LiU-ITN-TEK-A-14/010--SE

A dynamic decision model and a system logic evaluation for Sandvik Machining Solutions distribution flows

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2014-06-05

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Examensarbete utfört i Transportsystem
vid Tekniska högskolan vid
Linköpings universitet

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Norrköping 2014-06-05

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A master thesis performed in transport system at the institute of technology at Linköping University

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Norrköping 2013-06-13

Acknowledgement

This master thesis has been inspiring, interesting and educational. Even though this challenging work has led to many late afternoons, long trips and busy meetings at Sandvik, it has been fun and exciting. We would therefore like to direct our gratitude to our remarkable supervisors at Sandvik; Andreas Molin, Patrik Eurenius and Tomas Lindberg for their help and dedication during the whole thesis. In addition, we want to thank our supervisor Stefan Engvall at the Univeristy of Linköping for his commitment and support. We also want to acknowledge Henrik Vedin, Ulf Olofsson and many others at Sandvik who had answered all of our questions. Finally, we would like to show our appreciation to our opponents Martin Andersson and Gustav Jonasson for their comments, support and participation.

It is now time for us to leave Campus Norrköping and face new challenges in life.

Best of luck!

Jonas Hutter

Mehnaz Mashayeke

Norrköping, 13th of June

Abstract

In the current distribution of Sandvik Machining Solutions, products are produced and kept in inventory until the product is sold. The inventory is kept in four different distribution centers, which together distribute the products to the customers. This master thesis focuses on the how the distribution is performed in two different aspects; Part 1 and Part 2.

Part 1 is focusing on the cost of the supplier in the distribution network. The distribution network is created in a manner where each product is using an individual distribution set up. The distribution centers supplied directly from a production unit of a certain product becomes the suppliers of the other distribution centers. To identify products not having the lowest possible total cost, a total cost model is suggested. The total cost model is created to be applicable for any assortment. When the products are identified, the set up can be changed manually by Sandvik Machining Solution. The conclusion of Part 1 resulted in the guidelines presented below.

Guidelines
1. Apply the total cost model on the entire/parts of the assortment 2. Identify all products with unsuitable set ups and the cheapest alternative 3. Follow up on results and change as many unsuitable set ups as possible, start with the products with the largest potential reduction in total cost 4. Repeat the procedure occasionally

Part 2 is focusing on how the system controlling the distribution automatically sends orders between the distribution centers and the production units. The system logic is used on a large assortment, since manual attention of all products is not an option. Since the system is making the decisions based on a predefined logic, the study is focusing on the cost efficiency and the service level linked to the decisions made with this logic.

The current system logic is evaluated for four specific exceptional situations. The evaluation is done based on studying stock levels, replenishments and sales and with an additional attempt to model the stock transfer situations in a simulation model.

The conclusion of Part 2 resulted in a realization that the current system logic works better than expected when assuming perfect precision in produced quantities and delivery times. However, high amounts of emergency shipments during stock outs at distribution centers can be seen in the data collected. These shipments mean that orders from customers are not delivered in time and leads to a lower service level than necessary. In addition, large amounts of products not needed in distribution centers but still kept in stock were identified as a consequence to the current system logic.

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List of abbreviations

ADC - America distribution center

APDC - Asian Pacific distribution center

CDC - China distribution center

CDP - Customer decoupling point

CO - Customer order

DAP - Delivery at point

DC - Distribution center

DIF - Days in finished

EDC - Europe distribution center

EOQ - Economic order quantity

EXW - Ex works

FC - Forecast

FCA - Free carrier

FTZ- Free trade zone

ICC - The International Chamber of Commerce

IP- Integer programming

LCS - Life cycle state

LP- Linear programming

MIP- Mixed integer programming

MTS- Make to stock

SA - Stock availability

SMS - Sandvik Machining Solutions

SS - Safety stock

SSC – Stock standard cost

STO - Stock transfer order

SU - Sales unit

OP - Order point

PO - Purchase order

PU - Production unit

WACC - Weighted average cost of capital

1. Introduction

This chapter aims to provide an understanding of the background to this study. The background will lead to the purpose of the study, which also is clarified by the two parts Part 1 and Part 2. The directives, delimitations and the outline of the report will be the closure of the chapter.

1.1. Background

Sandvik Machining Solutions (SMS) is a business area within the Sandvik Group and a global market-leading manufacturer of tools and tooling systems for advanced industrial metal cutting. The products are manufactured in cemented carbide and other hard materials such as diamond, cubic boron nitride and special ceramics. According to Eurenius *et al* (2014) Sandvik Coromant is one of the biggest brands included in SMS product range. The standard assortment of Sandvik Coromant consists of approximately 60 000 products. More about the products can be read in Chapter 2.1

Sandvik Coromant products are currently produced in approximately 30-40 Production Units (PU's) spread around the world and distributed in four Distribution Centers (DC's). The DC's are located in the Netherlands (EDC), US (ADC), Singapore (APDC) and China (CDC). An exemplified description of SMS current distribution flow is illustrated in Figure 1.

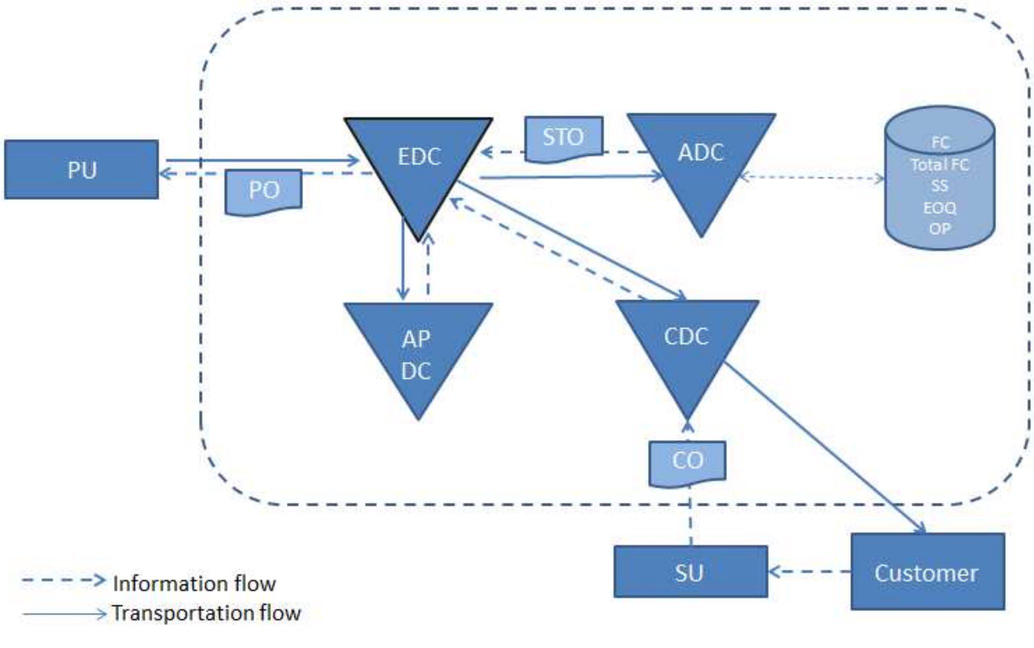


Figure 1 – An exemplified description of the current system

The current business model for the distribution flows is that the PU delivers their order for a unique product to one or several DC's, called Main DC's for that unique product. The Main DC's then supply the other DC's with the product. DC's that are being supplied by a Main DC are called secondary DC's for that unique product. EDC, with black outline, is set as the Main DC as an example in Figure 1 above. All DC's can send to all DC's but no PU's can directly supply the DC in China (CDC). This means that CDC must be supplied by one of the other three DC's and cannot be a Main DC in the current set up. The three other DC's (EDC, ADC and APDC) can be supplied by almost all PU's and all the DC's have the possibility of delivering to each other if needed. The initial decision of Main DC for a unique product is set when the product is created and set up (this can be read about in chapter

7.2.1). This decision is based on several factors, for example where the expected sales will occur and how the Main DC set up does look like for similar products. The DC's receives customer orders (CO) through Sales Units (SU's) but deliver the order directly to the customer. The SU handles all the contact with the customers and are allocated to different geographical areas, e.g. country. There are several SU's connected to a DC, but only one specific DC to each SU. The different supply paths can be divided in three situations explained by Eurenius *et al* (2014):

1. One PU of a specific product delivers to one Main DC (EDC in Figure 1 above), and that Main DC is supplying the other three DC's.
2. One PU can deliver the same product to multiple Main DC's. This can be performed by SMS, if the sales forecast (FC) for a product is high enough to still generate high production batches while being divided. SMS would in this case set up two or three Main DC's for the same product (this means that both EDC and ADC in Figure 1 can act as Main DC's for a unique product). Even if they are both Main DC's, they must make separate requests when ordering the same product, purchase order (PO) to the PU. This is because that the system never split one order to different delivery locations.
3. If there are more than one PU producing the same product, the PU's must supply two different DC's and cannot deliver to the same DC. This means that a DC can only be supplied from one PU for each product. In the case when there is more than one Main DC, there is only one of them supplying the other two secondary DC's and the other Main DC only supplying itself.

As also shown in Figure 1, there is data for each DC in the company's ERP system. The ERP system is containing following information: Sales Forecast (FC), Total Forecast (Total FC), Safety Stock (SS), Order Quantity (OQ) and Order Point (OP). A stock transfer order (STO) seen Figure 1, is only sent from the supplying DC, that is the secondary DC (for example CDC in Figure 1) when the stock level is below OP, with the fixed calculated quantity (OQ). When the Main DC (EDC in Figure 1) is at or below its OP or out of stock it sends a PO to PU, also with a fixed predetermined EOQ. The replenishment time (given per product in the current system) from PU to DC normally varies between 3-8 weeks depending on the product. The time between DC's is normally within one week and the delivery time from DC to customer is desired to be within 24 hours.

1.1.1 Problem clarification

To clarify the current problem situation for this thesis, the study will be divided in two problems. These two problems will be the basis for the study and will be referred to *Part 1* and *Part 2* further in the report.

Part 1

One of the problems at SMS today is when the Planning function set up a Main DC for the supply path of a product from a PU as the planners has a restricted amount of information and no strict guidelines. Sandvik believes that further information would improve the planners' decision and reduce costs and unnecessary activities. This part will be referred to *The Main DC switch* further in the report.

The main questions for Part 1 are stated below:

- 1:1 – *How does the planning function currently decide a Main DC switch?*
- 1:2 – *What complementary information could be used to reduce the total costs of the supply chain when deciding a Main DC switch?*
- 1:3 – *How would the new set of guidelines reduce the total costs of the supply chain when deciding a Main DC switch?*

Part 2

Another problem is that Sandvik believes that the system logic used for DC stock transfers is not flexible enough to handle four certain exceptional situations. These four exceptional situations are according to Eurenius *et al* (2014) believed to cause increased amounts of supply chain activities and higher costs relative to the regular DC stock transfer situation. Sandvik lack an overview of these four exceptional situations causing increased costs and activities. Therefore, SMS needs an evaluation of the effect the exceptional situations has on total costs and suggestions of new system logics to reduce the total cost during these four situations. The specific situations are further described in Chapter 6.2.3. This part will be referred as the *DC stock transfer logic* further in the report.

The main questions for Part 2 are stated below:

- 2:1 – *What is the current logic for DC stock transfers?*
- 2:2 – *How does the current system logics handle the four exceptional situations?*
- 2:3 – *How would alternative system logics affect the costs and the service level?*

1.2. Aim and purpose

The aim of this thesis is partly to create a dynamic decision model for Sandvik Machining Solutions distribution flows and partly to evaluate how the stock transfer system logic handle four specific exceptional situations. The purpose is to reduce the total costs while keeping/improving the service level.

The decision model being dynamic means that the components in the model should be input generic and should not be bound to a specific state in time.

1.3. Directives

The directives presented below are to navigate the scope of this study and to make the result usable to SMS.

1. **Quantifying results**

To introduce the results for the management of the company and then implement results, SMS needs the results of this study quantified. The interesting measurements are transport-, duty-, handling- and inventory costs.

2. **Data from 2013**

The obtained data for this study is set to the year of 2013, i.e. 13 periods from 1st of January to 31st of December. One period is 4 weeks, where a week is 7 days.

3. **Censured costs of transports**

Since the company has certain sensitive information, it has been instructed not to disclose the exact cost of transport in the report. The costs will in this case be presented as fictional numbers.

4. **When defining new logics and guidelines; it should be kept as simple as possible and it should be possible to prove the improvement**

Since the outcome of this study partly is to instruct planners and partly to define and recommend new logics, the result must be easy to understand and follow. It is therefore desirable to have as few changes as possible. To convince that changes lead to improvement, the result should also be validated and illustrated with an example.

5. Evaluate effects of possible changes of current restrictions when seemed fit

Some restrictions in the current system might be changed in the future. If the study points towards large economic benefits in reducing certain restrictions, the changes have to be well motivated and documented.

6. Use the same stock interest rate for all DC's according to Santrade

Santrade is multi-lined trading and Logistics Company within the Sandvik Group with headquarters in Lucerne, Switzerland. Currently Santrade owns the inventory in EDC in Netherlands and CDC in China. As of March 15th and April 12th of 2014, Santrade will take over the ownership of ADC in the US and APDC in Singapore. With this change in ownership, Santrade will handle administration of the invoicing with all PU's and SU's for all DC's. All DC's will then share tax affiliation of Lucerne, Switzerland. Because of this change of ownership, sole principle, the interest rate will be the same for all DC's.

1.4. Delimitations

The study is delimited with respect to the focus, aim and purpose of the study. The effects of these delimitations will be discussed in Chapter 11. The scope of the study is limited by the delimitations listed below:

1. Limited numbers of products and LCS 20

Since the products of Sandvik Coromant's are too many to handle in this thesis, the study will only focus on a limited amount of products. The selected products are chosen by the supervisors at Sandvik with the explanation that these are standard products and are sold worldwide through the four mentioned DC's above. The selected product families are CoroCut, CoroMill and T-Max P. The study will only focus on products in a life cycle state of being released to the market and for sale (=LCS 20). More about life cycle states can be read in chapter 7.4.1.

2. The restriction that some PU's cannot deliver to all DC's

As described in the Background, it is possible for all PU's to deliver to all DC's. In reality, some PU's cannot ship directly to all DC's and needs to ship via another DC (see Chapter 7.3.1). All shipment will be allowed but considered to have the total cost of transshipment via another DC's with feasible delivery possibilities.

3. No consideration of products using a Multi-Main DC strategy

Described in the background, some PU's can deliver the same product to several Main DC's. Even if this is one of the possible supply paths used today, the study is not considering products using a Multi-Main DC strategy. The reason is discussed in Chapter 12.1.5

4. Delimited cost elements considered

The cost elements considered in the scope of this study are transport costs, inventory costs, handling costs and duty costs. Other cost components, e.g. the effects and variations on the cost of production will not be considered.

