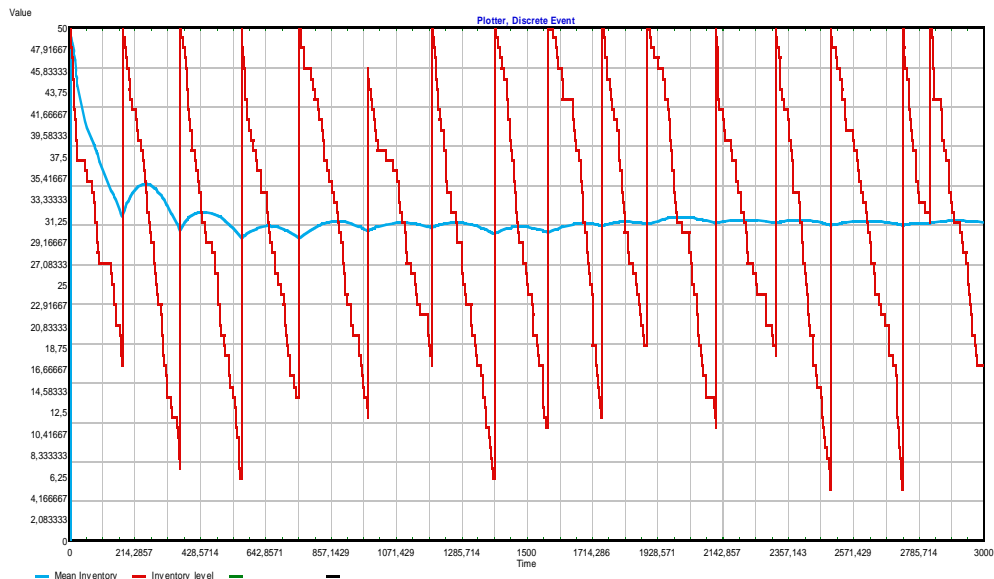


Figure 1. Steady-state for a product.

A major downside with optimization is that the model has to run many times which can take a long time and that the algorithm has an inability to tell when the best solution has been found. It is therefore important to run the optimization several times to make sure that the answers are the same so that one answer is not false or suboptimal.

2.2.5 Test and Refine the Model

Verification of the model should be done continuously and not after the entire model is finished according to Banks (1998). During the building of the models discussions with the stakeholders have continuously taken place when each step of the models has been verified. All requirements have also been discussed thoroughly.

To verify the simulation model Extendsim's plotter was used to give a graphical representation on how the inventory levels changed over time. The plotter was also used to see if the joint replenishment was correctly modelled. This can be seen in figure 2. The graph displays the order queue for five products. When an order is made, all products queue should be emptied, which is also does. With this tool it was very easy to spot any errors and irregularities in the models.

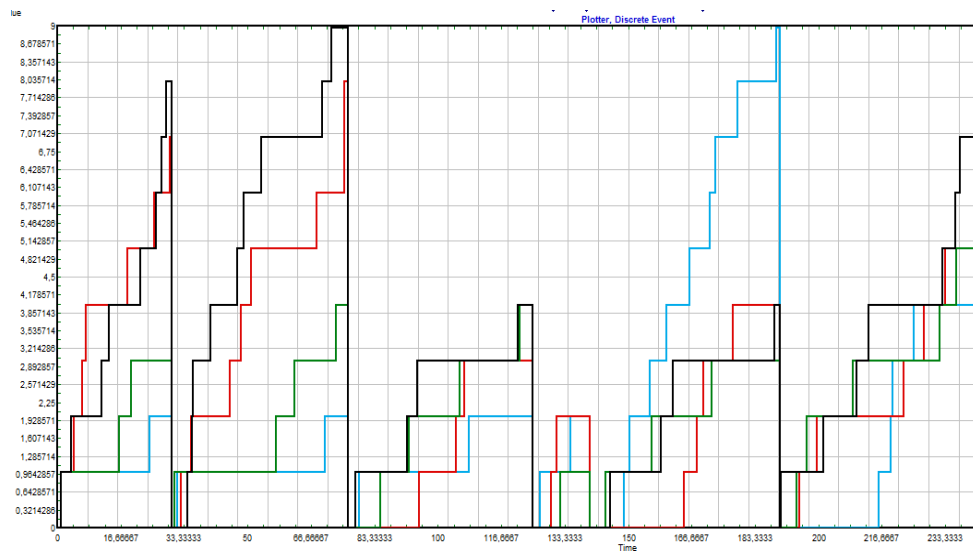


Figure 2. Order queue.

Input Parameters

For the simulation model to run correctly several input parameters are necessary. The simulation model is linked to an Excel sheet where all parameters are entered, and then imported to the model at the start of the

simulation. See *Appendix A and B* to see how the Excel sheet is constructed. The parameters are described below.

- A product's demand over a year.
- Transportation time between the depots and the central warehouse as well as the lead time between the suppliers and the central warehouse.
- Wage cost of driver per hour as well as fuel cost per km for the transport between depots and central warehouse.
- Holding cost for all installations.
- Order cost when a depot orders units as well as when the central warehouse orders units from a supplier.
- Start position for the inventory level, here set to S , and the reorder point s .

During optimization, the starting position S and the reorder point s are changed for each simulation. All other parameters are held constant during optimization.

Output Parameters

In order to compare the models with each other, the following results are needed.

- **The mean total cost per day for the system:** The sum of holding, transportation and order costs.
- **The number of orders per day:**
 - The number of times a depot has placed an order to the central warehouse or to the supplier for the decentralized model.
 - The number of times the central warehouse places an order to the supplier.
- **The number of transports per day:** The number of transports between a depot and the central warehouse.
- **Service levels:** Service levels for all products in a depot.

After a simulation all results are exported to an Excel sheet which can be seen in *Appendix C and D*.

2.3 Credibility of This Master Thesis

When simulation models are used to evaluate a system it is important that the results and conclusions are correct. A high level of credibility is obtained when the following aspects are met: *validity, reliability and objectivity* (Björklund & Paulsson, 2003).

2.3.1 Validity

Validation is done to determine if the model is an accurate description of the real system (Banks, et al., 1998). Björklund and Paulsson (2003) define validity as “to what extent something really measures what it intends to measure”. It has to be done once the model has been created and before any tests can be completed. There are four general angles when validating a simulation model. Those are: *performing self-validation, a third party performing the validation, validation is performed by the model user and validation is performed using a scoring model* (Sargent, 2004).

Most validations are done by the developers themselves. However, the credibility will suffer because the developer’s objectivity is uncertain. To increase the objectivity it is important to let the users perform the validation (Sargent, 2004).

Another way to validate a model is to do a retrospective test. This is done by using historical data as input data and then to compare the results from the simulation model with the results from reality. This reveals if the model give better results than reality. The draw back with retrospective testing is that a correct result does not mean that the model provides good results in the future.

Validity of the Simulation Model

The validations of the models were done by its developers and its users. For this thesis a face validation test was done which involved showing the models to the users to make sure the behaviour of the models reflects the reality. All assumptions made in the models were also discussed in detail with them. Since there is not sufficient historical data a retrospective test could not be done.

We could compare the decentralized model with a similar model made by Arriva DK’s Operations Research Manager. The scenario simulated was with four products with different demand from the same supplier. The inventory system was controlled by a periodic review system policy with

joint replenishment. On Monday, Wednesday and Friday the inventory position are checked and an order is placed when a products inventory position declines to or falls below the reorder point. The lead time was set to one day and if an order was made on a Friday the units would arrive on the next Monday. The parameters that were checked were the average inventory levels, number of orders per day and all products' service levels. The simulation time was set to 100000 days in order for the model to reach a steady state. The results of the simulations were almost identical and difference was less than a per cent.

For the centralized model, we could also use Arriva DK's model to validate it. The centralized model is an extension of the decentralized model and it was possible to create a scenario where the two models behave in the same way. To make it work we had to adjust the central warehouse so that it works as a supplier. The central warehouse's stock levels were changed to very high levels so that no stock outs could occur. This is because we have assumed that the supplier can always deliver. The transportation time between a depot and the central warehouse was set to 1 day. Besides these changes, all settings and parameters were the same. The results of the simulations were again almost identical and the difference was less than a per cent.

2.3.2 Reliability

Reliability describes how consistent a measure is (Björklund & Paulsson, 2003). A study has a high reliability if it can be performed multiple times with the same results. To obtain a high reliability, one has to ensure that the measurements do not contain any random errors and are as accurate as possible when gathering information.

Reliability in this Master's Thesis

To achieve a high reliability in this master's thesis all measurements during the simulations were taken in a steady state. As the input parameters used in the simulations are based on historical data, it is likely that the input data will change if a similar study is carried out in the future. Since the results are based on a variety of lead times, suppliers and demand patterns it is not likely that a change in them will affect the results significantly. Therefore the reliability in this study is regarded as high.

2.3.3 Objectivity

A study's objectivity is defined as the extent to which the authors' values influence the results. To increase a study's objectivity it is important to clearly explain and motive choices made by the authors so that the reader

can form his own opinions. Objectivity is also further increased if sources are properly reproduced and avoiding distorting facts (Björklund & Paulsson, 2003).

Objectivity in this Master's Thesis

We have kept our values and opinions aside throughout the project. All choices that we made have been explained thoroughly and based on facts to increase the objectivity. Furthermore, sources and references have been specified to support the objectivity. All assumptions made in the simulation models have been discussed with our supervisors to ensure a high objectivity. Since the data used in the simulations come from Arriva DK's ERP-system the objectivity will not be an issue.

3. Theoretical Framework

The theoretical framework is presented in this chapter. Initially, a brief introduction to inventory control is presented. Then the ordering policy and the costs connected to the models are discussed. Finally, the theory behind a central warehouse and joint replenishment are discussed.

3.1 A Brief Introduction to Inventory Control

The flow of material and the costs it generate within an organization often holds great potential for improvement. Regularly, the objective of inventory control is to balance conflicting goals. To keep stock levels down but at the same time meet service level requirements.

This chapter aims to give background to existing inventory control theories and - concepts.

3.1.1 Basic Concepts

- **Lead-time**
 - The time from the ordering decision until the ordered amount is available on shelf.
- **Stock on hand**
 - The number of physical items available in the inventory facility.
- **Backorder**
 - A record of a customer order that could not be immediately fulfilled and is waiting to be delivered.
- **Inventory position/- level**
 - $\text{Inventory position} = \text{stock on hand} + \text{outstanding orders} - \text{backorders}$
 - $\text{Inventory level} = \text{stock on hand} - \text{backorders}$
- **Continuous - and Periodic review**
 - At continuous review the inventory position is monitored continuously. An order is triggered at the same time the inventory position reaches its reorder point.
 - With periodic review the inventory position is only considered at certain given points in time. For example, once a day.