5. Changing the current way of calculating stock parameters

The study will describe the current way of calculating stock parameters such as the economic order quantity (EOQ), safety stock (SS), sales forecast (FC) and the total forecast (Total FC), but not consider changing the current calculation methods.

6. Batch sizes from production

Since there are many factors to consider when deciding the batch sizes from production, determination of batch sizes are kept out of scope.

7. Transport solution and cost rates for transportation

Variations when deciding carriers, transport supplier and transportation contracts are kept outside the scope. The study will not consider variation in the cost of a transport, only the average transportation cost per product between the different PU's and DC's.

8. Allocation of production

The study will not include the allocation of production amongst the PU's or the restrictions in production. The study will not reflect over the actual location of PU's in other aspects than in the costs in scope.

9. Allocation of sales

The study will not reflect on the allocation of sales and where SU's sends their CO's. The distribution of CO's received amongst the DC's will in this study be seen as unyielding and viewed as an unchangeable demand.

1.5. Outline of the report

The report follows the outline presented in Figure 2. The aim is to give the reader a view of what is included in the different chapters and provide a clear structure of the report. A short explanation of each chapter is presented below.

As the study's primary stakeholders are SMS, the authors have chosen to apply the abbreviations used by SMS as far as possible. The abbreviations are described at the beginning of the report and will be used through the whole report. This choice has been made in order to speak the language of the company of interest.

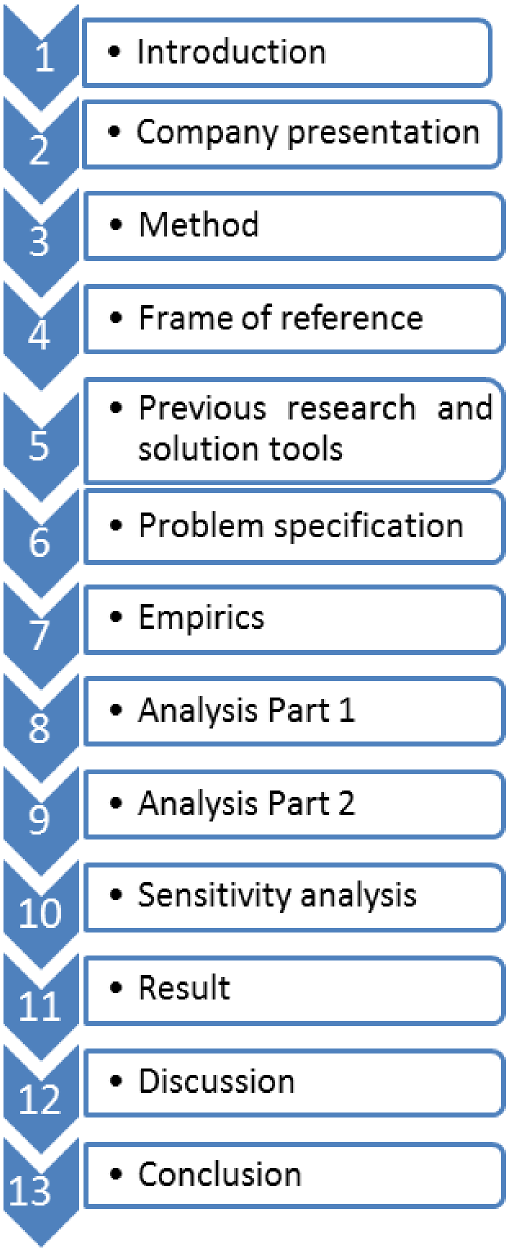


Figure 2 - The outline of the report

Introduction: This first chapter provides the reader with a description of the background and an understanding of the problem being studied. The chapter also contains directives and delimitations.

Company presentation: The second chapter contains a short description of SMS and the products in scope of this study.

Method: This methodical chapter will present the process and the methods used for the study. That is: the method approach, who being interviewed, the collection of data and the modeling part.

Frame of reference: This chapter aims to give the reader a basic knowledge in the subject of logistics and distribution.

Previous research and solution tools: This chapter is presenting a review of previous research in the relevant area of this study. The chapter is also providing an understanding of different possible solution tools relevant for this study.

Problem specification: The chapter is specifying the problem of the study. The questions stated in order to achieve the aim of the thesis, is in this chapter explained.

Empirics: Chapter 7 is presenting the result of the collected data. The questions stated in Chapter 5 (Problem specification) are answered here. The first main questions stated for Part 1 and Part 2 (Introduction) separately are also answered in this chapter.

Analysis Part 1: The analysis of the first Part begins with the mathematical formulation and modeling of the total cost model. An analysis of the model output, key factors and an evaluation of current flagging method is also made.

Analysis Part 2: This chapter describes the model created to analyze Part 2. This is done by first identifying the situations described in Chapter 5 (Problem specification) followed by the simulation model in Arena and a cost analysis of each exceptional situation

Sensitivity Analysis: Sensitivity analysis is made to measure how sensitive the model outputs are to its input data. The sensitivity of Part 1 contains measurements of transport costs, handling cost, duty cost and the stock interest rate. Part 2 contains the sensitivity analysis of the simulation model and estimation of costs.

Result: The results of Part 1 and Part 2 are presented in this chapter. The result is obtained by answering the main questions for each Part stated in Chapter 1 (Introduction) and analyzed in Chapter 8 and 9 which then are summarized to a conclusion for the report.

Discussion: This chapter contains discussions whether and how the results were affected by the assumptions made in the study. It also includes comments about the selection of the simulated products, the effect of future changes in the system and the choice of methods. The chapter closures with a summary of recommendations.

Conclusion: The final chapter will present the conclusion of the master thesis and confirm that the purpose of the study is correctly responded.

2. Company presentation

This chapter will give a short description of SMS and the products of Coromant. The importance lies in giving the reader information of the size and design of the products that are studied.

Described by Sandvik (2013) and Eurenius *et al* (2014), SMS is the biggest business area in the Sandvik groups. SMS is a global market leading manufacturer of tools and tooling systems for advanced industrial metal cutting. SMS is focusing on increasing customer productivity by providing products, services and application expertise. Customers include companies in the engineering, aerospace and automotive industries, the energy sector, the electronics and medical industries. The products are sold under a number of international brands such as Sandvik Coromant, Seco Tools, Walter, Safety, Dormer and Carboloy and additional sub brands. Originally, the business only was consisted of Sandvik Coromant. Due to acquired brands over time, the brand Coromant turned into one of many brands within SMS. The global market for tools in metal cutting and components made of cemented carbide and hard metal was in 2012 estimated to 165 billion SEK.

With a wide range of brands, SMS coordinate the supply chain management and the production amongst the brands mentioned earlier. The different brands share business area and coordination is done to find advantages of multiple branding. On the market, the different brands within SMS share customer target groups and use open competition in various aspects. Due to the recent switch of ownership in various brands, the company is, according to Eurenius *et al* (2014), in a phase of integrating the business systems and methods amongst the brands.

2.1. Products of Coromant

As mentioned in the background Sandvik Coromant is producing a large range of different products. The studied product assortments are products from the product families, described by Eurenius *et al* (2014):

- Product family CoroCut representing inserts
- Product family CoroMill representing tools
- Product family T-Max P representing tools and inserts (part of assortment)

2.1.1. Inserts

An insert is the smallest part at the front of the tool, the cutting part. There are a lot of different kinds of inserts depending of the component material, size, processing time and processing conditions. Figure 3 below shows a picture of different types of inserts taken from the website of Sandvik Coromant (2014).

Figure 3 - Different inserts in the product group of Coromant (Sandvik Coromant, 2014)

Product family CoroCut

Inserts of the product family, CoroCut are used for parting and grooving operations, se Figure 4 below. The weight of a CoroCut CM 1135 is 0.001 kg and the cutting width 2.5 mm.

Figure 4 - Products from the CoroCut family (Sandvik Coromant, 2014)

2.1.2. Tools

A tool is that part where the insert is placed. Both the insert and the tool are interdependent and must be fastened together to function, see examples of tools in Figure 5, taken from the website of Sandvik Coromant (2013).

Figure 5 - An example of tools from Sandvik Coromant. The figure to the right also illustrate were the insert is placed (Sandvik Coromant, 2013)

Product family CoroMill

An example from the product family CoroMill, according to Sandvik Coromant (2013) is the face milling cutter, see below, Figure 6. CoroMill 245 has the overall length of 50 mm and the weight of 1.595 kg.

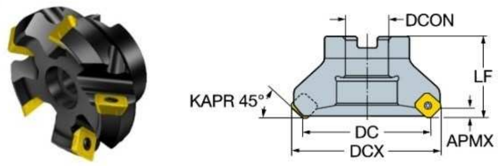


Figure 6 - An example of a tool from the CoroMill, product family (Sandvik Coromant, 2013)

Product family T-Max P

The product family T-Max P, according to Sandvik Coromant (2014), is recommended for general turning and boring of all kinds of materials, component sizes and industrial applications. An example from the product family T-Max P is the tool seen in Figure 7 below. The tool in the figure is a holder for metal boring inserts with a length of 308 mm, a diameter of 47 mm and a weight of 2.6 kg.

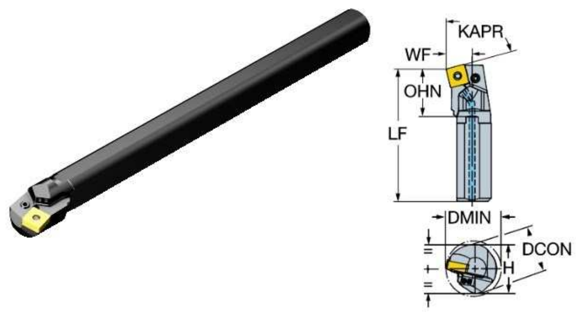


Figure 7 - An example of a tool from the T-Max P product family (Sandvik Coromant, 2014)

3. Method

This chapter starts with presenting the method approach and orientation of the study. The procedure and the methods used in order to answer the purpose is also described and motivated.

3.1. Method approach and orientation of the study

Ejvegård (2009) describes a method as a scientific way to approach a problem and how to process it. Björklund & Paulsson (2012) consider that it is necessary to explain the proceeding of the best way to achieve the purpose and are suggesting the importance of being aware of the selected methodological choices to pursue reliability. The reflection of the method selected is made in Chapter 11.

Which approach and method used is according to Bell (2006) controlled by the nature of the investigation and the type of data wanted for being able to solve the problem. Depending on the view of knowledge and reality of what is to be investigated, there are different objectives of the investigation. Björklund & Paulsson (2012) are describing these approaches as following.

- The *analytical approach* aims to explain the reality as objective and complete as possible by looking for cause-effect relationships. The analytical approach is based on discovering different parts of an overall as the sum of all the parts.
- In contrast, the *system approach* does also explain the fact but consider that the whole differ from the sum of all parts. This systematic approach emphasizes the synergy effects trying to understand the underlying factors for different types of behavior.
- Unlike the system approach, the *operator approach* depends on the investigator's experience and action.

The focus and type of a study depends on the level of knowledge in the relevant field of study. The different types, according to Björklund & Paulsson (2012) are *exploratory*-, *descriptive*-, *explanatory*- and *normative* studies.

- *Exploratory studies* are used in order to investigate and should be used if the area of knowledge is new and will provide a basic knowledge to the subject. Patel & Davidson (2012) are approving and mean that the purpose of an exploratory study is to obtain the greatest possible amount of knowledge in a given problem area to widely illustrate the problem. When collecting data and information, there are several techniques to use. But there is according to Lekvall and Wahlbin (2001) not clear which questions that are relevant or which action alternative are possible to consider in exploratory studies.
- *Descriptive studies* also called mapping studies by Björklund & Paulsson (2012) and are used if the goal of the study is to describe, without explaining, relationships within the problem area data and if the knowledge already exists. When collecting data it is only about specified questions and usually only one technique used, according to Lekvall & Wahlbin (2001).
- *Explanatory studies* are mentioned by Björklund & Paulsson (2012) and Lekvall & Wahlbin (2001), used when deeper expertise and understanding of the topic is desired and when a description and explanation of the topic is given. In explanatory studies, it is concentrated in a small number of variables when mapping causation.

- *Normative studies* are called predictive studies according to Lekvall & Wahlbin (2001) since it is used to make predictive FCs for future development of any occurrence. Björklund & Paulsson (2012) are saying that it used when the purpose is to suggest measures and guidance, but also when some understanding of the area already exists.

There are also different levels of abstraction when describing the relationship between the general and specific, that is, between theory and empirical data. The abstraction levels are divided, by Patel & Davidson (2012) and Björklund & Paulsson (2012), as *inductive*, *deductive* and *abductive*:

- *Inductive* means that the reality forms the basis of the research, where the patterns in the reality are summarized in models and theories. In that case, an empirical study can be performed without first scanning existing theories, that is, that the theories are formulated on empirical data instead.
- *Deductive* means that conclusions are drawn through general principles and existing theory about distinct cases and then confirmed with the collected data.
- *Abductive* can be seen as a combination of both inductively- and deductively levels of abstraction. This has both advantages and disadvantages. The advantage since it gives the researcher the opportunity to work both inductively and deductively and the disadvantage when experience and past research still affects the choices.

3.1.1. Chosen method approach

The scope of this study can be defined as a system where the different parts of the system are linked in different ways. As the different parts affect each other, this may be similar to the systematical approach.

By above descriptions the study can be consider as not being exploratory since the knowledge area is not new, however, a large amount of data were desired in order to perceive the problem in a comprehensive way. Nor can the study be regarded as descriptive as the relationships and correlations in the mapping were desired to be explained in this study. It can therefore be considered that this study is explanative as a deeper understanding of the subject was desired and an explanation of the relationships in mapping the system wanted. The explanative type can be further confirmed as the study focusing on a certain variable. The study can also be assumed as normative since some knowledge was obtained and the purpose of the study is to suggest measures and guidance. The abstraction level of the study can be considered to be inductive since the study were set on a reality basis and the theory formulated on the basis of available data collected. The abstraction level can be considered as deductive as delimitations and data required were based on existing theory. Therefore is the abstraction level viewed as abductive.

To summarize, it has been chosen that this master thesis has the ***system approach*** *and it is considered to be a combination of both* ***explanative****- and* ***normative*** *type of study with an* ***abductive*** *abstraction level.*

3.2. The procedure of the study

According to Lekvall & Wahlbin (2001), the objective should be visualized, detailed stages be identified to get a mind of the scope of the study including the implementing steps. The same authors are also presenting, what they call, “Det Wahlbinska U:et”, which aims to give an idea of the activities involved in a study; how they are related and why they exists. Based on “Det Whalbinska U:et, a schematic figure of the process were created, see Figure 8.