3.2 Ordering Policy

3.2.1 (s,S policy)

The ordering policy used by *Arriva DK* is the policy denoted (s,S). Where s is the reorder point and S is the maximum inventory level. When the inventory position reaches s or below, an order is triggered up to position S . In case of continuous review and continuous demand, the inventory position can never decline under s . Because the reorder point, s , will always be hit exactly and at the same time the order will trigger. Also the order quantity will always be $S-s$ units.

If the demand is not continuous and/or the review is periodic, the order quantity will vary. Under these conditions the inventory level and – position can, in theory, be anything between negative infinity and s when an order triggers.

A negative inventory level implies backorders. There are always costs connected to backorders, but they can be hard to quantify. Therefore, it is common to implement service constraints instead when determining the s and S parameters. This is an optimization problem where one wants to minimize the costs, and at the same time uphold a certain pre-determined service level.

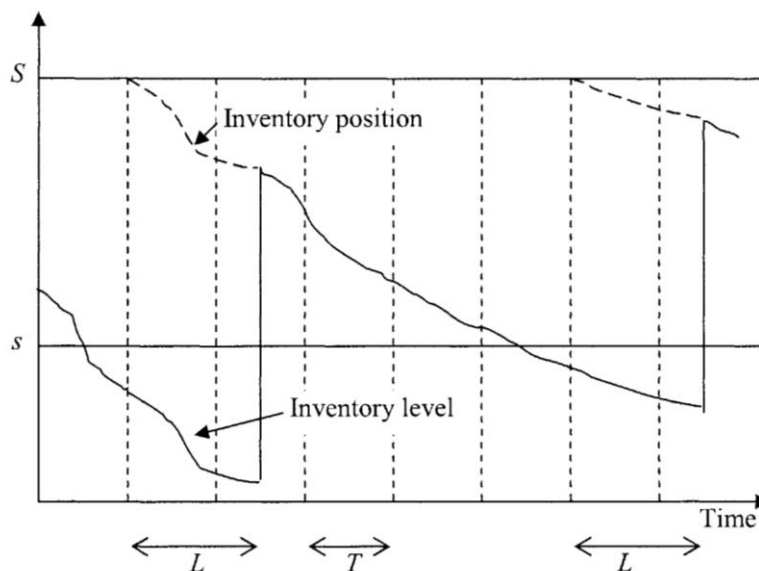


Figure 3. (s,S) policy with periodic review. Continuous demand (Axsäter, 2006).

3.3 Costs Connected to the Optimization Problem

3.3.1 Holding Costs

The dominating part of the holding cost is the cost for keeping capital tied up in inventory. The opportunity cost for this capital is usually a percentage of the total value of the inventory. The percentage is often derived from what return an alternative investment yields. Although there are other parameters such as financial risk to take into consideration. This makes the opportunity cost more complex to determine than setting it equal to the expected return of the alternative investment.

Other parts of the holding cost are for example: material handling, storage rent, insurance, damage and obsolescence. These costs should be allocated to different product types depending on their characteristics. Some product types take up more volume than others and should therefore carry a bigger part of the rent. Unless the rent is fixed which implies it is independent of the total volume.

3.3.2 Ordering Costs

When ordering from an outside supplier there are several costs connected with replenishment. The costs can either be fixed or variable. Fixed costs are independent of the number of units and – product types in an order. This can for example be costs for order forms and handling of invoices from the supplier.

The variable cost varies with the characteristics of an order. Often are these costs connected to the number of man-hours required for handling - and register the ordered material.

3.3.3 Backorder Costs

A backorder costs occurs when a demand cannot be met due to a shortage. There are two scenarios regarding a backorder.

1. The customer chooses another supplier and the sale is lost. In this case, the cost is the loss of the contribution the sale would have raised.
2. The order is backlogged and delivered at a later point in time. This usually means extra costs for administration, price discounts and transportation.

Both scenarios result in a loss of good will and reputation that may affect future sales.

Backorder costs are difficult to estimate and vary from situation to situation. Therefore, it is common to replace these costs with service constraints. This method is regarded to be simpler in many practical situations even though an adequate service level can be hard to determine. There are different definitions of service level and they may yield different results.

3.3.4 Service Constraints and - Levels

There are three main definitions of obtained service level.

1. Probability of no stock out per order cycle.

This definition can be interpreted as the probability that an order arrives before the stock on hand is finished. It is a very simple method to use, but has its disadvantages. The drawback is that the definition doesn't consider the length of the order cycle. If the order quantity is large, it can cover the demand for a long period of time. Even if the definition yields a low service level, there is plenty of stock on hand most of the time due to the large order quantity. Similarly, with a short order cycle and small order quantities, the actual service level can be very low.

In case the customer only can order one unit at a time, the two other definitions are equivalent:

2. Fill rate – fraction of demand that can be satisfied immediately from stock on hand.
3. Ready rate – fraction of time with positive stock on hand.
Fill rate and ready rate gives a good picture of the actual service. They differ if the customer can order units in batches. Even if the stock on hand is positive, it might not be enough to cover large orders. This can result in a high ready rate but a low fill rate.

Service measures can be defined in many other ways than the three discussed above. How a company chooses to define its service is individual and could have a wide range of underlying factors. Although, when setting the service level it should be based on the expectation of the customers and weighted against the cost of maintaining the level of service.

3.4 Central Warehouse – Bundling and Distribution

A central warehouse can have a variety of purposes. Often, when referred to

in literature, it means replacing many smaller depots with one or a few larger central warehouses. According to Oskarsson et al (2013) the advantages of this strategy can be divided into two parts.

1. Cost reductions

- Lower fixed costs for personnel, inventories and administration due to the reduced number of warehouses.
- Reduced opportunity costs for capital tied up in safety stocks.
- Easier to control and manage the flow of material from a centralized position.

2. Increase in service

- Better precision in lead times due to the ability of keeping stock of a wider range of products than would be viable at a smaller warehouse.
- Faster and more precise delivery information to customers.

A central warehouse can also act more as a wholesaler. The main task is bundling and distribution of products to the existing depots. This strategy aims to decrease the number of communication paths and relations needed within the supply chain, see figure 4 (Oskarsson, et al., 2013). Another important factor is the discounts outside suppliers' offers when ordering large quantities (Arjan & Van Weele, 2010). By coordinating the demand of several depots, the same increase in service can be obtained as listed above.

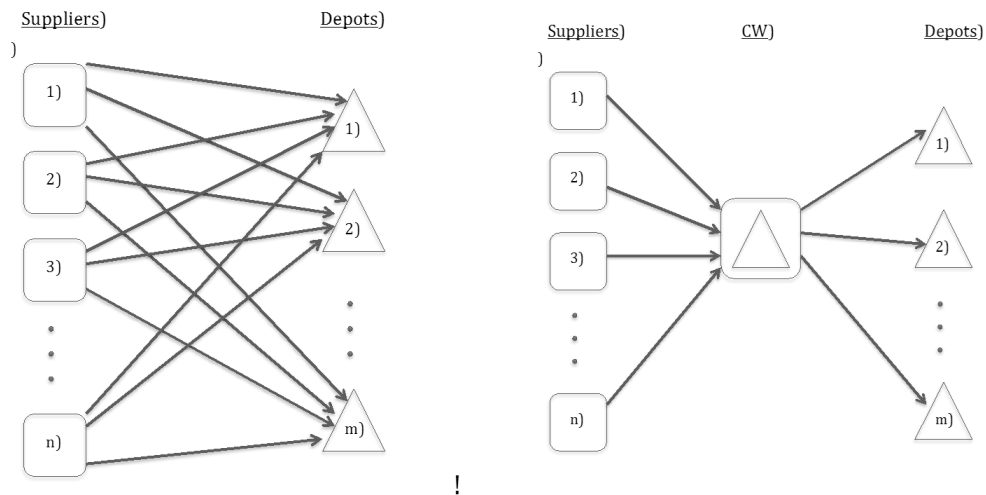


Figure 4. A decentralized system to the left and a centralized system to the right

However, Jonsson & Mattson (2011) argues that the need for bundling and aggregation may decrease. The increase in customer specific products and wide range of product variations makes the possibilities for aggregation scarcer. Also, the development within information technology makes it easier for suppliers to coordinate transports of different products to different recipients. This enables smaller order quantities to be carried out at reasonable transportation costs.

3.5 Coordinated Ordering

As discussed before, large costs are connected to procured material. Therefore it is worthwhile finding strategies to reduce the total cost of the procurement process. It is not uncommon that the indirect costs (e.g. order -, billing -, material handling - and holding costs) exceed the direct costs (e.g. cost price and transportation) (Jonsson & Mattson, 2011).

One strategy, to reduce these costs, is by coordinating the replenishments for different products. It can be advantageous to trigger orders for a group of items at the same time and thereby replenish them jointly. This strategy may enable discounts if the total order value from a certain supplier is higher than it otherwise would have been. It can also reduce the transportation costs because of fewer transports or by filling a truckload (Axsäter, 2006).

The possible gains of applying coordinated ordering depend on the company's specific situation and conditions. However, implementing a joint replenishment policy also raises difficulties, which will be discussed in "The joint replenishment problem".

3.6 The Joint Replenishment Problem (JRP)

The joint replenishment problem (JRP) is well known and there are several different proposed approaches to it in the literature. The problem differs depending on the incentives, of the specific company, for practicing joint replenishment. The components of the problem vary whether the goal is to reduce order costs, - setup costs, - transportation costs or to achieve quantity discounts.

The main problem, however, is that the products that are jointly replenished get intertwined and affect one another's reorder point. The system gets much more dynamic and there are an increase in parameters and restrictions to consider when determining the optimal batch quantities and reorder points.

This means that individually determined reorder points is not optimal to apply with a joint replenishment policy. Normally, individual reorder points are set so that a certain service level is upheld. If all products are ordered when one of the products reaches its reorder point, all other products are ordered too early. This results in a higher than intended service level, and thereby, higher inventory levels and - holding costs. (Axsäter, 2006)

Due to the increase in complexity a joint replenishment policy causes, the optimal solution is often very hard and time consuming to obtain from a deterministic model. Therefore, it is common to use heuristic methods or simulation when finding solutions to the JRP.

3.7 Mathematical Model

To gain a better understanding of the system dynamics it is advisable to describe it mathematically. Stefan Vidgren and Lars Bonke (2013) describe the current supply system at Arriva DK in the working paper *An Exact Model to Evaluate Joint Replenishment at Arrivas Workshops*.

With this mathematical model it is possible to calculate the total cost of a joint replenishment system. With a central warehouse, however, the model would have to expand significantly and consider even more parameters than it already does. It is a very demanding and advanced task to get such a model accurate.

This is the main reason to why simulation is the most suitable tool to evaluate a joint replenishment system of this dignity.

4. The Supply Chain Set-Up

This chapter aims to give a background to the real world set-up for the flow of spare parts at Arriva DK and describe the two set-ups used in the simulation study.