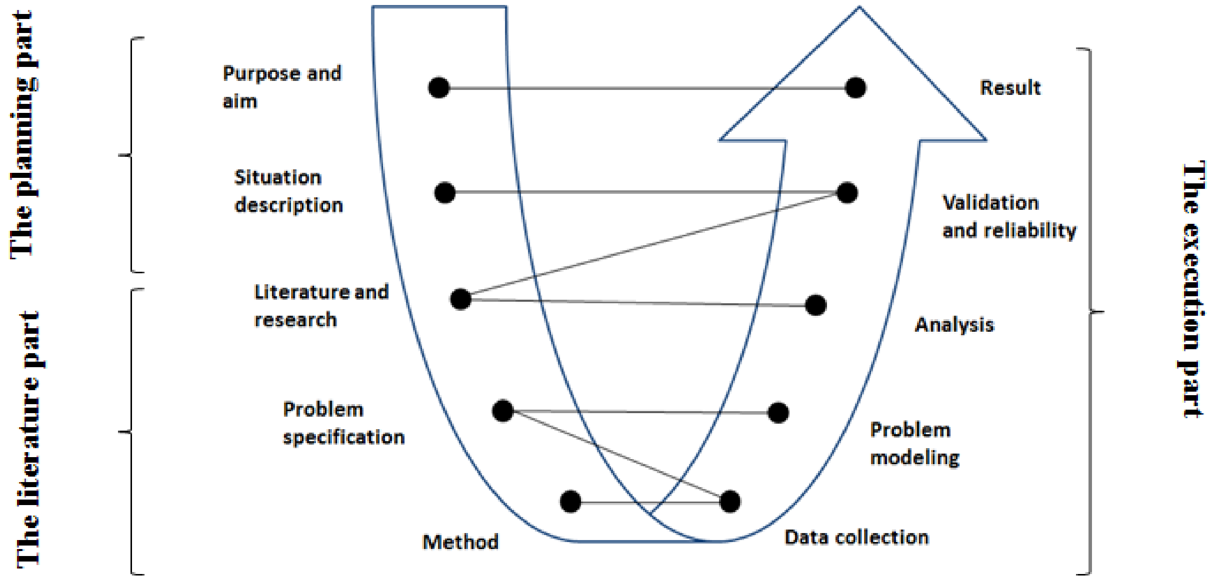


Figure 8 - A visualization of the procedure for this study inspired from (Lekvall & Wahlbin, 2001, p. 183)

As shown in Figure 8 above, the path was divided in different stages: *The planning part, The literature part* and *The execution part*. The aim of the first two parts was to develop a basis for the execution part. Beyond this, it gave the authors an idea of data and time required for this study, it simplifies for further planning, data handling and visits, for instance. The path also illustrated how the authors proceeded to achieve the final result and by letting the reader be a part of it, it considered to increase the credibility of the study.

3.3. The planning part

This section, the planning part, represents the first part of the work, resulted in *Purpose and aim* and *Situation description* in order to clarify the different activities and partial results. The activities and choices made are presented and motivated below.

3.3.1. Purpose and aim

In Chapter 1, the problems that led to the aim of the study were presented. The background and situation description composed the base of the created aim (see Chapter 1.2) and as stated in the same chapter, the aim was divided into two specific parts, Part 1 and Part 2. The primary reason for this division was that these different parts had different objectives and purposes to obtain. But they were still based on the same system and therefore under the same scope of interest.

3.3.2. Directives, delimitations and scope

According to Björklund & Paulsson (2012), an early definition of delimitations is essential to define a scope of study. During the planning phase of this study, the scope and delimitation of the study was determined together with the supervisors of Sandvik. The size and scope of the study was agreed to be limited with respect to resources of the project but agreed to be large enough to create valuable results for the assignment client. According to Björklund & Paulsson (2012), delimitations are necessary to define the focus of the study and directives are necessary to broadly aim the focus of the study. Directives and delimitations of the project can be seen in Chapter 1.3 and 1.4. Björklund & Paulsson (2012) and Lekvall & Wahlbin (2001) also emphasize the importance of defining, motivating and discuss the consequences of the delimitation made (see Chapter 12.1).

3.3.3. Situation description

Lekvall & Wahlbin (2001) means that there is a risk of misunderstanding if the problem is not described in general and then gradually stepwise entered the scope of the study. Based on this, the study will first describe the system in general and then in a later chapter (Chapter 7) go further into the system used for this study. Structuring the problem was started on the first visit to Sandvik. On the same visit, a presentation of the company was made, a meeting with the persons involved, a preliminary visit plan and work schedule was also planned. The structure of the problem resulted in the problem specification (Chapter 6).

3.4. The literature part

The literature part, *Literature, Previous research* and *Method* are representing the second part of the work. The activities and choices made are presented and motivated below.

3.4.1. Literature and previous research

The literature search was performed on two different levels; a basic part focusing on logistical terms and one more profound considering previous research in the field of the scope.

Depending on the aim of the collection of information, this determines whether it should be defined as primary or secondary data. Björklund & Paulsson (2012) defines *primary data* as ‘data collected in order to be used in the current study’, for instance interviews and observations. The same authors define *secondary data* as data produced for a purpose other than the current one. More about data collecting methods can be found in a later section (Chapter 3.5.1).

Literature studies are, according to Björklund & Paulsson (2012), studies in which secondary data is collected. This means that the literature does not have the exact same purpose or focus of the report and therefore may be partial. Literature can be divided in two groups depending on the format, published articles, books, reports or electronic documents. Patel & Davidson (2012) writes that books are often presents the whole, while articles contain specialized parts and the latest discoveries.

Since this study is a combination of explanative- and normative type of study, the authors decided to find literature that both defined basic logistics of the subject (Chapter 4) but also deeper research meant for the performance part to strengthen the analysis and the choices made (Chapter 5). The study therefore started searching for books related to stock control, DCs and logistical cost in distributions. The search started from the library of the university at Campus Norrköping and text books from previous classes in the program of Communications- and Transport Systems. Björklund and Paulsson (2012) argue that the use of multiple method for the examination of the same study, contributes to high reliability of the study since the authors conducting the same study from different perspectives. This use of two different methods, secondary data in form literature and primary data in form of interviews is called triangulation, illustrated in Figure 9 below.

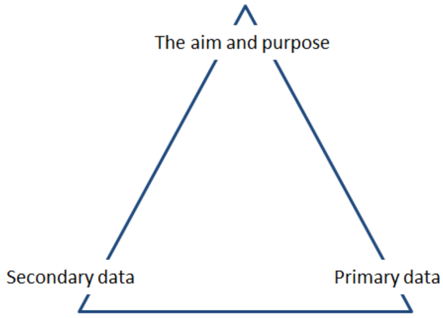


Figure 9 - Triangulation by using two methods when studying the same object illustrated by Björklund & Paulsson (2012)

Besides literature in the subject, methodological literatures have also been studied. This has been done during the whole planning stage to synoptically prove the choices made in this method chapter. A general method used when searching for both books and articles was a method called Snowball Sampling. Noy (2007) describes the method in which information can be found by other information. In some of the books and articles that were found in the literature search were also referred to more in-depth and specialized literature which was utilized in this study.

Surveying previous research

To avoid unnecessary work, obtain an overview of similar problems and to gain knowledge of previous research done to date in similar fields, the authors of this study found that a survey of previous research was necessary. To survey the extensive amounts of previous research done in the areas, an extensive literature review of inventory models with lateral transshipments made by Paterson *et al* (2011) was used. The scope in this study was converted to match the classifications done by Paterson *et al* (2011), described in Chapter 5.1. Since no previous publications completely matched the converted classifications for this study, the publications with the highest amount of matches were surveyed further. No previous publication was assumed to completely solve the authors' specified problem. Therefore an individual problem solving approach was created. The converted classifications to match the classifications done by Paterson *et al* (2011) for this study can be seen in Table 1 with the motives.

Table 1 - Classifications of this study converted to match Paterson *et al* (2011, p. 126)

Definitions	Classifications of this study	The authors motive
Number of items	M	Multiple items are studied
Number of echelons	2	First echelon assumed to be the echelon of the Main DC Second echelon assumed to be echelon of secondary DC's
Number of locations	3	Assumed to match three secondary DC's
Identical depots?	No	Assumed to match differences between DC's
Unsatisfied demands	Backorder	All CO's are served in the system

Timing of regular orders	Continuous review	Aim of study is to create a dynamic model applicable for continuous review of the system
Order policy	(R, Q)	System in this study orders a lateral transshipment with quantity Q at reorder point R
Type of transshipments	Reactive	Stock levels are constantly measured in the system
Pooling	Partial	Parts of the stock in the system are held back and DC's do not apply complete pooling.
Decision making	Centralized	Decision making for lateral transshipments is not made locally at the DC's
Transshipment cost structure	Both (Per item and per transshipment)	Both transshipment costs and costs per items are within this scope of study.

3.4.2. Problem specification

After doing some of the literature search and structured the study, the problem could be further specified. The problem specification was made on the basis of the collected literature, the current situation description and company directives, which consists of three sub-steps. First the aim of the study was divided in two parts, Part 1 and Part 2. In step two, specific questions to be answered for each part was determined based on different specific areas for each one of them. These two steps including figures (Figure 15 and Figure 16) can be seen in Chapter 6. In connection with the questions stated, delimitations were also determined, as a third sub-step. The stated delimitations were either objective or related to time and costs. The aim of the problem specification is to involve the reader in the steps that were made in order to meet the desired outcome. It was also written to increase the reliability of the work, but mostly to explain how and why the questions were needed to meet the result. Table 7 in Chapter 6 has summarized the stated questions and where the questions have been answered. Since this study affects different parts of SMS they also have different interest. The table has therefore been designed to both demonstrate the use of all questions but also for the reader to easily find the desired answer.

3.5. The execution part

This following section describes the activities of the execution part, which contains following: *Data collection and empirics, Problem modeling, Analysis, Result* and *Discussion and recommendations*. The different activities and motivation of the choices made are presented below.

3.5.1. Data collection and empirics

During the study, collection of large amounts of information and data from various sources were required. This information can be divided, as described earlier in Chapter 3.4.1, into primary and secondary data. The main questions stated in Chapter 1 are meant to be answered by the data collected in Chapter 7.

Interviews and presentation documents

Data collection through interviews are, according to Arbnor & Bjerke (2009) to be personal interviews (face to face), telephone interviews, questionnaires via email and questionnaires in groups. The advantage of personal interviews is that the researcher has the opportunity to study the respondent's body language during the interview. While the advantage of having an interview by phone or email is that the method is more effective when there is a large geographical distance between the interviewer and respondent. The general advantage of collecting primary data through interviews is that the collected information has direct relevance to the purpose of the study since it is possible to adapt the hearing of each respondent. The disadvantage is that this method takes time to prepare and perform. Presentation documents in this context are referring to written collections of information not necessarily presented for the objective of the secondary user. In the case of presentation documents, the information is, according to Björklund & Paulsson (2012) often secondary data where the investigator himself must consider how to precede the information and reflect over its primary purpose. Just as literature studies, it provides a lot of information to the little work effort but the disadvantages is that presentation documents often are secondary and further examination is therefore required.

It was not considered to use a questionnaire in group for this study as it automatically would contribute influence of opinions among the group. It would also mean that other people's opinions could affect our own analysis of the system and situation. Since the authors wanted a general and objective result, this method was not suitable. For this reason, the primary data collection contained personal interviews by email and phone as the respondents often were abroad. Björklund & Paulsson (2012) present structured-, semi-structured- and unstructured interviews. In a structured interview, all questions are predetermined and brought up in a specific order. The opposite are the unstructured interviews with no question determined in advance. An intermediate is semi-structured interview, which means that only a frame of topics and questions are set. The setup of the questions will depend on the responses of the interview, as well as the follow-up question will be designed the interview is in progress.

For this study, both structured- and semi-structured interviews were used. Structured since detailed information had been requested and used specified and prepared questions were therefore of favor. Semi-structured in order to still give the respondent the opportunity to influence in a reasonable degree as well as for giving the authors a more transparent picture of the situation and reduce the risk of getting stuck on anything. However, Patel & Davidson (2012) warns about using leading questions, as in structured interviews, because of the risk to lose the reliability. Therefore, the authors also used unstructured interviews in situations it suited.

The persons interviewed and the areas of the stated questions are presented in Table 2 below. The table also contains information of the interviewing person's responsibilities and how the interview was structured.

Table 2 - Table of interviewed persons, question areas and how the interview was structured

Position of the interview person	Question area	Structured
Supply Chain Engineer Manager at SMS Supply Chain Engineer at SMS Supply Chain Planning Director at SMS	Description of the current system (used for chapter 5) Inventory related costs and description of the ERP-system	Both structured and unstructured with examples (email and face-to-face meetings)
Process Expert Product Data at SMS Supply Chain Management, Planning at SMS Supply Chain Planning Director at SMS	Certain guide lines used for the planning function today (switching Main-DC) Multi- Main DC strategy Cross docking	Both structured and unstructured with examples (email and face-to-face meetings)
Business Controller OTD and Planning	Stock standard cost, interest rate and its cost elements Santrade and sole principal (its function and ownership)	Structured with examples (abroad)
Customs & Trade Affairs Advisor-Santrade Ltd	Duty costs and customs	Structured with examples through email (abroad)
Transport & Shipping Manager at Santrade Ltd	Transport costs and its cost elements	Structured with examples through email (abroad)

Huge-Brodin (2013) suggests that before each interview, meeting or visit, material for the interview can be sent to the respondent so that he or she has time to get prepared and to increase the quality of the interview as much as possible. This was also done for this study. During an interview or meeting, Lekvall & Wahlbin (2001) mentioning different ways of handling information; either can the information be directly noted by anyone present during the interview, taped or just post main points and then immediately read or write the information. According to above, the authors of this study were both taking notes during meetings and interviews. Since Lekvall & Wahlbin (2001) raise the problem with misinterpretation of the respondent's answers, both authors were always present. As a further step to ensure that the right information was received, the respondents had to approve the interview material.

Secondary data from collection of systems within the ERP-system

In Chapter 6 the objective of the study is broken down into specific questions. The answers to the questions cannot be obtained with current knowledge and require secondary information of statistics and data based on measurements for a general purpose. According to Moore & McCabe (1999), statistical methods provide strategies and tools for using data to gain insights in real problems. Further, Lind *et al* (2010) summarizes the reasons to limit data with sampling methods. According to Lind *et al* (2010), examples of reasons to sample is that studying entire collections is likely to be time consuming, might even be infeasible or still might be inadequate due to the uncertainty of measurement accuracy. Therefore the collected information in form of data was sampled on a part of the assortment.

Secondary data to complement the search for answers of the questions in Chapter 6.4 (Table 7) was enquired from the company's ERP-system. The table of the summarized question also contains the chapter where the certain question is answered. A list of desired data and justification how this data would be used was sent to the supervisors at SMS, who either brought it out from the system or requested it from other proficient people at Sandvik. Substitutions were made of certain enquired data which could not be obtained or lacked credibility in the information storage systems.

3.5.2. Problem modeling

Mentioned by Björklund & Paulsson (2012), a combination of different methods is often used in different phases of the problem solving process. To be able to apply necessary methods for different phases in the solving process, these phases and activities are identified in this section.

As described in Chapter 5.2.1, Lundgren *et al* (2012) is presenting the optimization process, including a number of phases (see Figure 14). This study has used this approach as a basis when modeling the problem. The phases of solving the problem and reach the desired goals differ in the two parts. The problem modeling processes were divided in different key activity phases in Part 1 and Part 2 respectively. This section focus on the method used of modeling the problem with the data collected. When modeling a problem it is important to make simplifications of the real problems such that the level of detail and complexity becomes reasonable. A model with an increased level of details will lead to better realism in the model, but also to larger model (more variables and constraints) that may decrease the solvability or even the possibility to find a solution. It is therefore, according to Lundgren *et al* (2012) important to find a balance between complexity and size of the problem modeled.

Part 1 - Activity phases and modeling

The activity phases in Part 1 were divided into *Data analysis*, *Comparison*, *Key factors* and a *Dynamic mathematical model*, illustrated in Figure 10.

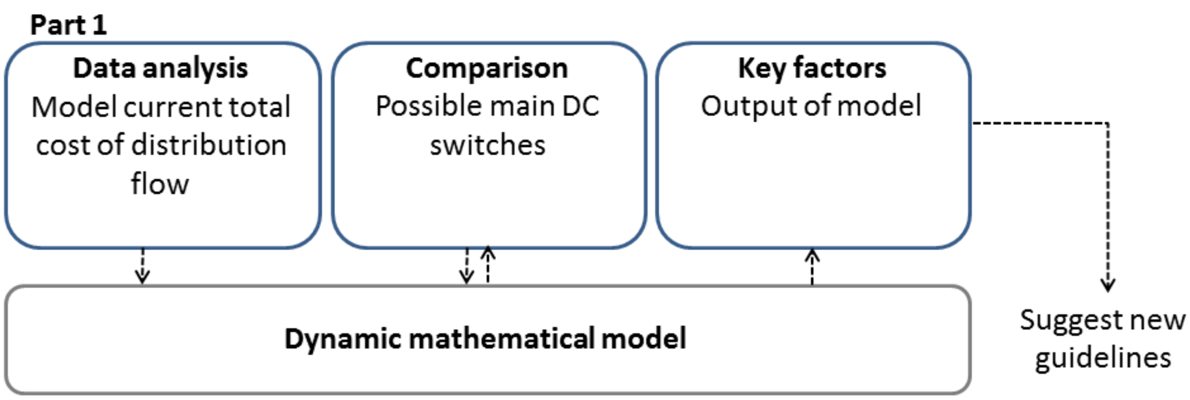


Figure 10 - Problem modeling process of reaching the goals of Part 1

A dynamic mathematical model was required to describe the total cost of the current DC setups for each product in the *Data analysis* activity phase. The mathematical model that is the total cost model created in Excel was based on a combination of the elements described in Chapter 4.3, Table 3. The combination of Table 3 were primarily based cost elements mentioned by Mattsson (2012) and Oskarsson *et al* (2013) with additional elements (inventory risk for an example) described by Grant *et al* (2006). The total cost model was created in order to achieve the purpose of reducing the total cost by investigating the costs of transports, handling, duty and inventory (mentioned as a directive in Chapter 1.2). The total cost model was created by a mathematical formulating described in Chapter 8.1. The same way as Lundgren *et al* (2012) explains in Chapter 5.2.4, a mathematical formulation is used to provide an understanding of how the total cost model is constructed.

The aim of the *Data analysis* phase was to find the total cost of the current Main DC set up for each product. This was done by using the total cost model. The data analysis part of the current set up was based on the conditions of 2013. The result of the data analysis was the comparison scenario[1].

The goal of the *Comparison* phase was to identify what effects a switch of Main DC would have on the total costs. The result of the Comparison phase gave the total cost of alternative setups and compared them with the current supply path set up.

The phase *Key factors* had the aim to identify factors affecting the changes in total costs depending on the choice of Main DC and supply path set up. The goal of the phase was to summarize the key factors that reduce the total cost of distribution in the supply path set up. The key factors identified in the result of the phase were general factors applying to all products' individual set up. Examples of key factors affecting the total cost of distribution can be products features (e.g. weight and value), distribution conditions (e.g. OP, EOQ and lead times), sales (e.g. distribution of CO's amongst DC's, FC deviations) and Main DC set ups.

Part 2 - Activity phases and modeling

The activity phases in Part 2 were divided into *Data analysis*, *Situation analysis*, *Model logics* and *Discrete sub modeling*, see Figure 11.

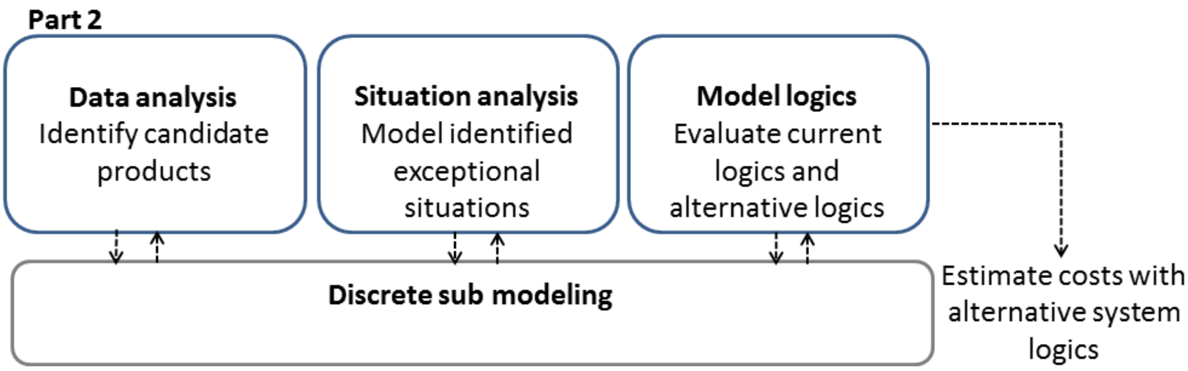


Figure 11 - Problem modeling process of reaching the goals of Part 2

The phase *Data analysis* had the aim to create an overview of the stock transfer situation with the conditions based on historical events of 2013. The goal of the overview was to quantify the cost of distribution amongst DC's with the logic used today, as a comparison scenario.

The phase *Situation analysis* was to identify if, when and to what extent the four exceptional situations mentioned in Chapter Exceptional situations6.2.3 happened during the year of 2013. The goal was to identify the conditions in the stock transfer orders during these exceptional situations. The result of the phase was to find output parameters describing real exceptional situations happening during 2013.

The *Model logics* phase had the aim to evaluate current logics to find system logics preventing the four exceptional situations identified in the *Situation analysis* phase. The output of this phase then became an estimation of costs with alternative system logics.

A *Discrete sub modeling* was assumed to be necessary to simulate models logics. This sub modeling was made in the simulation software, Arena. As suggested by Kelton *et al* (2008) in Chapter 5.2.4, a

[1] Comparison scenario describes the current situation and can be seen as the scenario of doing no changes in the supply path.

simulation model is useful when systems can be rather complicated which generates complicated models and therefore hard to solve by traditional tools. This simulation model followed the same logic and approach as for optimization processes, illustrated by Lundgren *et al* (2012) in Figure 14, Chapter 5.2.5. The four exceptional situations were identified by searching identifiers and dates of exceptional situations. The conditions in the system during the dates of the four exceptional situations were sampled and used as parameters for creating discrete sub models. As explained in the problem clarification (Chapter 1.1.1), SMS lack an overview of these four exceptional situations, which made the choice of using simulation as important to be able to visualize the system logics. The choice of method and simulation software is further discussed in Chapter 12.2.3.

3.5.3. Analysis

This section focuses on how to analyze the modeled problem in order to achieve required information for the result. The analysis was made by using the frame of reference (Chapter 4) and solution tools (Chapter 5.2) combined with the empirical material (Chapter 7), which is the data collected from SMS. The analysis models used for this study are the models described in above section, Chapter 3.5.2. The analysis is based on a modeling of the current situation and then divided by the main questions stated in Chapter 1.

To analyze the current situation, data from Sandvik's ERP-system had to be examined. The research began with controlling if the data received was consistent and reasonable with the reality, i.e. missing data or having large quantity deviations in inbound and outbound flows. This was done along with SMS, where data were compared and verified until it got accepted as representative information. When this was done and data was approved, the authors could begin to examine how the current situation looked like. This was done to identify the existing problem in the current situation but also to verify that the system worked as transcribed in the primary data collection.

Part 1-Total cost analysis

This examination, in order to identify all situations where appropriate Main DC switches would fit, was based on summarizing the total cost of transport, duty, inventory and handling of all possible switches. The Main DC switches were ranked by the largest deviations in total cost. An analysis of factors contributing to the cost depending on the choice of Main DC was made and the factors identified and ranked. A search for general factors applying to all products was also made.

The model used for this analysis was based on a modified total cost model inspired by models in Chapter 4.3, containing the cost elements of transport-, inventory-, handling- and duty cost as defined in scope. As described in Figure 11, the analysis was done using a total cost model (dynamic mathematical model) created in Excel for this study. With the total cost model costs were presented, comparisons were made and key factors could be analyzed. The analysis made in Part 1 was by the authors assumed to give insights in the elements of costs in the distribution set up.

Part 2-Analysis of the distribution logics

Part 2 was an extension of the current situation analysis. The insight in the elements of costs in Part 1 was assumed to be reused in Part 2 to evaluate the actual difference in costs for the alternative system logics. The identification was made by closely examining the order data and stock levels to identify products believed to have been exposed to the four exceptional situations to be evaluated. To evaluate the current system, the authors had to investigate *when* the situation occurred, *why* the situation occurred and *how* the situation occurred. By modeling the stock transfer situations through collected orders and stock levels and evaluation of the current system logic was made. The evaluation was made by examining events at certain dates of interest were the four exceptional situations occurred according to collected data. A simulation model was created by using stock levels, sales and order quantities of the entire year. The simulation model was made to illustrate, gain knowledge and create and understanding of the current system.

Sensitivity analysis

As the study is based on different models and systems whose output is affected by the input given, an investigation of how sensitive the models are to its input data. A sensitivity analysis was made by varying the input data and studying the output from the models. The input data being examined are the various cost components of transport, handling, duty and inventory. The procedure and results are described in Chapter 10.

3.5.4. Result

The achieved results have naturally been based on the aim of this thesis, directives and restrictions obtained together with supervisors.

Result Part 1 - Suggestion of new guidelines in a situation of a Main DC switch.

Result Part 2 - An evaluation of how the current stock transfers in the system logics handles the four certain exceptional situations.

3.5.5. Discussion

Patel & Davidson (2012) describes the discussion as a chapter in which the authors reflect their own study. This could be done by describing the ways in which things could have affected the results, the choices that was made during the study and if the authors got the result they expected. The discussion in Chapter 12 has been written to demonstrate the validity, reliability and objectivity with the study by discussing the impacts of delimitations for Part 1 and the simulation model in Part 2.

Validation, reliability and objectivity

This section aims to highlight the choices made during the study but most importantly it presents how to ensure validation, reliability and objectivity of a study. The chapter is also including reflections on the choices of method and factors that could affect the outcome.

In order for a study to be regarded as credible, it is important to ensure that the validity, reliability and objectivity are at a high level. Following paragraphs describes methods to clarify the study's credibility according to Björklund and Paulsson (2012):

Validity measures whether the study has reached the area of interest and considered all possible approaches. To obtain high validity, interviews should conduct representatives from involved stakeholders. Increasing the validity can also be done by applying triangulation (also mentioned in Chapter 3.4) and to phrase questions as specific as possible. To ensure that the correct information is brought up in the literature research, several sources should be regarded, if possible.

Reliability measures whether the results of the study are credible and consider the probability of getting the same results if the study is performed again. To increase reliability, the same questions should be asked to several people, if possible. This is to confirm that the responses actually reflect the reality and not the person’s own opinion.

Objectivity measures the extent of values affecting the study. It is therefore important to consider that no result will be colored by our own view of the system and task. The objectivity of a study means that the authors carefully justify the choices made to give the reader an opportunity to consider the study's results. The objectivity can be increased by addressing arguments criticizing choices, assumptions and methods chosen.

To increase the validity of this study, the authors used triangulation. By using both primary and secondary data; questions through email were all well-described and mostly included examples to avoid misunderstanding and to receive answers on the exact requested area. Interviews and face to face-meetings were more similar to semi-structured to make greater perspectives and not reflecting the content too much. The situation descriptions were also approved by SMS, to ensure higher validity.

Since the reliability is confirmed by reducing misunderstanding, it was important that both of the authors wrote notes during meetings and interviews, but also looked through information directly afterwards to avoid that information could be misstated. The reliability of the literature was ensured by that just current information was taken into account, and that information was only collected from credible sources. For example the article used, was collected in databases available through the website of the university containing Business Source Premier, Scopus and Emerald. The reliability were further ensured since SMS, together with the authors checked, discussed and filtered the data in order to get the right information and to ensure that the data were not obstacle by systemic problems and reducing risk of misunderstandings. This was important to confirm while visiting the supervisors at Sandvik and working with experts and proficient people when interpreting the data. A further comment regarding the reliability is the credibility of the analysis made in Chapter 8 and 9. Since the analysis for both Part 1 and Part 2 are based on real data obtained from the company's ERP-system without major assumptions made, the results can be considered to reflect the reality pretty well. The part of the analysis based on the frame of reference, previous research and solution tools (Chapter 4 and 5) are used when modeling the different parts (described in Chapter 3.5.2).

The authors have attempted to obtain the most objective view by taking a critical approach to the implementation of data collection through interviews, literature and be influenced by subjective values. By holding an academic approach using different and several sources to each area is consider to increase the objectivity of the study. The objectivity could be further discussed since the four situations mentioned in Chapter 6.2.3 are situations and problems the supervisors at SMS together have developed based on their own experience. This does not mean that the authors have excluded potential situations. However, it could mean that the company has affected the focus area of investigation based on individual opinions and individual experiences.

3.5.6. Conclusion

According to Patel & Davidson (2012) it is essential to finish a study with a conclusion to summarize the most important from the results. They also believe that it may be appropriate to describe the conclusion of stated main question to round of the study. Therefore, the conclusions in Chapter 13 present the answers to the main questions that were stated in Chapter 1 and analyzed in Chapter 8 and 9.

4. Frame of reference

This chapter will provide the reader with a basic knowledge in the subject of logistics and distribution. The chapter will contain following sections: logistics of distribution, distribution strategies and structures, logistical costs of distribution, customer service and logistical impacts on supply chains.

4.1. Logistics of distribution

Oskarsson *et al* (2013) describes the distribution as the part of the supply chain supplying finished products to the customers. Distribution requires logistical activities of inventory movement and inventory management. According to Oskarsson *et al* (2013), the general aim with the distribution is having high efficiency compared to costs and at the same time meets a desired level of service.