4.1 General Background

4.1.1 The Depots

Arriva DK has a total of 29 depots. The four depots, considered in the project, are all located in the same major city with the longest distance of 41, 2 kilometres between two of them as can be seen in table 1. Each of the depots has a fleet of busses allocated to them that they serve and repair on a daily basis, also on weekends.

Table 1 The distance and time between the depots (Google, 2013)

Depot	1	2	3	4
1	0	9,5	30	7
2	16	0	41,2	19,8
3	23	31	0	23,2 Kilometres
4	10	18	19	0 Minutes

4.1.2 The Suppliers

Most of the suppliers are local and can usually deliver an order the following weekday.

Table 2. Number of suppliers and products for each depot

Depot	# Active Suppliers	# Products
Depot 1	59	1907
Depot 2	54	1252
Depot 3	55	971
Depot 4	43	836
Total	90	3091

As can be seen in the table 2 above, there are a total of 90 unique suppliers that deliver to at least one of the four depots. A bus fleet consists of busses of different makes and models. The configuration of the bus fleet varies

from depot to depot and, with that, the demand for specific spare parts. That is the reason why not all suppliers deliver to all depots.

4.1.3 Demand

Demand is generated individually for every product at every depot and follows a Poisson process which is described in more detail in section 2.2.2.

4.2 Decentralized Set-Up (DC)

The DC set-up is constructed to reflect the flow of materials as of today.

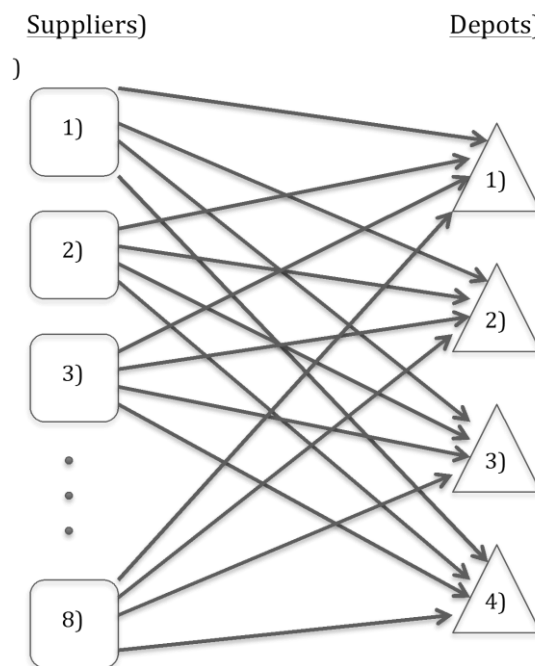


Figure 5. The decentralized system.

4.2.1 DC - The Depots

A total of four depots are considered. The depots operate all days of the week. They all carry stock of spare parts and the replenishment of the inventory is managed separately at each location. Each depot can carry up to 10 different products.

4.2.2 DC - The Suppliers

All suppliers operate during the weekdays (Monday to Friday) and are closed on weekends. A maximum of eight different suppliers can be considered at the same time and each of them can carry up to five different products. They are assumed to have infinite stock of these products.

4.2.3 DC - Ordering Process

The depots' order processes are independent of each other.

The (s,S) ordering policy is utilized for every product at all depots. Every product has its individual reorder point (s) and maximum inventory level (S).

All inventory positions are reviewed once every weekday, and not on weekends since the suppliers are closed.

An order is triggered when a product's inventory position is at – or below its reorder point (s). This means that orders can be placed with suppliers once every weekday, when the review is done. Products with the same supplier are replenished jointly. This means that all products with the same supplier will be ordered when one of them reaches its reorder point.

The order quantities are matched so that each ordered product is at inventory position (S) when the order has been placed.

4.2.4 DC - Lead-Times and Transportation

The suppliers deliver the goods directly to the depots. The transportation cost is embedded in the cost price and are in a way independent of the volume or number of different products in an order.

The suppliers can always deliver a complete order on set lead-time but never on weekends. If an inbound delivery should coincide with a weekend, the goods will not be delivered until the Monday after.

4.2.5 DC - Costs and Constraints

4.2.5.1 Holding Cost

The holding cost is calculated for every product at every depot. The annual holding cost ($H_{i,j}$) for product i at depot j is calculated through:

$$H_{i,j} = r \cdot \bar{I}_{i,j}^+ \cdot CP_i$$

where

$r = \text{the cost of capital on an annual basis}^*$

$\bar{L}_{i,j}^+ = \text{time weighted mean of stock on hand of product } i \text{ at depot } j$

and

$CP_i = \text{the cost price for product } i$

*The cost of capital (r) used by Arriva DK is 7 %.

4.2.5.2 Order cost

The order cost depends on the number of different products in an order and is calculated through:

$$C = \gamma + f + a \cdot b \quad b \in \mathcal{Z}^+$$

where

$C = \text{the order cost}$

$\gamma = \text{the constant cost for an order}^*$

$f = \text{the billing cost for an order}^{**}$

$a = \text{the variable cost for an order}^{***}$

and

$b = \text{the number of different products in the order}$

*The constant cost for an order (γ) is derived from the average pay of personnel at the depots and man-hours spent on an order. This includes administration, receiving, controlling and putting the goods on shelves. The derived constant cost for an order is 110 DKK.

**The billing cost (f) is set to 10 DKK per order, as estimated by Arriva DK.

***The variable cost (a) is the extra cost that occurs for every different product in an order. This cost is estimated by Arriva DK to be 15 DKK.

With the above-mentioned costs, the order cost function can be written:

$$C = 110 + 10 + 15 \cdot b \quad b \in \mathcal{Z}^+$$

4.2.5.3 Backorders

If a demand cannot be met immediately due to stock-out at the depot, the customer will wait and be served when the stock is replenished. A backlogged customer is never lost and there are no extra costs connected to them. Instead, service constraints are used to ensure an adequate level of service.

4.2.5.4 Service Constraints

The ready rate is measured individually for all products at all depots and the service level is set to 99 %.

This means that all products should have positive stock on hand at least 99 % of the time.

4.3 Centralized Set-Up (CW)

The CW set-up introduces a central warehouse to the supply chain.

4.3.1 CW - The Depots

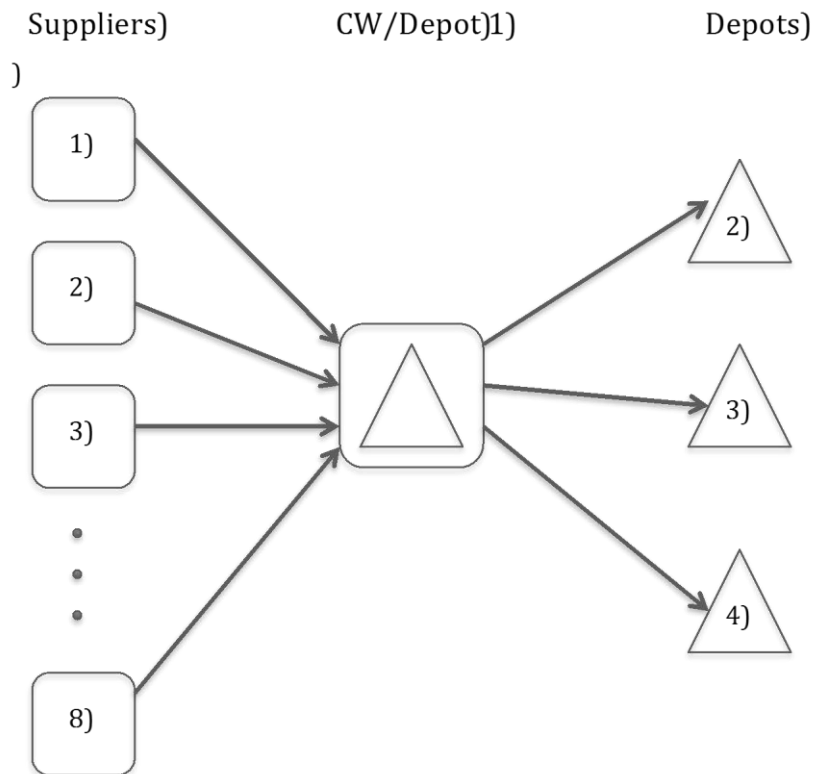


Figure 6. The centralized system.

The set-up for depots 2, 3 and 4 are the same as in the DC set-up, see section 4.2.1.

Depot 1 now also functions as a central warehouse, see section 4.3.3.

4.3.2 CW - The Suppliers

The set-up for the suppliers is the same as in the DC set-up, see section 4.2.2.

4.3.3 CW – Depot 1/The Central Warehouse

Depot 1 functions as a central warehouse while still continuing to serve its own bus fleet. It can generate demand for up to 10 different products but does not carry stock for any of the products. Instead, the demand is satisfied directly and immediately by the central warehouse stock.

The central warehouse operates all days of the week and can keep a maximum of 40 different products in stock.

4.3.4 CW - Ordering Process

Depots 2, 3 and 4 replenish their inventories from the central warehouse while the central warehouse replenishes its inventory from the outside suppliers.

The Central Warehouse

The order process for the central warehouse is exactly the same as for a single depot in the DC set-up.

- (s, S) policy
- Joint (supplier-dependent) replenishment
- No reviews or orders on weekends

See section 4.2.3 for details.

The Depots

Depot 1 does not carry any stock and places therefore never any orders.

Depots 2, 3 and 4 utilizes the (s,S) policy and only order from the central warehouse.

Because the central warehouse operates all days of the week, orders can be placed on all days. This means that reviews of a products inventory position in a depot is made twice every day as well.

The replenishment is not supplier-dependent. When a depot places an order with the central warehouse, all products at that depot will be replenished jointly.

Contrary to the suppliers, the central warehouse does not have infinite stock. This means that a depots' ordered quantity could exceed the available stock. If so, the depots' ordered quantity is changed to match whatever quantity is

available at the central warehouse. This policy makes it impossible for orders to be backlogged at the central warehouse.

4.3.5 CW – Lead-Times and Transportation

From Suppliers to Central Warehouse

The suppliers always deliver a complete order on a set lead-time but never on weekends. If an inbound delivery date should coincide with a Saturday or a Sunday the goods will be delivered on the following Monday.

From Central Warehouse to Depots

There is one van assigned to carry out the transports between the central warehouse and the depots. The van operates all days of the week.

The lead-time depends on the time it takes to drive between the central warehouse and the depot in question. Also, time for picking – and loading of the goods is added to the total lead-time. The time for picking and loading is set to two hours.

4.3.6 CW – Costs and Constraints

4.3.6.1 Holding Cost

The holding cost is calculated individually for every product at the depots and the central warehouse.

The annual holding cost ($H_{i,j}$) is calculated in exactly the same way as for the DC set-up:

$$H_{i,j} = r \cdot \bar{I}_{i,j}^+ \cdot CP_i$$

See section 4.2.5.1 for details.

4.3.6.2 Order Cost

The cost for an order (C) to an outside supplier is calculated exactly as in the DC set-up:

$$C = \gamma + f + a \cdot b \quad b \in \mathcal{Z}^+$$

See section 4.2.5.2 for details.

Arriva DK does not practice internal billing. Hence, the order cost between a depot and the central warehouse will be:

$$C_{cw} = \gamma + a \cdot b \quad b \in \mathcal{Z}^+$$

The actual values of γ , f and a is estimated to be the same for both set-ups:

$$\gamma = 110 \text{ DKK}$$

and

$$a = 15 \text{ DKK}$$

4.3.6.3 Transportation Cost

The cost for a transport (D_j), between the central warehouse and depot j , consists of two parts: hourly pay for the chauffeur (p) and fuel cost per kilometre (g). Every transport is considered to be a round trip.

$$D_j = 2 \cdot (p \cdot \theta_j + g \cdot \Delta_j)$$

where,

$\theta_j =$ time it takes to drive between the CW and depot j (hours)

and,

$\Delta_j =$ distance between the CW and depot j (kilometers)

The actual values of the hourly pay (p) and fuel cost (g) are based on costs for a similar, existing, transport operation within Arriva DK:

$$p = 277 \text{ DKK/h}$$

$$g = 1,22 \text{ DKK/km}$$

The distance and driving time between the central warehouse and the depots were obtained from *Google Maps*TM (Google, 2013).

Table 3. Transportation distance and time.

Depot	2	3	4
θ_j (hours)	0,27	0,38	0,17
Δ_j (km)	9,5	30	7

With these parameter values, the cost per transport for each depot is:

$$D_1 = 0 \text{ DKK}^*$$

$$D_2 = 2 \cdot (277 \cdot 0,27 + 1,22 \cdot 9,5) = 172,76 \text{ DKK}$$

$$D_3 = 2 \cdot (277 \cdot 0,38 + 1,22 \cdot 30) = 283,72 \text{ DKK}$$

$$D_4 = 2 \cdot (277 \cdot 0,17 + 1,22 \cdot 7,0) = 111,26 \text{ DKK}$$

*There is no transportation costs associated with satisfying the demand Depot 1 generates. The central warehouse stock is assumed to be directly available to Depot 1.

4.3.6.4 Backorders

As discussed in section 4.3.4, backorders are not allowed at the central warehouse.

If a demand cannot be met immediately due to stock-out at the depot, the customer will wait and be served when the stock is replenished. A backlogged customer is never lost and there are no extra costs connected to them. Instead, service constraints are used to ensure an adequate level of service.

4.3.6.5 Service Constraints

The ready rate is measured individually for every product at every depot and the service level is set to 99 %.

There are no individual service constraints for the central warehouse since it is only the level of service to external costumers that is of interest in this project.

5. Simulation Scenarios

In this chapter the results from the different simulation scenarios are presented. In order to see if a central warehouse is better than a decentralized model; different scenarios have been created to get different views and outputs.

5.1 Scenario 1

5.1.1 Description

This scenario was constructed to get an overall performance indicator of the two models when optimized.

Eight products from eight different suppliers were selected (one product per supplier). The parameters, such as demand, cost price and lead time, are all based on real historical data extracted from Arriva DK's ERP-system. The lead time from the suppliers is set to one day.

The purpose of this scenario is to gain knowledge of the total costs for the two systems and how the costs are allocated.

5.1.1 Result and Discussion

Table 4 below presents the results from the simulations of the models.

Table 4. Results from the simulations.

Costs/Model	DC	CW
Costs/year		
Mean holding cost	24,96	33,19
Order cost	20,82	21,54
Transportation cost	0	4,62
Total Cost	45,78	59,35
Orders/year		
Number of orders to suppliers	56,28	32,45
Number of orders to the central warehouse	0	18,03
Total	56,28	50,48

The most distinct difference is the holding cost. With joint replenishment and shorter lead times between the CW and the depots, the depot can have

less inventory and keep the same service levels as before. This reduction is, however not enough to compensate for the increased inventory levels at the CW for this scenario. This could have its explanation in that the order cost, together with the transportation cost, between CW and depots is too high to fully exploit the shorter lead times. The central warehouse has to hold large quantities in stock to be able to supply the depots. Stock that otherwise would be at the suppliers.

The total number of orders is lower for the CW but at the same time the order cost is higher compared to DC. That is because more products are ordered at the same time with a CW than without. The cost for ordering eight products is more than twice as high as for ordering one product.

The transportation stands for about 10% of the total cost in the CW model. This is a service otherwise provided by the suppliers. The transportation cost is not entirely fair because in the real world the cost would be distributed on several products. It depends on the number of orders not the number of products.

Table 5 below presents the key figures and key differences.

Table 5. Key figures from the simulations.

Key figures	/year
TC_{DC}	16707,9
TC_{CW}	21660,9
Difference in TC	4952,9
TC_{CW}/TC_{DC}	1,296
Total purchase price of demanded units	638262,6
TC_{CW}/TC_{DC} with total purchase price	1,0076
Discount needed on cost price for the same total cost	0,78%
Difference of orders to suppliers	57,66%

The model with a central warehouse has a total cost of almost 30% more than the decentralized model. In a year, this corresponds to almost 5000 DKK. However, if you factor in the total purchase price of demanded units, the difference is very small. The model with the central warehouse is only 0,76% more expensive.

The number of orders to suppliers with a central warehouse is almost half that without a central warehouse. With a central warehouse, the suppliers

only have to deliver to one place instead of four. The central warehouse will therefore order larger batches but not as often. This is a significant reduction and should motivate a discount on the cost price which has been discussed with the Purchasing Manager. Discounts on the cost price of 0,8 % have to be achieved for the two models to have the same total cost.

From this scenario it is hard to get a definitive answer whether a central warehouse is a better solution than a decentralized model so more scenarios have to be considered.

5.2 Scenario 2

5.2.1 Description

In this scenario we examined how the number of different suppliers as well as the demand affected the results. In order to see how the number of suppliers affects the result we ran four different scenarios, which can be seen in table 6.

Table 6. The scenarios that will be simulated.

Scenario 1:	1 Supplier - 8 Products
Scenario 2:	2 Suppliers - 4+4 Products
Scenario 3:	4 Suppliers - 2+2+2+2 Products
Scenario 4:	8 Suppliers - 1+1+1+1+1+1+1+1 Products

All products have the same demand and cost price in each scenario. However in order to see how demand affected the results, each scenario were run two times with different demand. The first time the demand was set to 50 products per year and the second time the demand was set to 100 products per year. The reason we chose these demands was that they reflected the demand for an average product and spare parts have generally low demand. The cost price was set to 1000 DKK. The lead time for units shipped from a supplier was set to one day.

5.2.2 Result for the scenario with 50 in demand

The result for the scenarios with 50 in demand can be seen in table 7.

Table 7. 50 in demand and 1000 DKK in cost price

Scenarios	Model	Holding cost/day	Order cost/day	Transportation cost/day	Total cost/day
1 Supplier	DC	32,41	28,29	0	60,7
	CW	43,34	34,30	11,67	89,32
2 Suppliers	DC	35,15	31,50	0	66,64
	CW	50,22	32,59	9,71	92,52
4 Suppliers	DC	40,67	33,53	0	74,20
	CW	48,46	40,39	10,49	99,34
8 Suppliers	DC	44,67	41,99	0	86,66
	CW	49,15	48,30	10,66	108,07

The total cost is higher for the centralized model for all scenarios. One can also see that when the number of suppliers increases the difference becomes smaller. The differences in holding cost between the models are much less with 8 suppliers than with 1 supplier. For the centralized model, the stock levels at the depots are the same no matter how many suppliers are used thanks to the use of a central warehouse. Due to the benefits of using joint replenishment the maximum stock levels can be lowered resulting in lower holding costs.

The difference in order cost decreases as well when more suppliers are used. This is also a result of using a central warehouse. The number of suppliers has no effect when a depot places an order. On the other hand the transportation cost, which is added with a central warehouse accounts for a large part of the total cost. In table 8 below the number of orders are presented. In table 8 below the number of orders are presented.

Table 8. Number of orders

Scenario	Model	Number of orders to suppliers per year
1 supplier	DC	43,77
	CW	17,82
2 suppliers	DC	73,44
	CW	26,86
4 Suppliers	DC	94,96
	CW	36,43
8 Suppliers	DC	129,53
	CW	54,42

The numbers of orders to the suppliers are much lower for the model with a central warehouse. On average the DC-model places more than twice as many orders to suppliers as the CW-model. The central warehouse orders larger batches and fewer times. This is a significant reduction in orders and should motivate a discount on the cost price. Table 9 below presents the discounts needed for the models to have the same total cost.

Table 9. Discounts needed for the same total cost

	1 Supplier	2 Suppliers	4 Suppliers	8 Suppliers
Total cost DC / year	1622157	1624324	1627081	1631632
Total cost CW / year	1632604	1633768	1636259	1639444
Discount needed	0,65%	0,59%	0,57%	0,49%

As one can see it requires very small discounts for them to have the same total cost. This is because the cost price represents a very large part of the total cost.

5.2.3 Result for the scenario with 100 in demand

The results for the scenarios with 100 in demand can be seen in table 10.

Table 10. Results from simulation

Scenarios	Model	Holding cost/day	Order cost/day	Transportation cost/day	Total cost/day
1 Supplier	DC	52,88	30,51	0	83,39
	CW	73,87	34,38	12,23	120,48
2 Suppliers	DC	64,77	28,79	0	93,55
	CW	79,73	35,49	12,38	127,6
4 Suppliers	DC	49,3	52,15	0	101,46
	CW	84,19	38,88	11,95	135,02
8 Suppliers	DC	58,5	60,91	0	119,41
	CW	79,72	53,75	12,09	145,56

The total cost is lower for the DC as at it was with the model with 50 in demand and the difference in cost decreases as the number of suppliers' increases. The order cost per day is actually lower for the CW and the cost is starting to be lower at only four suppliers.

On the other hand the holding cost is much higher for the CW. The reason for the holding cost is much higher, is due to the optimization algorithm. It tries to lower the order cost and the transportation cost by keeping more units in stock and fewer orders. The total cost will be lower with more in stock and fewer orders because the order and transportation costs are so high. However, the transportation cost does not stand for as high proportion of the total cost as previous example but is still a significant share.

Table 11 below presents the number of orders to the suppliers for the different models.

Table 11. Number of orders to suppliers

Scenario	Model	Number of orders to suppliers per year
1 supplier	DC	56,63
	CW	13,47
2 suppliers	DC	88,97
	CW	36,43
4 Suppliers	DC	123,17
	CW	49,06
8 Suppliers	DC	176,48
	CW	57,96

Even at the double demand the number of orders to the suppliers is much lower for the model with a central warehouse. On average the DC-model places almost twice as many orders to suppliers as the CW-model. As discussed earlier, one can expect discounts on a products price cost if there is a central warehouse. Table 12 presents the discounts needed in order for the CW to have the same total cost.