4.1.1. A Distribution Center

The aim with a distribution system is according to Lumsden (2006) transferring goods from one place to another and has to meet different criteria's. Lumsden (2006) also mentions following examples of criteria's, where he point out that customer rate the importance differently on different criteria: available stock at desirable locations, offering competitive prices and keeping a certain level of service.

Higginson & Bookbinder (2005) describe a DC as a specific type of warehouse to accumulate products from multiple points of manufacturing, for combined shipment to common customers. According to Arnold, *et al* (2008), a DC has a dynamic purpose of movement and mixing.

'Goods are received in large-volume uniform lots, stored briefly, and then broken down into small individual orders of different items required by the customer in the marketplace.'

- Arnold et al. (2008, p. 376)

4.1.2. Movement of inventory

Arnold*, et al* (2008) describes the physical distribution as a part of the supply chain concept of movement of materials. Mentioned by Mattsson (2012), the movement of inventory in distribution is either done directly to the customer or through a distribution network. To satisfy customer demands movement of inventory must be done to some extent. The movement of inventory, according to Oskarsson *et al* (2013), requires activities of handling, administrating and transporting inventory and is a factor affecting the logistical costs of distribution.

Hill & Hill (2009) are describing an inventory as a mechanism used to stabilize the delivery system from unstable markets, which includes order backlog, proactive capacity, forecasting, scheduling, process improvement, demand- and capacity management.

4.2. Distribution strategies and structures

Mattson (2012) is describing the choice of distribution strategies as a central requirement for a company's competitiveness and profitability. It is about to make products available at the market in the most cost-effective way possible. He means that it will indicate a company’s ability to keep short and secure delivery times to customers and therefore achieve high service.

4.2.1. Distribution network and systems

The background of distribution systems is in the need for rapid and frequent distribution between production facilities and customers. Lumsden (2006) means that the development of distribution system goes from the general direct deliveries with rapid but low-frequency distribution using multi-terminals towards one-terminal to hub systems with frequent but inflexible relations.

Mattsson (2012) also mentions the importance of identifying the roles of distribution nodes that exist in a distribution network; the aggregation role, the dissemination role and the consolidation role. The aggregation role is letting a distributor near a market be responsible for corresponding to customer demand. The dissemination role is bringing the storage function as close to the market as possible in order to supply with short delivery times. The consolidation role is to aggregate intermediary stock from different product manufactures.

Direct delivery

A system based on direct deliveries involves a lot of rapid but resource-demanding transports. Lumsden (2006), mention that a company that produces a major number of products which must be connected to each and every customer will create a system with lot of relations. In turn, the relations will lead to low frequency on each link, low resource utilization and a large demand of vehicles.

A Multi-terminal system

In order to limit the number of direct-relations, additional terminals are often introduced to the system. This means that the goods will pass a terminal on the way between the PU and the customer where the travel distance might be extended for all modes. This system often implies that a number of customers will be linked to a special terminal, to increase customer focus. The customer will then always get the delivery from this specific terminal, allocated depending on geographical or other circumstances. In the same way this system will imply to an amount of PU’s of being connected to a specific terminal, to increase manufacture focus. With a multi-terminal system, Lumsden (2006) believes that a higher efficiency can be accomplished as the goods can be grouped and the amount of transports can be decreased.

One-terminal system

By reducing the numbers of terminals Lumsden (2006) means that the number of transport relations will also be reduced. And when reducing necessary relations the average amount of goods in each relation will increase.

Hub systems

A hub system will not distinguish manufactures from customers, but handle them the same way. Lumsden (2006) describes it as when goods arrive to a hub, it does not need to wait for goods arriving from manufactures, customers or other nodes. This means that the lead-time can be reduced and the shipment frequency can be increased. But he also points out that these hub systems cannot be used in all situations, since a two-way relation is necessary and sometimes even infeasible.

4.2.2. Constraints in warehousing

Constraints in warehousing are tied to the desire to limit costs. According to Arnold *et al* (2008), costs in warehousing can be broken down into capital and operating cost. The capital cost is the cost of space and materials handling equipment while the operating cost is labor and necessary operations for running the warehouse. According to Arnold *et al* (2008), the constraints in warehousing are affected by the desire to provide timely customer service, possibilities to provide accurate information flows and of the physical effort of moving goods into and out of storage. One goal of supply chain management is, according to Christopher (2005), to reduce or eliminate the buffers of inventory.

4.2.3. Constraints in distribution and transports

A constraint in distribution and transports are the possibilities in flow of information within the supply chain. According to Christopher (2005), leading organizations have long recognized that the key to success in supply chain management is the information system. A basic principle is that the accuracy of logistical decisions can as best be as accurate as the information it is based on. Constraints in distribution are also limitations in transshipment capacities and accepted cost levels of transport, warehousing and transshipment. Constraints of transports are mentioned by Arnold *et al* (2008) as cargo capacity, modal range and the desired levels in the trade-off between service levels and costs.

4.2.4. Forecasting

Most firms cannot wait until orders are received before planning what to produce. Arnold *et al* (2008) describe forecasting as prelude to planning, where estimation can be made of demands and conditions of future periods. Jonsson & Mattsson (2011) describe forecasting as a method to use information to balance supply and demand. According to Oskarsson *et al* (2013), the aim of FC's is to predict the future of supporting decisions and to enable the right product at the right location at the right time.

Tracking the forecast

Arnold *et al* (2008) discuss that FCs are usually incorrect and errors must be expected. Jonsson & Mattsson (2011) emphasizes the importance of continuously controlling the error between the FC and the actual situation and to follow up on deviations from acceptable margins. According to Arnold *et al* (2008), error can occur in two ways; random variation and bias. There will always be random variation varying around the average. The systematic deviation exist when the cumulative sales varies from the cumulative forecasts and will have continuous error increase in the long run if no adjustments are made.

4.2.5. Stock control and strategies

Stock control is done to control stock levels on desired levels. The desired level is a trade-off between costs. The trade-off is, according to Olhager (2000), between the desire to minimize stock levels and to match the demand with inventory.

To describe the order- and delivery process, Oskarsson *et al* (2013) use the location of the customer decoupling point (CDP) as an example (see Figure 12). The location of CDP determines all the planning and control of logistics in a manufacturing company. The most common is to have CDP in the distribution or in the final assembly. In the supply chain configuration of this scope, SMS have their CDP in the distribution.

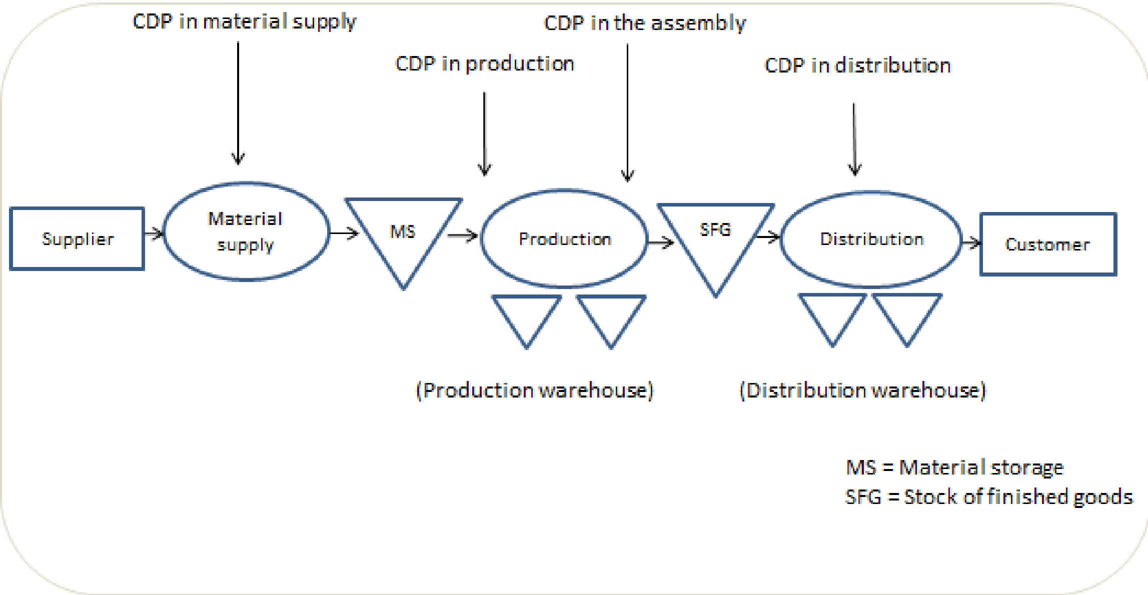


Figure 12 - The position of CDP, examples from Oskarsson *et al* (2013)

By having the CDP in the distribution, seen in Figure 12 above, the products are produced based on forecast and then placed in stock. These products are according to Oskarsson *et al* (2013) usually standardized where the customers expect short lead times.

There are different systems used for controlling a stock but the one used in this study is only ordering point (OP) systems since SMS is using it. Other stock control systems are by Olhager (2000) described as Periodic ordering system and the Kanban-system.

4.2.6. Order point system

In an OP system, stock levels are continuously measured. When the stock level reaches a defined level, an enquiry of stock replenishment is made. Olhager (2000) describes the defined level as the quantity called the OP. SS can be used to cover unforeseen deviations. The OP is desired to be on a level to cover all demand (D) during the lead time of replenishment (L) without the need of consuming the SS.

Depending on possibilities and limitations of replenishment, the quantity of replenishment can be determined in many ways. There is commonly a desire to order an amount that is profitable. Olhager (2000) describes three different ways of determining the order quantity: successive replenishment, instantaneous replenishment and quantity discounts replenishment. For instantaneous replenishment the order quantity (Q) can be determined with the Wilson formula commonly used to estimate the optimal order quantity with respect to the total cost.

According to Olhager (2000) the Wilson formula use the derivative with respect to the economic order quantity (EOQ) of the cost function combining the ordering cost (K) and the inventory cost (H), equation 1.

$$EOQ = \sqrt{\frac{2KD}{H}} \qquad (1)$$

The Wilson formula will find the lowest total cost (C) of the inventory and the ordering cost with the total cost of EOQ, equation 1.

4.2.7. Make to stock (MTS)

MTS is a type of method in material supplying, also defined as a push system which implicates producing products to stock, i.e. pushing from production. According to Olhager (2000), this method is usually used with standardized products with a usually high and steady demand over time (i.e. CDP in distribution seen in Figure 12 above).

4.2.8. IT-systems for managing distribution

Higginson & Bookbinder (2005) mention two common computerized IT-systems when discussing information requirements to manage a DC; *Enterprise Resource Planning* (ERP) and *Warehouse Management System* (WMS). An ERP-system is a general name of a computerized system that aims to handle and integrate the data of the entire organization. According to Higginson & Bookbinder (2005), an ERP-system typically include application modules in distribution and sales, finance and accounting, human resources, inventory control, manufacturing and purchasing. Arnold *et al* (2008) compare the ERP-system with a system encompassing the total company, taking the whole enterprise into account.

"In addition, many ERP systems are capable of allowing managers to share data between firms, meaning that these managers can potentially have visibility across the complete span of the supply chain." Arnold et al. (2008, p. 30)

Unlike an ERP-system, Higginson & Bookbinder (2005) describes WMS-systems denoting computerized software intended for real-time planning on the flow through a warehouse or DC.

4.3. Total cost analysis

According to Lumsden (2006), an analysis of the total distribution cost shows that several elements affect each other individually in a complex way. This dimension of efficiency, according to Mattsson (2012) provides benefits in productivity. The same author divides the concept into following elements: tied capital committed to inventory, capacity utilization, flexibility and logistical costs. This study will in this section focus on the logistical costs of material flows; transport cost, inventory-related cost, duty cost and administration cost.

To measure the efficiency of material flows, it is important to consider all relevant costs since any change or action affects a majority group of costs. In such aspect, a total cost analysis should be used since the total cost model considers all changes in costs that occur due to a certain procedure. When evaluating the efficiency impact, Mattsson (2012) emphasizes that the changes in the total cost are of greater interest than the absolute cost. The model used to perform a total cost analysis is described differently depending on the situation to be analyzed. Oskarsson *et al* (2013) presents the cost components which usually tend to be included in a total cost model, which in Table 3 is compared to two other sources.

Table 3 - Cost elements in a total cost model according to Oskarsson *et al* (2013), Grant *et al* (2006) and Mattsson (2012)

Oskarsson *et al* (2013)	Grant *et al* (2006)	Mattsson (2012)
Stock holding cost	Inventory carrying cost	Shortage- and delay cost
Warehousing cost	Warehousing cost	Warehousing cost
Transportation cost	Transportation cost	Transport- and handling costs
Administration cost	Order-processing and information systems costs	Administration cost
Other costs	Lot quantity cost	
	Capital-/ opportunity cost	
	Storage space cost	
	Inventory risk cost	

Oskarsson *et al* (2013) highlights the importance of adapting a cost model after the purpose since the model is not about including the cost components, but including the cost components the specific problem is affecting. They mean that it is what is included in the actual calculations that matter to describe the size of the economic consequences. Which model selected for this study, was discussed in Chapter 3.5.2.

4.3.1. Transport costs

Transport costs are the cost of executing and administrating transports. According to Oskarsson *et al* (2013), transport costs does not include the cost of transports within a company facility, but instead the costs of transports between internal[2], internal to external[3] and external to internal facilities. According to Mattsson (2012) the internal transport intends the costs for transport and movements including the cost of tied capital committed to inventory for both the transportation and the handling at picking in stock.

Lumsden (2006) describe transportation as a collection of resources during a movement, where the goods and carrier are parts of this collection. He means that if the right transport mode is set, the cost for capital and the transport costs should be in balance. On such ground, high-valued goods are often sent with airplanes. Lumsden (2006) also notes that the transport mode not only is set by the delivery value, it also depends on a time demand or availability for instance.

Oskarsson *et al* (2013) mentions that most companies let external companies handle their transports. Brought up by Arnold *et al* (2008), transportation agencies providing transport service are freight forwarders, couriers, shippers or the post office. According to Arnold *et al* (2008), the carrier charges the transport buyer with a fixed cost and a variable cost per mile or a tapered rate[4] depending on the carriers transportation cost elements. Explained by Lumsden (2006), the rate will also depend on the value, density, perishability and packaging of the commodity.

The fixed costs, also called actual costs, are by Lumsden (2006) splitted in four groups of costs: movement, loading, transhipment and unloading. The variable cost, also called other transport costs,

[2] Internal facility in this case is a warehouse, DC or other facility managed by the company (Oskarsson, et al., 2013)

[3] External facility in this case is an external supplier facility, customer facility or other facility managed by another company (Oskarsson, et al., 2013)

[4] Tapered rate means that the rate per mile is reduced when the distance increase (Arnold, et al., 2008)

are depending on more than just the movement of the goods. Following categories are mentioned in Lumsden (2006) as wrapping, temporary storage occuring due to the transports or the planning of transports, damages on goods, assurance, interest charge for the goods during the transport, compensations for attended time, customs procedures, administration and planning. Since there is both national and international policies, certain alternatives can be more beneficial than another. The distribution of transports by different modes is partly due to access, techincal factors but also to the total cost of transportation. Even though some transport modes are more cost-effective for large shipments, it could still be more competitive with smaller vechicles despite the high cost. It is therefore, according to Lumsden (2006) important to notice that the transport costs are composed in different ways depending on situation, technical-, economical- or local qualification.