Table 12. Discounts needed for same total cost.

	1 Supplier	2 Suppliers	4 Suppliers	8 Suppliers
Total cost DC / year	3230438	3234148	3237032	3243585
Total cost CW / year	3243976	3246574	3249282	3253130
Discount needed	0,42%	0,39%	0,38%	0,30%

The total cost includes the cost price of all items for one year. The discounts needed on the price cost are also very small if the demand is 100 per year.

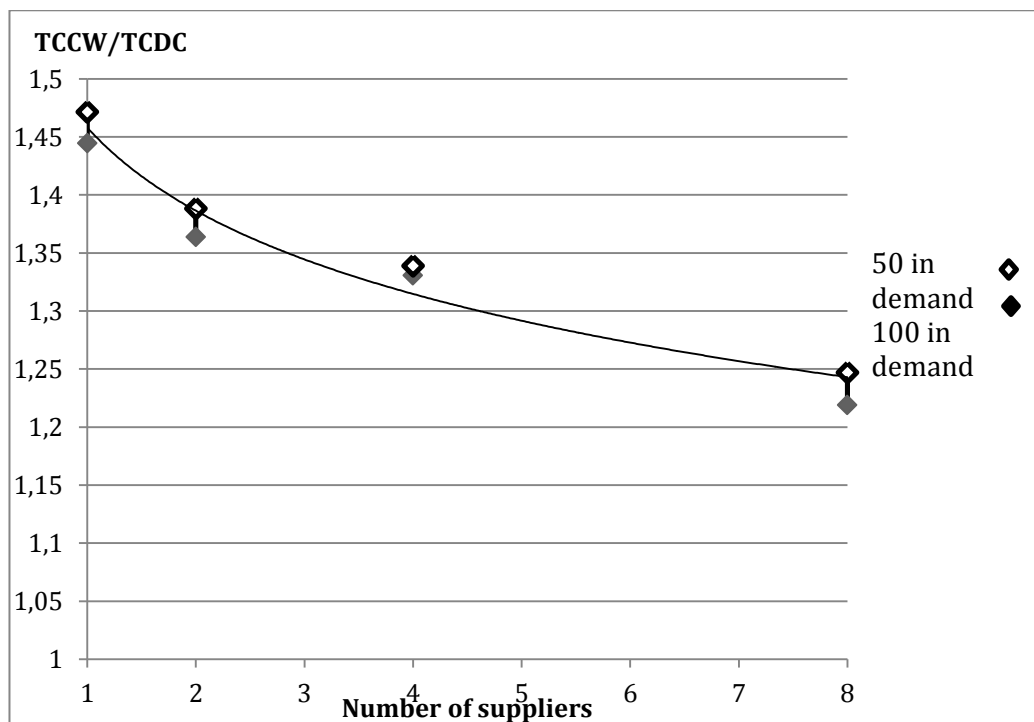


Figure 7. Ratio between the total costs

In figure 7 one can see the ratio between the total costs for CW and for DC. The demand does not play as big a role as the number of suppliers. As

shown in the figure the ratio decreases as the number of suppliers increases. However the slope of the curve decreases slightly when the number of suppliers increases.

5.3 Scenario 3

5.3.1 Description

This scenario was carried out to determine whether the number of depots served by the central warehouse had any effect on the total cost compared to the DC model.

There are eight suppliers with one product each that has a cost price of 500 DKK and a demand of 100 units / year per depot. As before, the lead time is one day from the suppliers.

In this scenario the depot adjacent to the CW is not taken into account. Since it has no lead time and no inventory of its own, it doesn't serve the purpose of this scenario simulation.

5.3.2 Result and Discussion

Table 13 below presents the results for the different scenarios.

Table 13. Results from the simulations.

Scenarios	Model	Holding cost/day	Order cost/day	Transportation cost/day	Total cost/day
1 Depot	DC	11,15	10,04	0	21,19
	CW	16,79	22,10	3,09	41,98
2 Depots	DC	22,30	20,09	0	42,39
	CW	27,65	36,33	11,32	75,30
3 Depots	DC	33,45	30,13	0	63,58
	CW	39,75	45,2	12,21	97,15

The simulation shows that the CW model has a significantly higher total cost than the DC model. However, the graph shows that the ratio of the total costs between the models decreases when the number of depots increases as can be seen in figure 8. This suggests that the CW model has an advantage over the DC model when the size of the system increases.

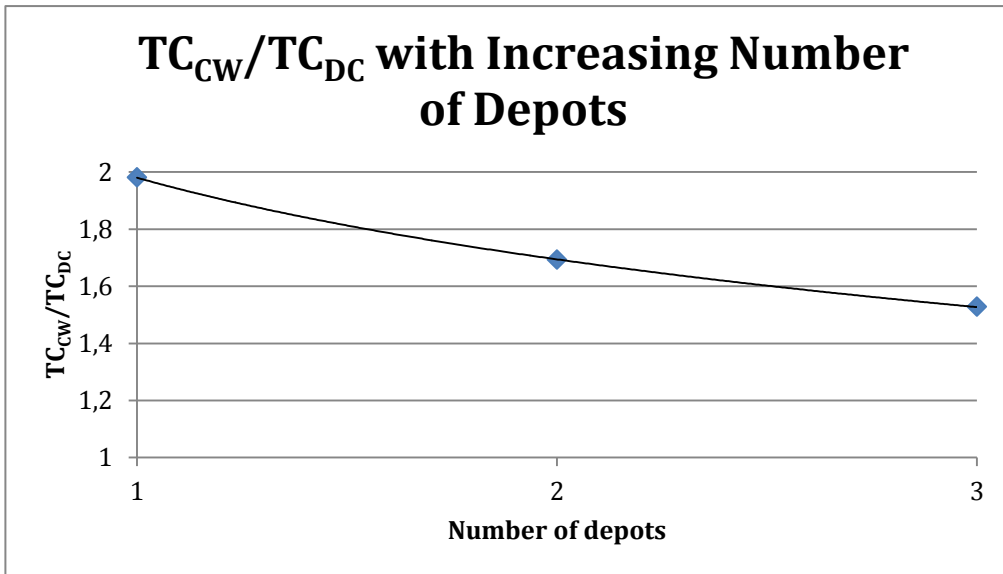


Figure 8. Ratio between the total costs

When adding a new depot more stock has to be placed at the central warehouse to meet demand. However the maximum level does not need to be raised as much each time. The number of orders to suppliers is much lower for the central warehouse and the difference will increase with every new depot.

Table 14 below presents the number of orders to the suppliers.

Table 14. The number of orders to the suppliers

Scenario	Model	Number of order to suppliers per year
1 Depot	DC	27,16
	CW	29,33
2 Depots	DC	54,31
	CW	39,87
3 Depots	DC	81,47
	CW	46,85

The difference becomes larger with each depot thanks to the central warehouse. In a system with three depots the number of orders to the suppliers for the centralized model is almost half compared to the decentralized model. A central warehouse will enable discounts on the purchasing price of the products.

The discount needed for a central warehouse to be profitable reduces for each new depot and this can be seen in table 15 below.

Table 15. Discounts needed.

	1 Depot	2 Depots	3 Depots
Total cost DC / year	407736,1	815472,2	1223208,32
Total cost CW / year	415323,9	826186,0	1235463,4
Discount needed	1,89%	1,34%	1,02%

5.4 Scenario 4

5.4.1 Description

In this scenario we examined how a change in lead time affects the results. We ran three different scenarios where the first one's lead time was 5 days; the second one was 10 days and the last one was 15 days. All scenarios had eight products from eight different suppliers. All products had the same demand, which was 100 units per year and the same cost price, which was 500 DKK.

5.4.2 Result and discussion

Table 16 below presents the results from the different scenarios.

Table 16. Results from the simulations.

Scenarios	Model	Holding cost/day	Order cost/day	Transport cost/day	Total cost/day
5 days	DC	47,69	37,67	0	85,36
	CW	45,41	45,23	11,51	102,15
10 days	DC	46,21	40,39	0	86,6
	CW	49,37	42,5	10,24	102,1
15 days	DC	48,08	40,56	0	88,65
	CW	48,16	44,51	10,35	103,02

The total cost is lower for the DC in all scenarios. The differences in holding costs are small and decreases when the lead time increases since the DC has to hold more in safety stock when the lead time increases. The same is true for the central warehouse on the other hand the local warehouses can have the same safety stock independent of the lead time. The transportation

cost stands for about 10 % of the total cost and is a big reason why the total cost for the CW is much higher. In figure 10 one can see that the gap between the models decreases as the lead time increases.

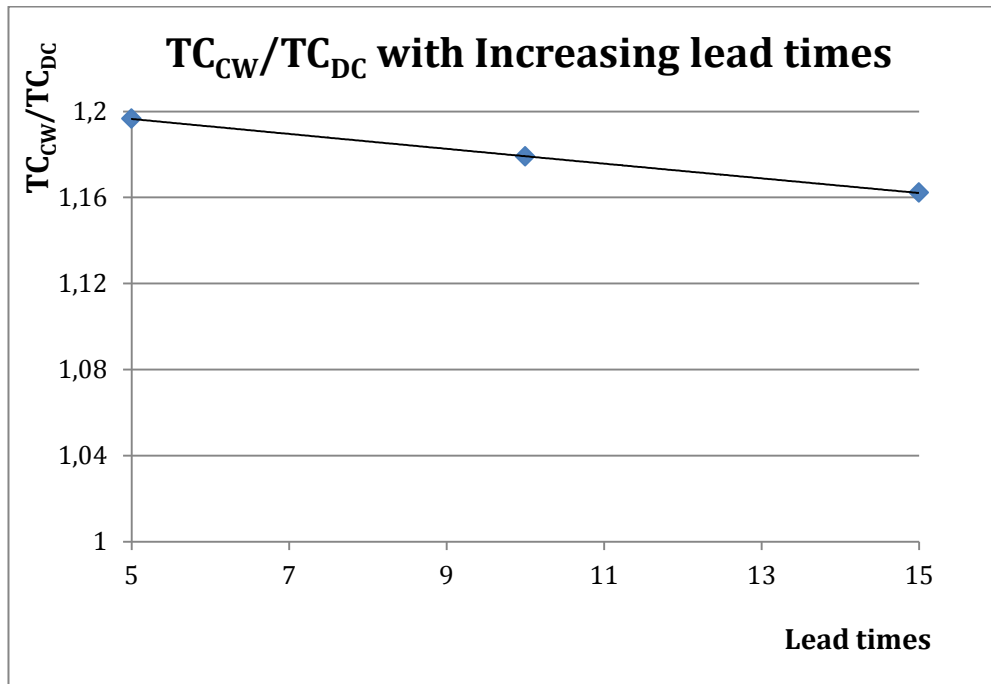


Figure 9. Ratio between the total costs.

The CW model makes on average half as many orders as the DC, which can be seen in table 17 below. As discussed previously this will enable discounts on the purchasing prices.

Table 17. Number of orders per year

Scenario	Model	Number of order to suppliers per year
5 days	DC	102,55
	CW	56,68
10 days	DC	109,21
	CW	56,69
15 days	DC	109,67
	CW	63,33

Discounts needed on the cost prices for the two models are presented below in table 18 and as can be seen the discounts needed for a central warehouse to be profitable are very low.

Table 18. Discounts needed

	5 days	10 days	15 days
Total cost DC / year	1631158	1631608	1632356
Total cost CW / year	1637356	1637319	1637580
Discount needed	0,38%	0,35%	0,33%

6. Analysis

In this chapter the analysis of the costs are presented. A trend analysis is also presented as well as an analysis of the organization.

6.1 Overall Cost Analysis

What is common for all scenarios simulated is that the total cost of the CW set-up exceeds the total cost of the DC set-up.

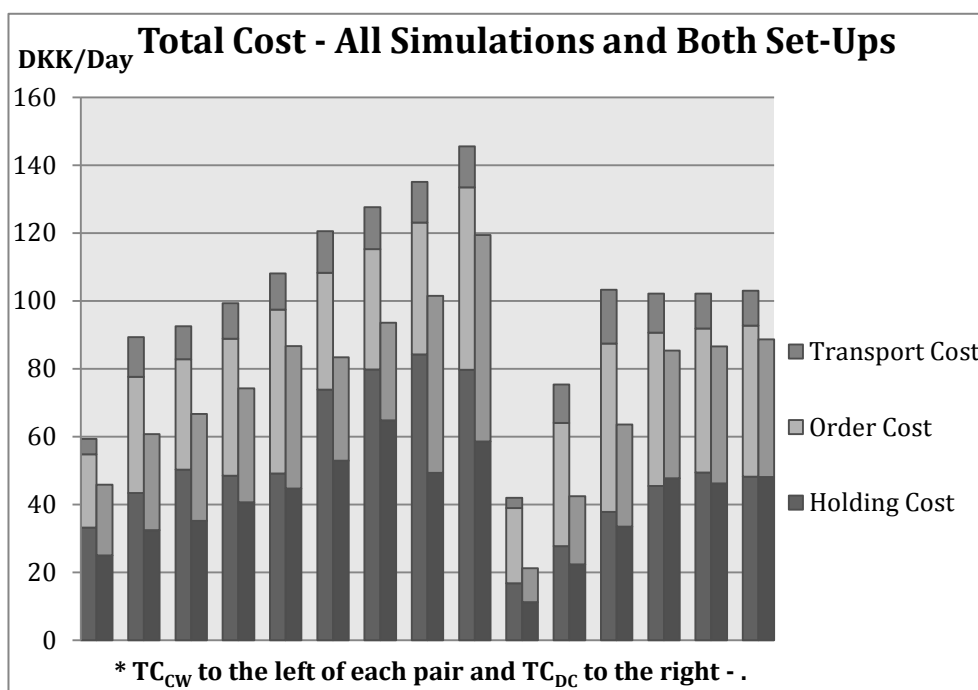


Figure 10. Total cost – all simulations and both set-ups.

With very few exceptions, both the order – and the holding cost are higher with a central warehouse. And on top of that, there is an additional cost for transportation, between the central warehouse and the depots, which does not directly occur in the DC set-up.

However, there are distinct trends that the CW set-up is closing the gap to the DC set-up, as the system gets bigger.

6.1.1 Analysis of Holding Cost

The holding cost represents about half of the total cost for both the DC set-up and the CW set-up as can be seen in figure 11.

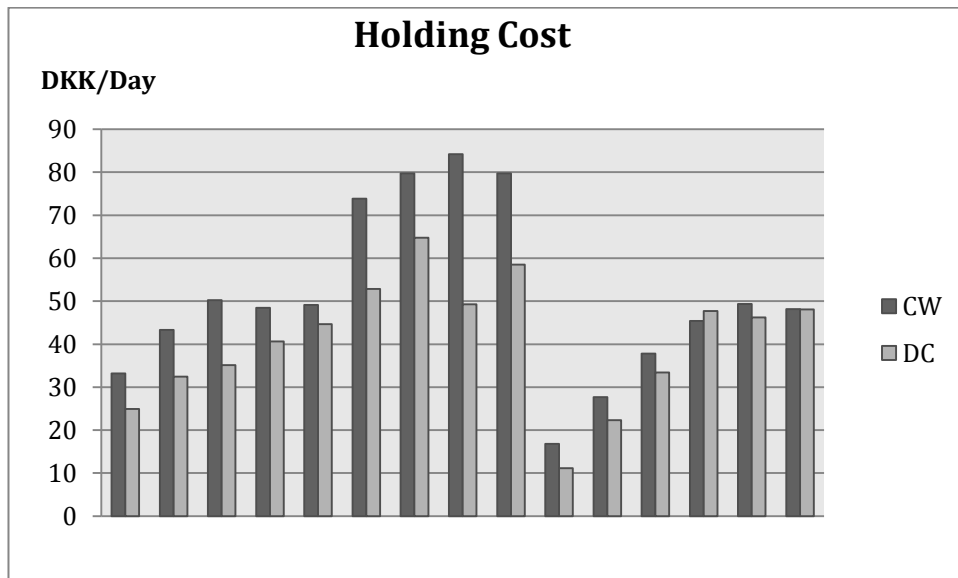


Figure 11. Holding costs for all scenarios.

The central warehouse is forced to keep high inventories to be able to meet the depots' demand. At the same time, the inventories at the depots can be reduced due the shorter lead times a central warehouse brings along. This reduction is, however, not enough to compensate for the increased holding cost at the central warehouse. This is mainly because the order – and transportation costs are too high to fully exploit the shorter lead times and with that, minimize the holding cost at the depots.

6.1.2 Analysis of Transportation Cost

The transportation cost stands for an average of 10, 5 % of the total cost in the CW set-up. As discussed in *section 6.1.1*, a key to reduce the total cost of the CW set-up is to optimize the transportation. That is a project of its own and the values used in this project, concerning the transportation, are rough estimates.

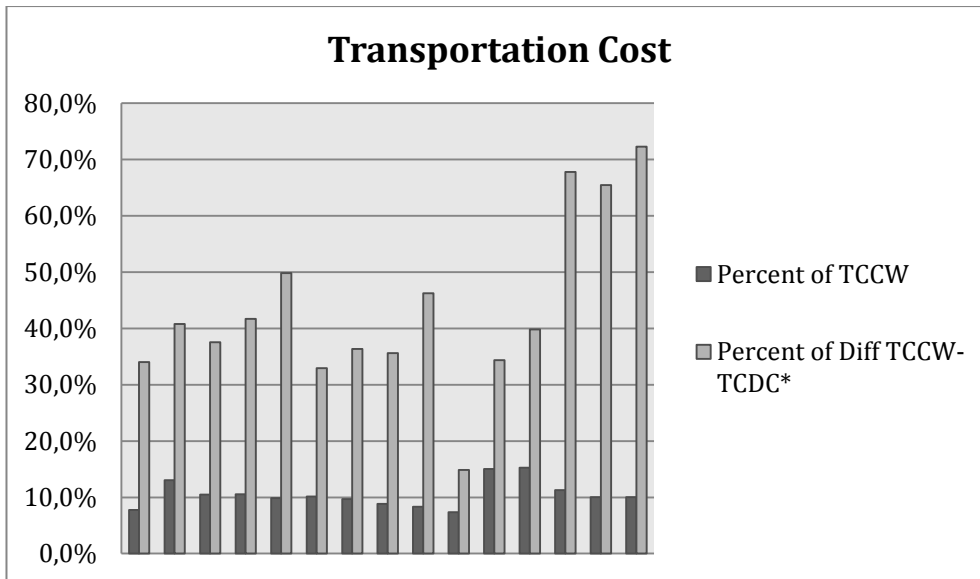


Figure 12. Transportation costs for all scenarios.

*Diff TCCW-TCDC = the difference in total cost for the CW set-up and the DC set-up.

As can be seen in chart 12, a large part of the difference in total cost between the CW set-up and the DC set-up can be attributed to the transportation cost. It stands for an average of 43,3 % of the difference, which further consolidates the earlier analysis that optimizing the transportation is key to closing the gap between the total costs of the two set-ups.

6.1.3 Analysis of Order Cost

The order cost stands for about 40 % of the total cost in the CW set-up and 50 % in the DC set-up. Even so, the order cost of the CW set-up exceeds that of the DC set-up for almost all scenarios.

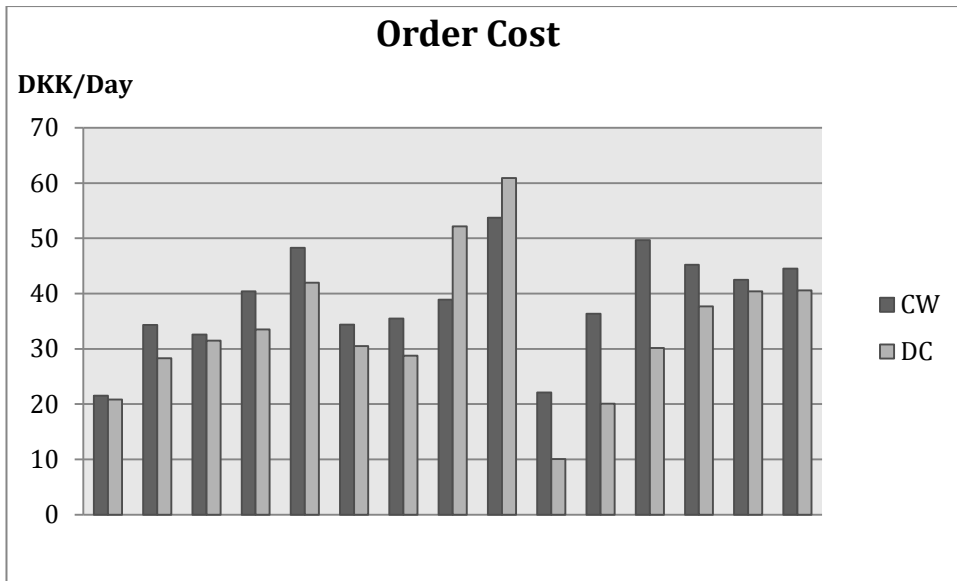


Figure 13. Order cost for all scenarios.

The order cost for the CW set-up includes both external orders to suppliers and internal orders between the depots and the central warehouse. However, looking only at the number of orders to external suppliers, for both set-ups, it is clear that they are reduced with a central warehouse. See figure 14.