4.3.2. Transportation documents

Bill of lading, are according to Lumsden (2006) containing different obligations to the carrier against the shipping company included in the transportation contract, the supplier of the goods or the reciever of the goods of transportation. Common for all transportation documents are that they are signed by the carrier. There are also different kinds of standards depending on shipment. Lumsden (2006) describes that the standard for the shipment is more focused on vessel and transportation mode while the transportation documents adjust the relation between the shipper of the goods and owner of the goods.

4.3.3. Handling costs

Mattsson (2012) defines the handling cost as recent both internal and external in the supply chain. The handling cost is primary related to the company's material supply and distribution, but also the production. The external handling is about the number of shipments and the need for residual deliveries from the production. The internal handling cost relate to costs for movements including capital cost for equipment well as for entering and picking from stock.

4.3.4. Duty, tax and customs

Described by Siebert (2009), there are global differences in international and domestic rules which affect the cost of trade. Customs and trade-related laws are used to protect the domestic economies and protect domestic assets from foreign competitors. According to Dinlersoz & Dogan (2010), tariffs and duties are tools to protect industries from foreign competition and to generate revenue. Mentioned in Martelli & Abels (2011), rules of trade and duties also affect transnational corporations with subsidiaries in multiple countries. Rules and costs of international trade vary geographically depending on international and domestic circumstances, economic state and geographic conditions.

4.3.5. Inventory-related costs

According to Christopher (2005), inventory-related costs are *Order Preperation Costs, Inventory Carrying Costs, Shortage and Customer Service Costs* and *Incremental Inventory Costs*. He lines up following costs as the costs of inventory as the cost of capital, storage and handling, obsolescence, damange and deterioration, decrement, insurance and management costs:

- Order Preperation costs are the specific costs that are incurred each time an inventory replenishment request is made. Order preperation costs can be administration costs of associated paperwork, setup costs and component movement costs.
- Inventory carrying costs are costs related to inventory quantity, items' value and time in stock. Inventory carrying costs does also consists of the following missing capability of using

inventory invested fundings for other purposes. Insurance and risk costs are also a component of the Inventory Carrying Cost.

- Shortage and Customer Service Costs consists of the costs caused when the demand exceeds the available inventory. Examples of Shortage and Customer Service Costs are accordng to Vollman *et al* (2005) shortage costs equal to the products' lost contribution margin and costs of adminstrational work required to keep track of dissatisfied orders until inventory is available. A study mentioned to by Christopher (2005) is saying that the impact of out-of-stock situations leads to potential loss of business as customers chooses to either substitute to a different product of the same brand, buy items of another store or even substitute to a product of a different brand. Both Vollman *et al* (2005) and Oskarsson *et al* (2013) emphasis the importance but the diffuculty to measure the Shortage and Customer Service Costs. Christopher (2005) describes the significant diffrences in profitability between customers. Different customers buy different products or quantities and the cost of serving different customers vary.
- Incremental inventory costs, according to Vollman *et al* (2005), are the cost of having stock facilities, personnel and to operate stock. Incremental inventory costs are also mentioned in Mattsson (2012). Since every order has a small contribution on long term cost components like hiring staff or investing in a new stock facility, there is a desire to measure and distribute the effect the incremental inventory cost on entities when determining the cost of inventory. Mentioned by Arnold *et al* (2008), is the incremental inventory cost named capacity-associated costs and described as costs incurring when output levels must be changed. Examples mentioned are costs of overtime, hiring, training, extra shifts and layoffs.

According to Arnod *et al* (2008) these inventory related costs make infinite stock infeasible and motivates the concept of minimizing stock levels.

4.3.6. Product value and landed cost

According to Oskarsson *et al* (2013), the product value is the cost of purchasing components, cost of production operations and costs to finalize the product. Arnold *et al* (2008) describe the landed cost as the product value of an item and associated costs in getting the item to the current location. Arnold *et al* (2008) mention that costs that could be included in a landed cost are transportation, custom duties and insurance. For items manufactured in-house, the cost includes direct material, direct labor and factory overhead.

4.3.7. Administration costs

The administration costs, according to Mattsson (2012), include all the costs associated with control of material flows and value gain. Primarily it includes administrative staff handling such as order processing, planning and inventory control. Administration costs also include costs of material management.

4.4. Customer service

To orient processes in a company is usually essential in order to achieve the cooperation and integration across company boundaries, which are essential to increase the level of efficiency of supply chains. The two main processes are material flow process and the payment flow. The efficacy variables that define the efficiency in a company's material flow, also affecting the company's profitability are, according to Mattsson (2012), customer service and costs. Lumsden (2006) is describing the logistical efficiency in the components of service, costs and tied capital committed to inventory and mean that the totality of these components should be as good as possible. The idea is that the demand and consequently the income of a company should relate to customer service and the tied capital relate to costs (resource).

Customer service can be seen from a competitive point of view and provide useful profit benefits according to both Mattson (2013) and Storhagen (2011). Christopher (2005) mean that there is no value in the product until it is in the hands of the customer, which in turn leads to the complex concepts of availability for the customer, also designated as customer service. Both Stadtler (2008) & Oskarsson *et al* (2013) are describing customer service as a multi-dimensional concept divided in three elements: pre-transaction, transaction and post-transaction. For measuring customer services and setting targets in the practice, key performance indicators are used. Mattsson (2012) divides customer service in following three parts: delivery service, information service and logistical services. This study will only be focusing on the delivery services.

According to Harrison & Van Hoek (2008) and Oskarsson *et al* (2013) the delivery service measures how effective the flow of material are in a company and how it is supported by the information flow. The delivery service can also be used to control and manage the internal operations as it provides performance indicators. Lumsden (2006) describes that the goal of a producing company is in an efficient manner satisfy the customer requirements by maintaining a high delivery service. The elements presenting the delivery service vary between companies and literature. Even the interpretation may differ from case to case. Pointed out by Oskarsson *et al* (2013) it is important to clearly define what each elements means in the particular case.

Oskarsson *et al* (2013), Lumsden (2006) and Jonsson & Mattson (2011) divide the delivery service in following service elements, Table 4, where the name may differ but the definition is similar.

Table 4 - The elements of delivery service defined by Oskarsson et al (2013), Lumsden (2006) and Jonsson & Mattsson (2011)

Oskarsson *et al* (2013)	Lumsden (2006)	Jonsson & Mattsson (2011)
Lead- time	Lead-time	Delivery time
Dependability in delivery	Dependability in delivery	Delivery precision
Reliability of delivery	Reliability of delivery	Reliability of delivery
Flexibility	Flexibility	Flexibility in delivery
Stock availability	Service level in warehouse	Service level in warehouse
Information	Information	

Following elements are described by Oskarsson *et al* (2013), Lumsden (2006) and Jonsson & Mattsson (2011).

Lead-time: the time between orders received until delivery can be made. The lead time, according to contains the time for activities as reception of orders, order administration, planning, manufacturing and distribution.

Dependability in delivery: the probability that the delivery is made within the time confirmed with customer.

Reliability of delivery: That the correct amount of the right product and quality is delivered. The reliability of delivery also could presume that all goods are delivered together if the goods are interdependent

Flexibility: The ability to adapt to changed customer desires in already agreed orders. The flexibility is often an important completive factor as it can enable finding new solutions.

Stock availability: The percentages of orders that can be delivered directly when a CO is received. This term of service is interesting in cases of supplying directly to customers from the inventory of finished goods. When direct supply is not possible, measuring lead time becomes more important.

Information: The extent to which an exchange of information between a supplier and customer prevents. This exchange of information is of key component involving communicating what could be offered to the customer, what the customer wants and what customer will get.

How the stock availability (referred as customer service) will be affected is discussed in Chapter 12.1.911.

5. Previous research and solution tools

This chapter will contain a range of various methods applicable for modeling, studying, altering and problem solving in order to achieve desired results for this thesis. The chapter begins with reviewing previous research and then describing the concept of mathematical formulation and modulation. A brief description of optimization methods and simulation will end this chapter.

5.1. Previous research

In a literature review, Paterson *et al* (2011) categorizes previous research of inventory models with lateral transshipments. The definitions of lateral transshipments are shipments between stocks in the same echelon in the supply chain. This can be compared with enabling stock transfers between secondary DC's in the SMS distribution set up, see Chapter 7.6.2. Paterson *et al* (2011) implies that the flexibility of lateral transshipments between stocks in the same echelon allows an inventory system more difficult to control and optimize with respect to costs.

5.1.1. Proactive or reactive transshipments models

Paterson *et al* (2011) divides previous inventory models with lateral transshipments made in two types referred to as *proactive transshipments* and *reactive transshipments*. Proactive transshipment models are modeled with lateral stock transfers redistributed on certain predetermined times before total sales are known. Reactive transshipment models respond to situations of stock out or risk for stock out while another has sufficient stock at hand. Reactive transshipment models are suitable for a distribution set up where the transshipment costs are relatively low compared to inventory costs and the costs of not meeting the demand. Reactive transshipments can be compared with STO's and Backlog STO's reacting to the inventory level and customer demand in the Sandvik distribution set up, see Chapter 7.6.5. Reactive models are further divided into models with continuous review and periodic review. In models with a continuous review, the stock situation is reviewed continuously and in a model with periodic review the stock situation is reviewed periodically.

5.1.2. Complete or partial pooling

In the same review, Paterson *et al* (2011) divides the feature of sharing inventory amongst stock in inventory models with lateral transshipments in policy groups *complete pooling* or *partial pooling*. Complete pooling refers to models with the policy of sharing the whole inventory between the different stocks. Partial pooling refers to models with the policy of sharing parts of the inventory where some of the inventory is held back to cover future demands. Complete pooling can be compared with Sandvik's distribution network strategy in a backlog situation, see Chapter 7.6.5. Partial pooling can be compared to the Main DC set up sharing available stock to secondary DC's reaching their OP, but holding back the quantity if insufficient at the Main DC, described in Chapter 7.6.2.

5.1.3. Classification of previous research

Paterson *et al* (2011) classify literature, related to the inventory system, ordering and transshipments. A summary of how he classifies previous publications in the area can be seen in Table 5.

Table 5 - Classification of key characteristics of published literature made by Paterson *et al* (2011)

Definitions	Classifications
Number of items	1 or any number M
Number of echelons	1,2 or P
Number of locations	2,3 or any number N
Identical depots?	Yes, (identical) costs or no
Unsatisfied demands	Backorder or lost sales
Timing of regular orders	Continuous review or periodic review
Order policy	(R, Q), (s,S), (S – 1,S)
Type of transshipments	Proactive or reactive
Pooling	Complete or partial
Decision making	Centralized or decentralized
Transshipment cost structure	Per item, per transshipment, both or none

Number of items, echelons and locations refer to the amount of different inventory items, amount of levels in the distribution chain and the amount of stock locations. Identical depots refer to if each stock is assumed identical, identical in the aspect of costs or if variations exist between the different stock depots. Unsatisfied demands refer to if how the studied or modeled distribution system answers to unavailable stock which cannot meet the demand. In Paterson *et al* (2011) classifications, the unsatisfied demand is either a lost sale or a backorder. A backorder means that the order gets logged and postponed. Timing of regular orders refer to if the ordering system is periodic or if a continuous review of inventory levels are done and orders are placed at certain levels, see OP systems in Chapter 4.2.6.

Order policy refers to the policy of placing transshipment orders in the systems. The system in the review made by Paterson *et al* (2011), are either (R, Q), (s, S), (S – 1, S), General or Other. According to Cakanyildirim & Luo (2003), a (R, Q) policy is a policy where a fixed order quantity Q is placed immediately when the inventory positions is below OP denoted as R. According to Lee & Srinivasan (1987), (s, S) is a policy for a Production/Inventory System where production periods are tied to the inventory levels s and S. Lee & Srinivasan (1987) describe the order policy as a stop in the production the instant the inventory level reaches S and that production begins again the instant the inventory level reaches the level denoted as s. According to Feeny & Sherbrooke (1966), a (S – 1, S) policy is a policy where transshipments are decided entirely by a single decision, the spare stock s. Described by Feeny & Sherbrooke (1966), in with the (S – 1, S) policy a reorder of equal amount of units is placed immediately as an CO of an arbitrary number of units is accepted.

Decision making refers to if the transshipment decisions are centralized or decentralized in the distribution system. Transshipment cost structure is according to Paterson *et al* (2011), the cost components in the scope of each study is classified in costs per item, costs per transshipment, both or none.

5.1.4. Research in the field of inventory models with lateral transshipments

Table 6, illustrates Paterson *et al* (2011) classification assumptions made in similar research in the field of inventory models for lateral transshipments. Definition of each classification can be seen in above chapter and Table 5. The articles chosen are the articles with the highest amount of matches with this study according to the classification presented in Table 5.

Table 6 - Classification of the scope in four published articles according to Paterson *et al* (2011)

Classification according to (Paterson, et al., 2011)	(Axsäter, 2003)	(Needham & Evers, 1998)	(Huo & Li, 2007)	(Kranenburg & Houtum, 2009)
Number of items	1	1	1	M
Number of echelons	1	2	1	1
Number of locations	N	3	N	N
Identical depots?	No	Yes	No	No
Unsatisfied demands	Backorder	Lost sales	Backorder	Lost sales
Timing of regular orders	Continuous	Continuous	Continuous	Continuous
Order policy	(R, Q)	(R, Q)	(R, Q)	(S-1,S)
Type of transshipments	Reactive	Reactive	Reactive	Reactive
Pooling	Partial	Both	Complete	Partial
Decision making	Centralized	Centralized	Centralized	Centralized
Transshipment cost structure	Both	Item	Item	Item

Axsäter (2003) has created a model for deriving and evaluating a new decision rule for lateral transshipments in inventory systems. The model considers a standard holding cost, backorder cost and an ordering cost at each warehouse. The decision rule in the paper is based on expected costs which are minimized under the assumption that no further transshipments will take place. The decision rule should be used repeatedly as an approximation. Axsäter (2003) evaluated the new decision rule in a simulation study. This decision rule creates difficulties optimizing reorder points and batch quantities but works very well in the aspect of reducing costs.

Needham & Evers (1998) has evaluated the influence of individual cost factors on the use of emergency transshipments. The authors draw the conclusion through their simulation model that the transshipment decision is increasing the likelihood of lower overall costs when the stock out costs is generally high.

Huo & Li (2007) has created a batch order policy for a multi-location spare part inventory system, when emergency lateral transshipments are allowed. The model, model and optimize the optimal batch ordering with respect to the probability of meeting the demand with stock at hand, meeting the demand with emergency transshipment or meeting the demand with backordering.