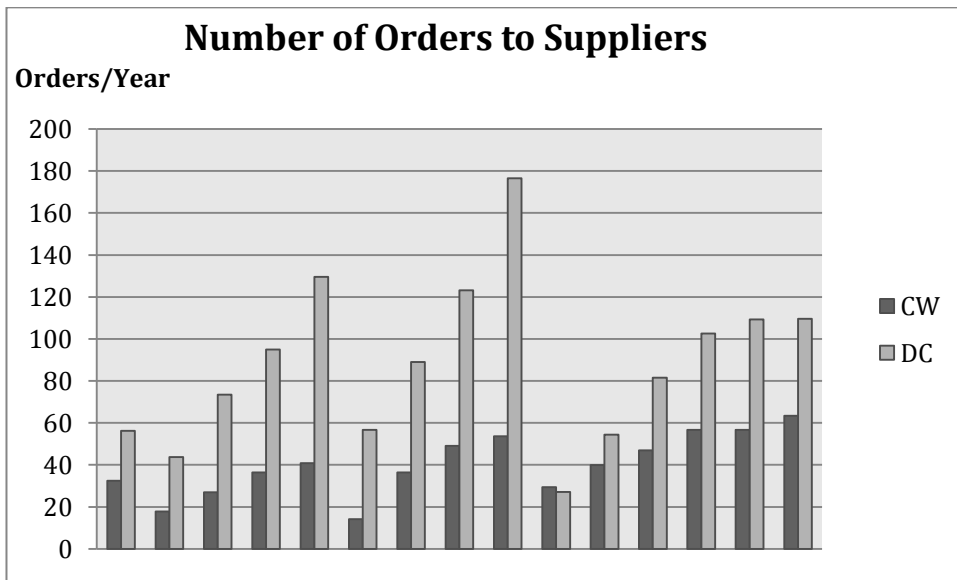


Figure 14. Number of order to suppliers.

On average, the CW set-up reduces the number of orders to external

suppliers by 50 % compared to the DC set-up. The reduced number of orders and the fact that the suppliers only will have to deliver to one single location motivates discounts on the cost price of the products.

6.1.4 Analysis of Discount on the Cost Price

The direct procurement cost (the cost price) is not included in the *total cost* since it is identical for both set-ups. However, with the benefits (*discussed in section 6.1.3*) a central warehouse brings along, a discount on the cost price could be expected for the CW set-up.

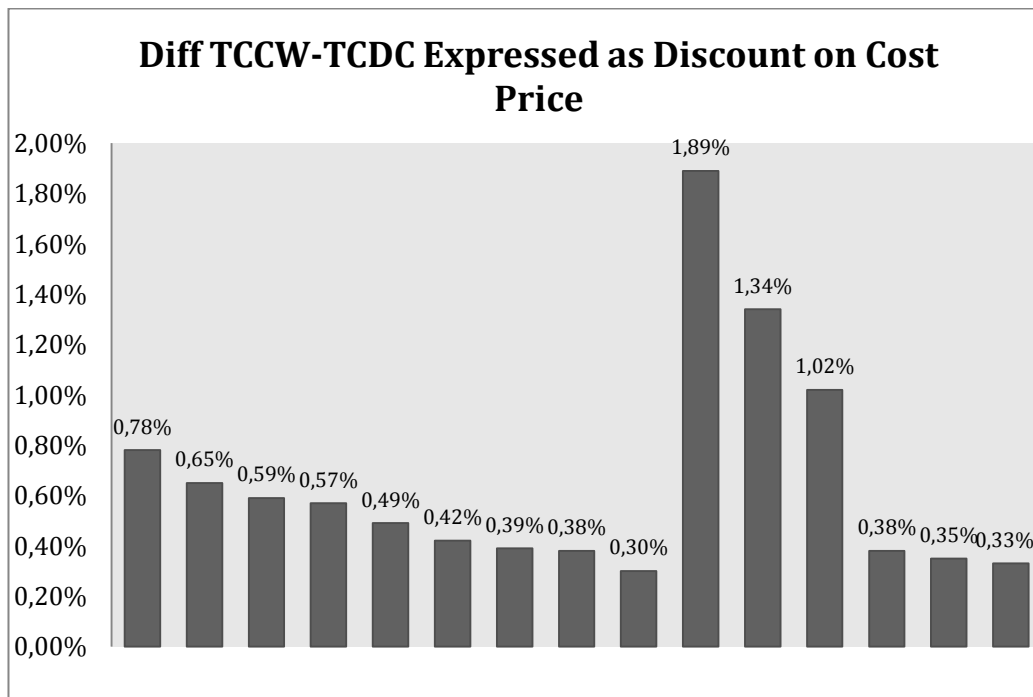


Figure 15. Discounts on cost prices.

As can be seen in chart 15, the discounts needed for the two set-ups to have the same total cost are quite low. The discounts required in Scenario 3 are significantly higher than for the rest of the scenarios, but decreases as the number of depots increases. This implies that the CW set-up scale more cost efficient than the DC set-up.

6.2 Trend Analysis

From the results of the simulated scenarios some trends can be distinguished. The general trend is that the CW set-up holds an advantage over the DC set-up as the supply system increases regarding number of suppliers and depots.

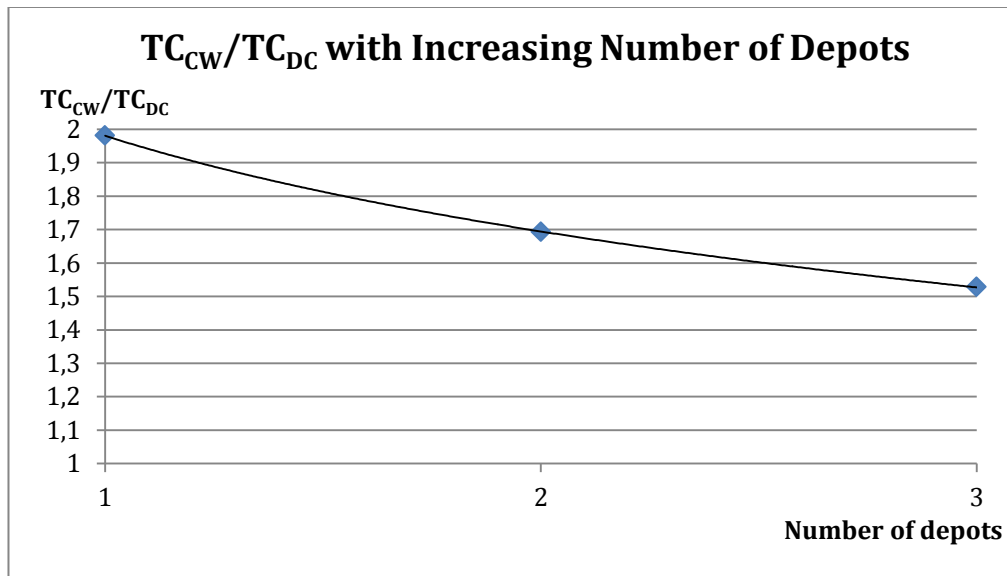


Figure 16. Increasing number of depots.

Scenario 2 and Scenario 3 points to just this trend as can be seen in charts 16 and 17.

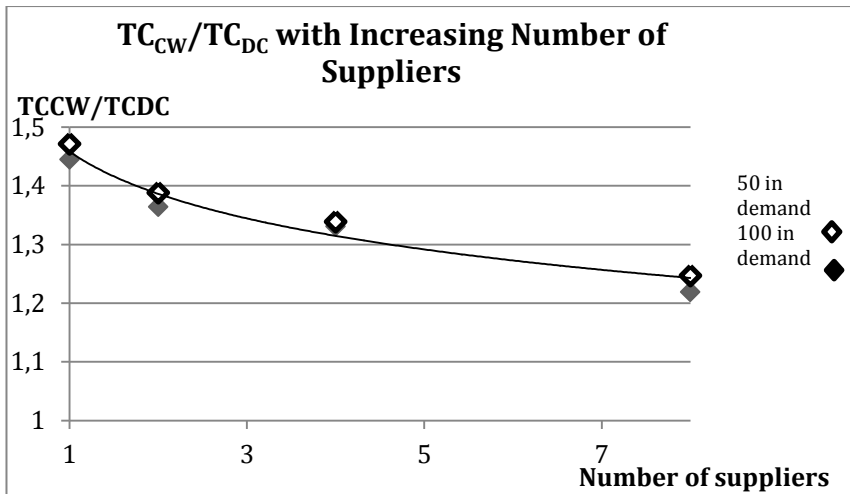


Figure 17. Increasing number of suppliers

Whether the number of suppliers or the number of depots is more decisive for the outcome of the simulations is hard to read from this data. It is, however, clear that both these parameters have a significant impact on the difference in total cost between the two set-ups.

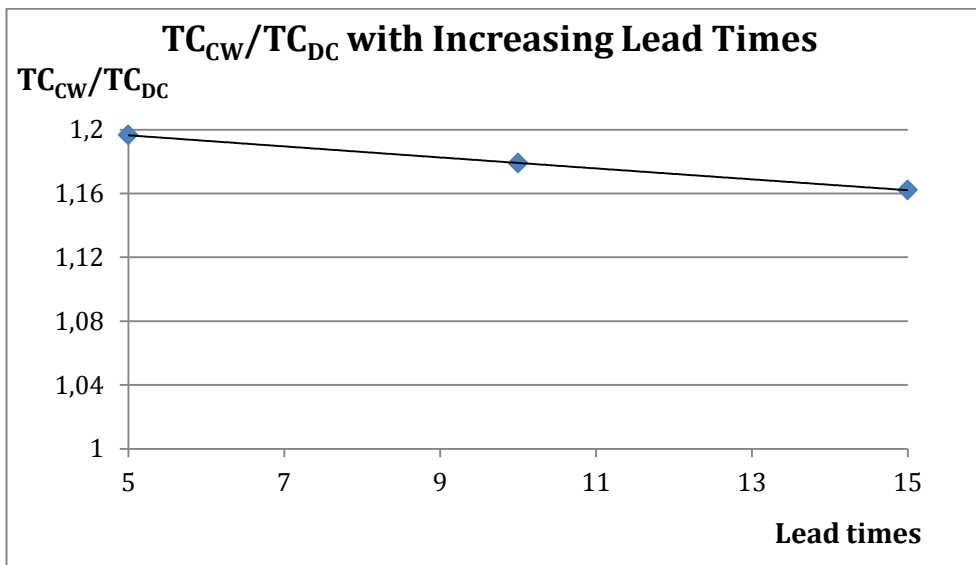


Figure 18. Increasing lead times

The result of Scenario 4 shows that the CW set-up has an edge when the lead-time from the external suppliers increases. See chart 18. The slope of the curve is quite flat but still significant.

6.3 Organizational Analysis

To control and manage the flow of spare parts is easier with a central warehouse since all goods pass through it. The credibility of this claim is strengthened by the reduced number of communication paths required with a central warehouse.

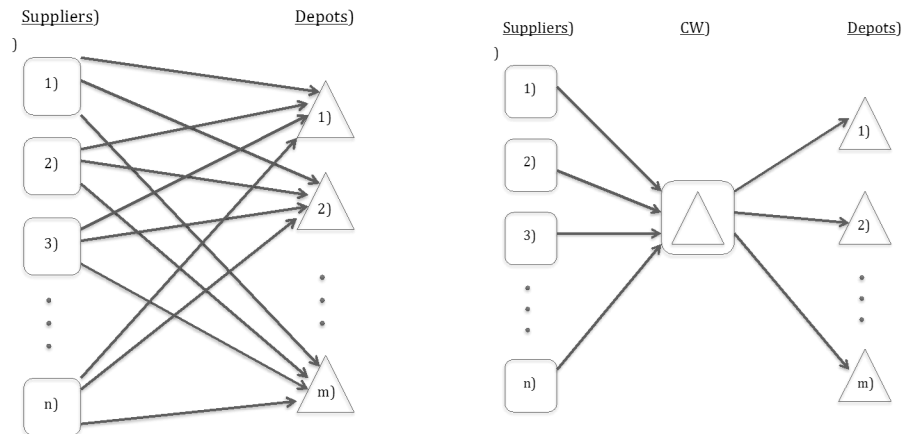


Figure 19. The decentralized set up and the centralized set up.

Managing the supply chain from a centralized position increases the possibilities to have specialized personnel dedicated to fewer tasks. This will increase the efficiency of the supply chain operations and utilize the competence within the personnel better.

By moving the decision making away from the depots (the consumers), a perceived decrease in flexibility could occur. But by taking control of the transportations out to the depots, the flexibility and possibilities increases. It facilitates unique on-the-spot solutions to unexpected events as well as enables different, more efficient, transportation set-ups than considered in this project.

7. Conclusions and Discussion

In this chapter the conclusions are presented and discussed.

7.1 Conclusions

The purpose of this Master's thesis has been to evaluate the economic benefits of introducing a central warehouse for spare parts.

The results from the simulation study showed that the total cost of the CW set-up is higher than the total cost of the DC set-up for all scenarios. The analysis of the holding- and order cost showed that they were higher in almost all scenarios. The main reason for a higher holding cost is that the central warehouse is forced to keep a lot of inventories in stock to meet demand from the depots. Due to the high order- and transportation costs, one cannot take advantage of the shorter lead times and decrease the inventory levels at the depots. The main reason for a higher order cost is that an order occurs in two places. When a depot orders from the central warehouse and when the central warehouse orders from a supplier.

The transportation cost between the central warehouse and the depots stands for about 10, 5 % of the total cost of the CW set-up. This is a major part of the excess cost the CW set-up hold over the DC set-up.

Under the conditions and restrictions of which the simulation models are built, the total cost for a CW set-up is unambiguously higher than for a DC set-up. However, if a CW set-up could motivate a discount on the cost price, it would immediately make it favourable. In most scenarios a discount on the cost price of as little as 1 % would cover the difference in total cost between the set-ups. A discount is motivated because a central warehouse reduces the number of orders to external suppliers by more than 50%.

There are also significant trends that the difference in total cost between the two set-ups decreases as the number of suppliers and/or depots increases. From this, the conclusion can be made that the CW set-up is to prefer for larger supply systems.

7.2 Discussion

There are several areas that need further consideration to be able to generalize the study. The low number of products and suppliers make it

more difficult to draw conclusions. Including more products and suppliers would make the results more accurate. This is however difficult since the models would be too big and take too long to simulate.

7.2.1 Difference between the models and reality

During the course of this study a number of assumptions and simplifications have been made. These are summarized in order to get the reader an overview so he/she can form an opinion about the validity of the results.

All simplifications and assumptions have been applied to both models; therefore none of them are favored. This makes the study's result valid, although not exact. It is important to note that it is impossible for simulation to reflect reality exactly.

Constant lead time

In both models, we have assumed all transportation times to be constant. In reality, this is not the case. It is especially the transportation time between the depots and the central warehouse that will fluctuate. But this will not have a big impact on the result since the transportation times are so small.

We have also assumed that a supplier never runs out of products. That a supplier always has products available is unlikely. More information about how often a supplier cannot deliver is needed in order to get more accurate results.

Transportation

The transportation cost is not entirely fair, since it depends on the number of orders. In reality, the cost will be spread over many more products and as a result the cost per products will be much smaller. This means that the costs we get from our models are overestimated.

Demand

Due to lack of historical data we assumed that customers arrived according to a Poisson process. Although, this is a fair assumption to make, securing more information about a product's demand would make the results more accurate. We also assumed that the size of a customer demand is always one item. In reality, this is not always the case. Since we are looking for a comparison of the models, this is not a big issue.

Lateral shipments

We have also not included emergency lateral shipments in our models. In reality a depot can provide stocked items to another depot that is out of

stock. Further research on how emergency lateral shipments in a multi-echelon model affect the result would be interesting. To see if it is possible to lower a product's inventory levels but at the same time be able to keep the same service level.

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Appendix A: Input data for decentralized model

Comm.code	Cost Price	Backorder	Max	Min	Total Draw	Service level	Leadtime
Product 1	1000	0	9	2	50	0,99	Number of products
Product 2	1000	0	9	2	50	0,99	
Product 3	1000	0	9	2	50	0,99	
Product 4	1000	0	9	2	50	0,99	
Product 5	1000	0	9	2	50	0,99	
Product 6	1000	0	9	2	50	0,99	
Product 7	1000	0	9	2	50	0,99	
Product 8	1000	0	9	2	50	0,99	
Product 9	1000	0	9	2	50	0,99	
Product 10	1000	0	9	2	50	0,99	

Appendix C: Result interface for the DC-set up

	Comm.code	Holding cost	Backorder cost	Max	Min	Service level
1	Product 1	0,349650137	0	9	2	0,998765
2	Product 2	0,350966407	0	9	2	0,997131
3	Product 3	0,352282678	0	9	2	0,995497
4	Product 4	0,353598948	0	9	2	0,993864
5	Product 5	0,354915219	0	9	2	0,99223
6	Product 6	0,35623149	0	9	2	0,990596
7	Product 7	0,35754776	0	9	2	0,998962
8	Product 8	0,358864031	0	9	2	0,997329
9	Product 9	0,360180301	0	9	2	0,995695
10	Product 10	0,361496572	0	9	2	0,994061
11		3,555733543				
12						
13						
14	Number of orders	235				
15						
16	Order handling cost	3,5235				
17	Total Cost	7,079233543				
18	Per year	2583,920243				

Appendix D: Result Interface for the CW-model

Depot 1				Depot 2				Depot 3				Depot 4										
Comm.code	Holding cost	Backorder cost	Max	Min	Service level	Comm.code	Holding cost	Backorder cost	Max	Min	Service level	Comm.code	Holding cost	Backorder cost	Max	Min	Service level	Comm.code	Holding cost	Backorder cost	Max	Min
500054	0	0	0	0	0,989493403	500054	1,933303974	0	15	0	0,999912945	500054	1,9230922	0	15	0	0,999930372	500054	1,888160555	0	15	0
8007505	0	0	0	0	0,985974411	8007505	1,895984112	0	15	0	0,999931986	3003052	1,926795518	0	15	0	0,999905091	8007505	1,874937904	0	15	0
3003052	0	0	0	0	0,993093068	3003052	1,937703699	0	15	0	0,999926957	8002238	1,91169513	0	15	0	0,999984502	3003052	1,930672673	0	15	0
3002556	0	0	0	0	0,989206887	3002556	1,945002315	0	15	0	0,999906854	0	1,906868607	0	15	0	0,999909043	3002556	1,913425292	0	15	0
8002238	0	0	0	0	0,99086104	8002238	1,894852346	0	15	0	0,999926244	0	1,766942945	0	15	0	0,999967524	8002238	1,952449371	0	15	0
2000854	0	0	0	0	0,985400446	2000854	1,920930719	0	15	0	0,999993048	0	1,808869484	0	15	0	0,999838156	2000854	1,873281916	0	15	0
2001897	0	0	0	0	0,990227602	2001897	1,900017157	0	15	0	0,99993855	0	1,812658456	0	15	0	0,999924506	2001897	1,892404637	0	15	0
8006065	0,327190455	0	0	0	0,990539474	8006065	1,881912047	0	15	0	0,999956155	0	1,820312283	0	15	0	0,999893437	8006065	1,92533744	0	15	0
0	0	0	0	0	1	0	0	0	0	-1	1	0	0	0	0	-1	1	0	0	0	0	-1
0	0	0	0	0	1	0	0	0	0	-1	1	0	0	0	0	-1	1	0	0	0	0	-1
0,327190455						15,30970637						14,87723462						15,25066979				
Order handling per day																						
Transportation cost per day		Fuel Cost	Supplier 1	2,673	10000 days	Depot 1	Depot 2	Depot 3	Depot 4	CW1	CW2	CW3	CW4	CW5	CW6	CW7	CW8					
Depot 1	0,00	8,00442	Supplier 2	2,673	Number of orders	0	376	366	373	198	198	199	199	199	199,5	199,9	200,3	200,7				
Depot 2	2,67543	0	0,850706 Supplier 3	2,6865	Number of transports		367	357	363													
Depot 3	3,66282	0	2,61324 Supplier 4	2,6865																		
Depot 4	1,66617	0	0,620004 Supplier 5	2,7																		
		8,00442	4,08395 Supplier 6	2,673																		
			Supplier 7	2,7																		
			Supplier 8	2,6865																		
			Depot 2	8,3795																		
			Depot 3	8,199																		
			Depot 4	8,36 Scania																		
			Supplier 1	46,4	Supplier 2																	
Comm.code	Holding cost	Max	Min	Comm.code	Holding cost	Max	Min	Comm.code	Holding cost	Max	Min	Comm.code	Holding cost	Max	Min							
5000054	5,143449611	55	0	3003052	5,0932703	55	0	8002238	5,087522027	55	0	2001897	5,089974657	55	0							
0	0	24	0	0	0	30	0	0	0	20	5	0	0	20	5							
0	0	18	0	0	0	0	-1	0	0	20	5	0	0	0	-1							
0	0	18	0	0	0	0	-1	0	0	0	-1	0	0	0	-1							
0	0	20	0	0	0	24	-1	0	0	0	-1	0	0	0	-1							
8007505	5,113720833	55	0	0	5,08446123	55	0	0	5,087692104	55	0	0	5,156875336	55	0							
0	0	24	0	0	0	24	0	0	0	0	-1	0	0	0	-1							
0	0	0	-1	0	0	0	-1	0	0	0	-1	0	0	0	-1							
0	0	18	0	0	0	0	-1	0	0	0	-1	0	0	0	-1							
0	0	20	0	0	0	0	-1	0	0	0	-1	0	0	0	-1							
10,25717044				10,17773153				10,17521413				10,24684999										
Order cost	46,4																					
Transportativ	12,08837																					
Holding cost	86,29457688																					
Total Cost	144,7999																					
Per year	52851,98061																					