Kranenburg & Houtum (2009) has created an inventory model of distributing spare parts with lateral transshipments. The inventory model contains an approximate evaluation method of partially sharing inventory with lateral transshipments. The approximate evaluation method is used in a greedy algorithm in a multi-item spare parts model. Kranenburg & Houtum (2009) exemplifies that by using partial pooling of inventory most of the benefits of full pooling can be obtained. The model has been implemented in the semiconductor supplying industry and has led to success in both reducing waiting times and costs.

5.2. Solution tools

One of the most investigated fields in mathematical inventory theory is according to Köchel & Nieländer (2005), a multi-location inventory model. To overcome restrictions in analytically controllable models, Langevin & Riopen (2005) believes that simulation can be used. Since simulation isn't an optimization tool, it is proposed by Kraneburg & Houtum (2009) to use a simulator combined with an appropriate optimization tool.

5.2.1. Definitions of different models

Kirkeby (1994) discusses the reason for modeling in science and research. A model has the purpose of describing the reality of an occurrence which cannot be observed directly. According to Fog (1993), as cited by Kirkeby (1994), science models are either verbal or mathematical. Mathematical models were created through expressed mathematical definition and equations, while a verbal model was expressed in words but created over mathematical truth. Further, static and dynamic models were set apart (see Figure 13). Static models were models not considered the aspect of time while dynamic models try to model the aspect of time. A static or dynamic model could also be deterministic or stochastic. A deterministic model uses exact values, while a stochastic model uses probability functions and introduces the dimension of randomness.

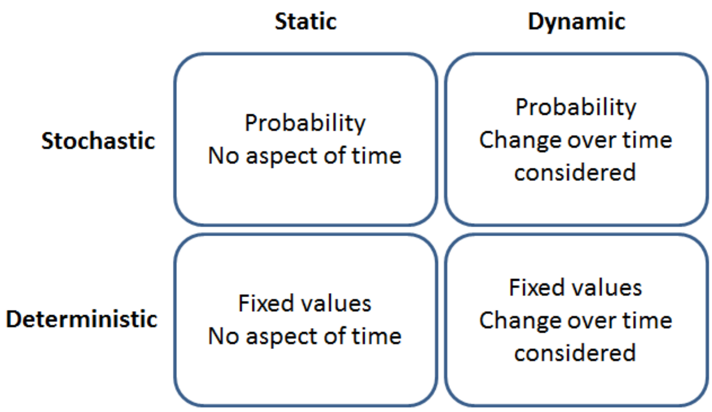


Figure 13-Four general model categories, inspired by definition written by Fog (1993), cited by Kirkeby (1994)

According to Carter (2001), static optimization is the search for the optimal choice at a single point in time. Dynamic models involve optimization over time. Dynamic optimization is applied on many economic models when optimizing variations in interest rates over time. Different techniques exist for dynamic optimization, but require extensions of static optimization techniques. Additional to combinations of static or dynamic and stochastic or deterministic models, modeling in simulation can either be continuous or discrete, according to Kelton *et al* (2008):

Continuous vs. Discrete

The state can change over time in a continuous model. In a discrete model changes can occur only at separated points in time, such as manufacturing systems with parts arriving and leaving at specific times. There is also a combined model called mixed continuous-discrete model were the model can handle both continuous and discrete changes.

5.2.2. Mathematical formulation

The purpose of modeling is to provide an understanding in how to reason when a model is formulated. Lundgren *et al* (2012) describes the first steps in the modeling process as identify and define decision variables and then introduce suitable notations, which will make it easier to understand and formulate the model and ease the conversion into a modeling language.

Described by Lundgren *et al* (2012) and Nocedal & Wright (2006), a model contains an objective function that is either to minimize or to maximize problem. Thereafter constraints are defining the objective within feasible region (the area between two constraint boundaries). Variables are used to define the amount during one time period. An index is included when extending a problem to several time periods or to represent categories or components. In short, Nocedal & Wright (2006) describes a mathematical formulation as a minimization or maximization of a function subject to constraints on its variables. According to Kelton *et al* (2008), a mathematical model is usually represented in a computer program exercised to address questions about the model's behavior. Most systems can be rather complicated which generates complicated models and therefore hard to solve by traditional tools. It is therefore useful, for instance, to use simulation as a tool.

5.2.3. Optimization models

Optimization models are often used to describe and analyze economic and technical systems by the use of mathematical models and methods to find the best alternative in decision making situations. The center of using optimization models is that something in the problem must be variable and able to be controlled or affected by the decision maker, also defined as the decision variables. A prerequisite for using optimization models, mentioned by Lundgren *et al* (2012) is that the objective and constraints can be expressed quantitatively in mathematical functions and relations. Areas of application are for instance transport-, logistics-, and packing problems.

When using an optimization model for analyzing a given problem, a given approach is used. Lundgren *et al* (2012) presents the optimization process, included a number of phases in Figure 14.

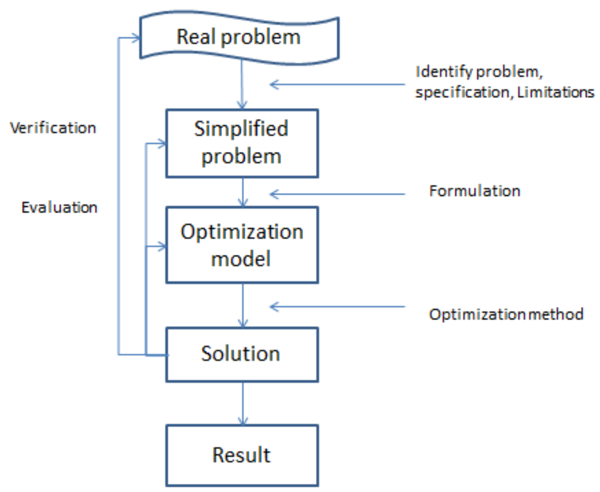


Figure 14 - An illustration of the optimization process by Lundgren *et al* (2012)

The main purpose of using optimization models and working with the optimization process is to provide support and guidelines for decisions in an actual problem. According to Lundgren *et al* (2012), an optimization model combined with a mathematical analysis of the model and solutions to the model will provide increased insights into the characteristics of the problem and the relations between its components. Willis *et al* (1996) writes that a proper application of an optimization method can reduce the time required in design and improving the cost of resulting plan.

5.2.4. Simulation

Banks (1998) and Kelton *et al* (2008) define simulation as an indispensable problem solving methodology for the solution of many real-world problems by imitating an operation, often over time. It is used to describe and analyze the behaviors of a system, ask what-if questions about the real world systems, and support the design of a real system. Reasons for analyzing systems by simulation are to measure its performance, improve its operation or design if it does not exist. Systems that are suitable for simulation, mentioned by Kelton *et al* (2008), are a distribution network of plants, warehouses and transportation links.

Basic simulation model components

To create and develop a simulation model, some types of components are necessary. Chung (2004) and Kelton *et al* (2008) are describing following components as the most major components in a simple simulation system:

- **Entities:** Entities are something that changes the state of the system. Entities are dynamic objects that are created, moved around and then disposed from the system. It can for instance be presented by either objects or persons. The number of entities that arrives at the same given time is called batch size and the amount of time between these arrivals is known as the inter-arrival time. To individualize entities, each entity may possess attributes, variables that are unique to each entity in the system.
- **Queues:** Queues are the simulation term for lines. Entities are waiting in line until it is their turn to be processed. There are also different queue priorities that can be used in a simulation model.
- **Resources:** Resources process or serve entities in queues. A resource can either be idle (available for recessing and there is no waiting entities in the queue) or busy (when processing entities). In more complex models, there is also resources that can be temporarily inactive (during meals, vacations, schedule work breaks etc.) or failed (when machines are broken or inoperative equipment). Resources take a certain amount of time when processing an entity, also called processing delay time or service time. Processing time is considered as input data.
- **Attributes:** An attributes is a common characteristic of all entities. Attributes are used to individualize entities with specific values that can differ from one entity to another. Examples of attributes mentioned by Kelton *et al* (2008), is Due Date, Priority and Color to indicate characteristics of individual entities.
- **Variables:** Variables is a piece of information that describes the characteristics of the entire system. In contrast with attributes, variables are not tied to a specific entity. Kelton *et al* (2008) describe variables as rewriteable writing on the wall.

6. Problem specification

This chapter will on the basis of the problem description and the frame of reference break down the problem of the thesis into objective questions used in the analysis for Part 1 and Part 2 respectively. The questions will therefore work as guidelines to ensure that the purpose of the thesis is answered.

6.1. Part 1 - The Main DC Switch

This study will analyze three different areas for Part 1 based on the delimitations and directives in Chapter 1.3 and Chapter 1.4.

To illustrate the different elements in each area for Part 1 see Figure 15 below.

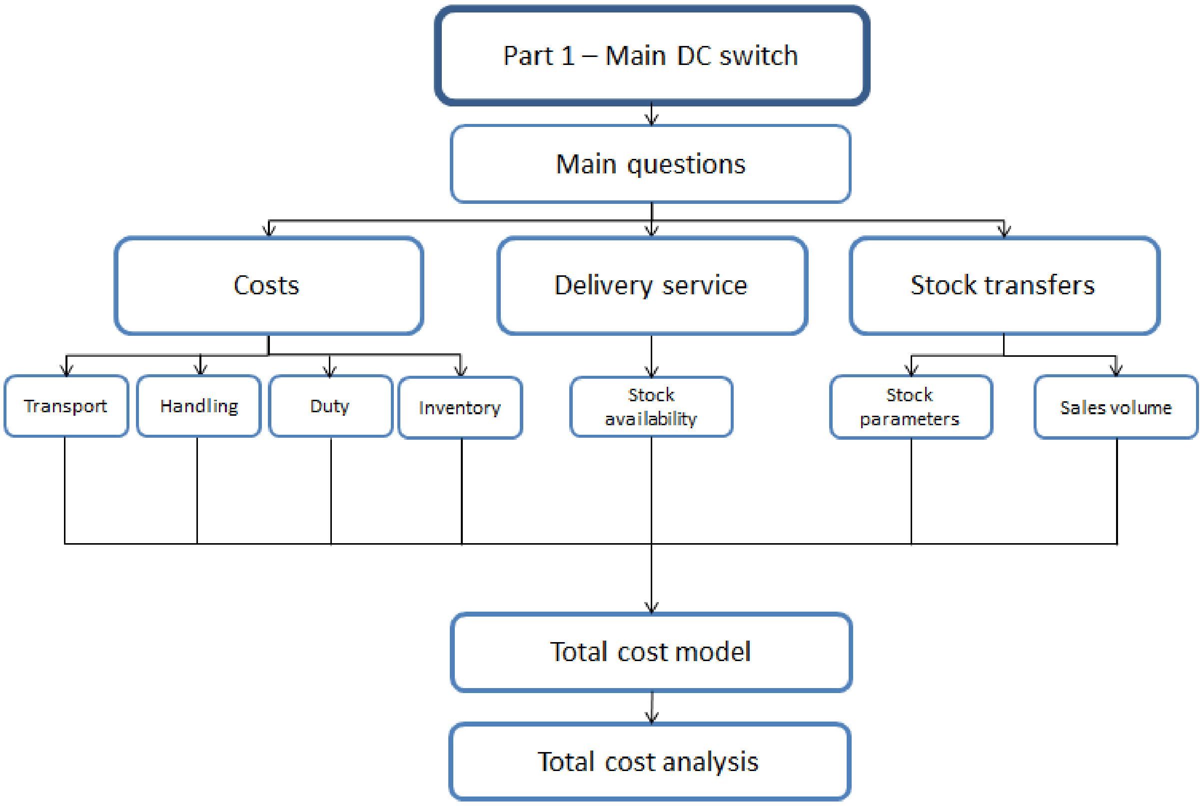


Figure 15 - Analysis area and the connected elements for Part 1

The elements of Part 1, as seen in Figure 15, belong to areas of interest for the results further in this study. It is also worth noting that the elements of each area are selected based on theory and what is assumed to be relevant for SMS.

The analysis will only consider transport-, handling- , duty- and inventory costs since these are the cost elements desired to investigate in this study. The second box, delivery service, will only be focusing on measurements of the SA since that is measured and used in terms of delivery service. The last area, actual sales for all DC's, will work as validating data to base the results on.

6.1.1. Costs

As written in Chapter 4.3, costs are important to consider when making any changes in a system or any part of a supply chain, since it affects multiple cost categories. In such aspect, the study will analyze the different costs relevant for this kind of change.

Transport

Since a Main DC switch would change the origins and destinations of stock transfer transports in the distribution network the transport costs would be affected. Since the Main DC is set up for each product individually, mentioned in the background, transport costs for each product is required. In the supply path set up for each product, a Main DC switch would also change the destination of the shipment from the PU to the DC. The transport cost between each PU and each DC for each product is therefore needed.

1. *What is the transport cost between PU's and DC's for each product?*
2. *What is the transport cost between DC's for each product?*

Handling cost

As described in Chapter 4.3.3, handling cost is an expense incurred every time a shipment is made. Whether if the shipment is to or from the PU or DC this cost need to be added in the total cost model.

Since this is a cost that is significantly affected depending on how the system handles the shipment of orders, this cost element is needed for analyzing the total cost of the distribution flow.

3. *What is the handling cost at each DC for each product?*

Duty

The differences in duty costs for shipments between DC's are assumed to be of interest as there is geographical differences between DC's. The current total duty expenditure of import or exporting shipments from each PU is assumed not to be affected since only the DC supply path set up would be changed in case of a Main DC switch. Neither is the current total duty expenditure of import customs for shipments to each customer affected in this assumption.

4. *What is the duty cost for shipments imported to each DC and for shipments exported from each DC, for every product?*

Inventory related

Inventory-related costs, described in Chapter 4.3.5, are assumed to be affected by a Main DC switch due to the possible change in inventory quantities and distribution of inventory. The products have different values depending on which product it is so the inventory carrying cost is therefore affected by the value of the product. The incremental inventory cost is assumed to be affected by the individual costs of running each DC respectively. Therefore, the product value and the landed cost factor at each DC and the cost of committing capital to inventory is required. The inventory carrying cost also includes the cost of handling inventory, insurance and risk costs. Shortage costs occur when an order is received and there is no available stock. The cost of inventory shortage is assumed not to increase as long as the service level is kept or improved. Due to the aim of keeping or improving the service level, the factor affecting the shortage cost is therefore kept out of scope.

5. *What is the inventory carrying cost per product in stock for each product and DC?*
    a. *Product value and landed cost factor*
    b. *Interest rate and committing capital to inventory and handling inventory*
    c. *Estimated cost of insurance and risk in carrying inventory*

6.1.2. Delivery service

Stated in the introduction, the purpose is to reduce the total cost while keeping/improving the service level. By letting the new Main DC inherit the values of EOQ and SS (more about this in Chapter 7.2.2) it is assumed that the availability is taken into account and therefore kept (Chapter 11.2.9 discusses this further). According to Chapter 7.5.7 the service level for SMS is measured in terms of SA. In Chapter 4.4, SA is mentioned to be one of the components defining delivery service.

Stock availability

The Main DC for a product provides the secondary DC's with the product. Since the SA is assumed to describe if a stock transfer is made or postponed, the SA is required to describe the current level of availability when an order is received at each DC. If there is no SA at a DC when an order is received, a backlog situation (Backlog STO), described in Chapter 7.6.5, will occur. As the Main DC is the responsible supplier for the secondary DC's, it is essential to find out which DC is set as Main DC for a product before looking into the SA for each product.

6. *Which DC is the Main DC for each product and PU?*

When the Main DC is known, the search of the SA is more valuable.

7. *What is the SA for each product and DC during 2013?*

6.1.3. Stock transfers

The stock transfer volumes describe the movement of inventory between the DC's and a Main DC switch is assumed to affect this movement of inventory.

Stock parameters

The OP generates the STO which creates the stock transfer. The fixed OQ is the quantity sent in a STO. The STO's, OP and OQ describe the movement of inventory, which is affected by a Main DC switch. Since the OP and the fixed OQ are automatically recalculated once every period of four weeks, data from every period during the whole delimited time period is required.

8. *What STO's has been sent between all DC's for each product during 2013?*
9. *What is the OP for each product and DC for each period during 2013?*
10. *What is the fixed OQ for each product and DC for each period during 2013?*

A SS level is kept for each product at each DC as a buffer to prevent stock outs. The SS is assumed to cover for to uncertainties, demand and supplier lead time at each DC, which is assumed to affect the stock transfer frequency in case of a Main DC switch. The SS also affect the inventory carrying cost.

11. *What is the SS for each product and DC for each period?*

Sales volume

CO's are sent to the customer's allocated DC and then supplied within the lead time if there is available stock. The sales volume is assumed to give information if a Main DC switch candidate would be identified with today's method. The sales volume at each DC is assumed not to be affected by a Main DC switch. However, a Main DC switch and the DC's sales volumes respectively are assumed to affect transports, inventory levels and movement of inventory.

12. What are the CO volumes for each product and DC during 2013?

6.2. Part 2 - The DC stock transfer logic

To analyze the effects of changes in the DC stock transfer logic, a comparison scenario must be created based on a situation analysis with present logics and statistics assumed to describe the current situation. The comparison scenario should contain all elements assumed to be affected by and affect a change in the DC stock transfer logic. Different elements for Part 2 are illustrated in Figure 16 below.

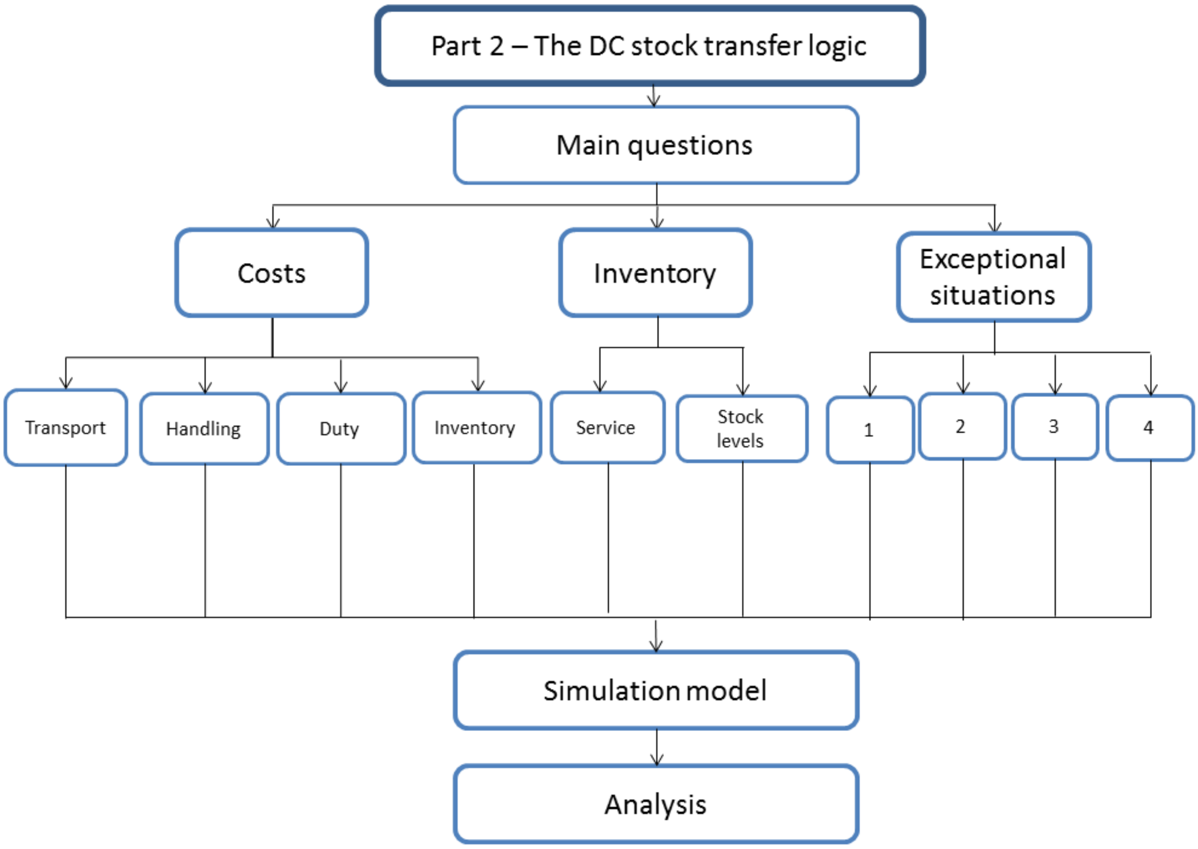


Figure 16 - Analysis area and the connected elements for Part 2

The decisions made by the DC stock transfer logic is assumed to be affected and limited by three elements; Costs, Inventory and Situations. A change in the DC stock transfer logic will affect costs when transports, handling, duty obligated and inventory levels are affected. Costs limit the changes in the DC stock transfer logic not to allow unrestrainedly high levels of inventory, transport frequencies and duty obligated events. A change in the DC stock transfer logic is assumed to affect inventory levels and SA due to the possibility of different stock transfer decisions being made by the system. The inventory service level and the stock levels limit the change of DC stock transfer logic not to worsen the current level of service. The changes in the DC stock transfer logic will be limited by the effect of new situations that might occur as a consequence of the change. The four exceptional situations will be further explained in Chapter 6.2.3.

6.2.1. Costs

Questions considering costs, questions 1-5 in Part 1, are assumed to be generic and be valid for Part 2.

6.2.2. Inventory

Inventory conditions are expected to be affected when changing the DC stock transfer logic. A change in the logic is assumed to either affect the movement of inventory, inventory quantities or distribution of inventory amongst DC's.

Stock levels

The stock level generates a STO when dropping below OP. Stock levels will therefore affect the movement of inventory. Since the stock level varies over time for every product, stock levels from 2013 is required. The stock levels for each product and DC is assumed to describe the current distribution of inventory amongst DC's.

13. *What is the stock level for each product and DC during 2013?*

The sampling rate (measurements per period) for stock levels must be high enough to give information about the movement of inventory. Therefore, OP levels for each product from each time period during the delimited time period is required. As the same delimited time period is surveyed in Part 1, the same OP's requested in question 9 could be used:

What is the OP for each product and DC for each period during 2013?

The OQ is also assumed to describe the movement of inventory and will therefore be affected by changes of the current DC stock transfer logic. Since the same delimited time period is surveyed in Part 2 as in Part 1, the same data as requested in question 10 can be used:

What is the fixed OQ for each product and DC during 2013?

The STO from 2013 is assumed to describe the movement of inventory with the current logic. As the inventory levels of DC's vary over time, and to get an overview of the current movement of inventory, the time when the STO is made is of interest. The STO's describe previous events and must already have occurred and therefore information from an historical delimited time period is required (question 8)

What STO's has been sent between all DC's for each product during 2013?

An OQ, which deviates from the fixed OQ is assumed to be a stock transfer in a backlog situation (Backlog STO), described in section 7.6.5. The priority of a Backlog STO is the same as the priority of the CO, while the ordinary STO is of lower priority. The information about the priority of the STO could therefore give information of the order type.

14. *What are the priorities of the STO's occurring during 2013?*

Another order type affecting the movement of inventory is when a Main DC sends a PO to a PU. Following questions are therefore stated:

15. *What PO's and at what time have PO's been sent to a PU for each product during 2013?*

Since the system state varies over time, the time for a STO and a PO to be fulfilled with a stock transfer or product replenishment is required.

16. *What is the replenishment time between a PU and DC for each product during 2013?*

The replenishment time between DC's as well.

17. What is the replenishment time between DC's for each product during 2013?

Service

The current SA for each order during the delimited time period is required to create a comparison scenario of the present service level (question 7).

What is the SA for each order of each product and DC during 2013?

6.2.3. Exceptional situations

Due to the current logic of the business system used for SMS distribution flows, SMS believe that certain situations occurring creates preventable activity and a preventable high total costs for the distribution of the intended product. This section summarizes four situations that are believed to cause this cost increase.

The section breaks down the problem in necessary information needed to identify these exceptional situations. All situations are illustrated with examples in Appendix 1.

Situation 1 – Multiple Backlog STO's sent after each other in a backlog situation

A Backlog STO is created when a DC has insufficient stock when a CO is received at the DC. When a Backlog STO is made, only the needed quantity to satisfy the CO is ordered by the enquiring DC, see Figure 17. If additional CO's are made during the same stock out additional Backlog STO's will be made, all separately. In a worst case scenario, the system will end up sending high amounts of separate shipments during a long period of time.

All Backlog STO's are sent in a predetermined specified search priority to the other DC's with the order EDC, APDC, ADC and then CDC. The search priority does not consider the different stock levels, actual sales, FC as longs as a DC has sufficient stock to meet the Backlog STO quantity. A Backlog STO is not sent if a regular STO is accepted and is under process.

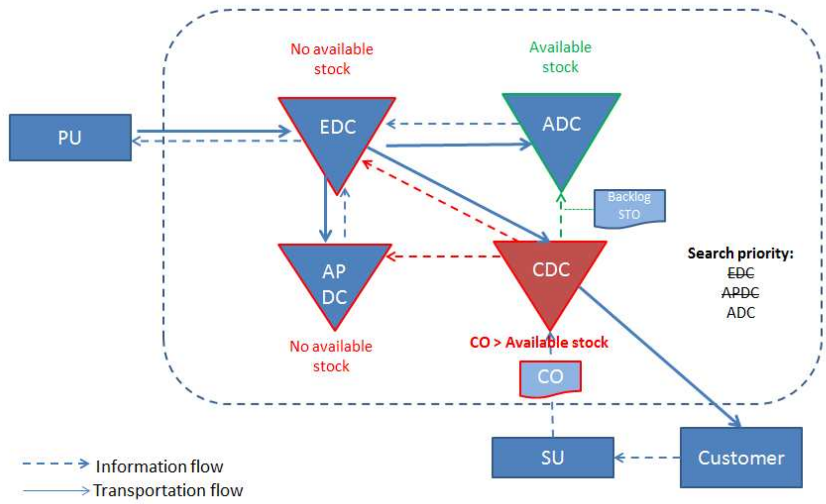


Figure 17 - A description of Situation 1- Backlog situation

In Figure 17, the enquiring DC is CDC. For every CO in this example sent to CDC and not satisfied by available stock, an individual Backlog STO's will be sent to ADC, according to the list of search priority. The inventory level in CDC will stay depleted until the regular order quantity replenishment (OQ) until the stock level gets below its OP, is received. During this waiting time many CO's can be received at the depleted DC (CDC in the figure) and generate many individual Backlog STO shipments from another DC (ADC in the figure), creating unnecessary costs and activities. A Backlog STO and a CO has the same priority, while the STO is of lower priority. The example meant to give a description of the procedure applied for all products and DC's. To know the exact time a DC crosses its OP or does not have enough available stock, the stock levels during the time of the order could give this information. To identify when and how often a backlog situation arises, the following questions are asked (question 13 and 14):

What are the stock levels at all DC's during 2013?

What are the priorities of the STO's occurring during 2013?

It is assumed that if the desired quantity does not correspond to the OQ of the product, it is a backlog order. The priority is assumed to give information if the order is a STO/CO or a Backlog STO. To identify if any backlog orders can be partly or entirely consolidated, it is relevant to know if any Backlog STO's have been sent after each other. Below question have therefore been created:

18. *How many Backlog STO's are sent after each other during 2013?*

This is requested in order to analyze if it is possible to improve the efficiency of transports and eliminate unnecessary activities and costs. If these questions are answered, a description of the current extent of which situation 1 is made.

Situation 2 - Fixed OQ disfavors secondary DC

When the stock level is below OP at secondary DC's (ADC, APDC and CDC in Figure 18 (the same figure used as Figure 1) the STO for replenishment is sent to the Main DC (EDC in the figure).

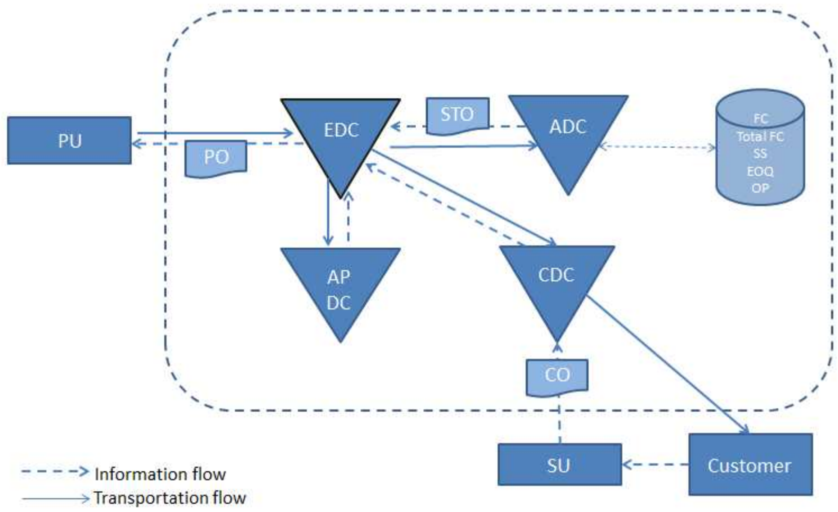


Figure 18 - A description of Situation 2- Fixed OQ disfavors secondary DC

An exceptional situation can occur if the Main DC cannot offer the entire fixed OQ to the secondary DC. In the example, even if EDC would have enough stock available to partly send quantities to the secondary DC in need, the secondary DC will be denied any requested quantities. As a consequence, the secondary DC might even become depleted and start sending Backlog STO's, described in Situation 1. To identify when the Main DC partially are able to supply the orders placed or when the

Main DC actually are unable to support the secondary DC at all, below questions are asked (same as question 17).

19. *At what times have the STO's from secondary DC's been denied and postponed for each product during 2013?*

What is the replenishment time between DC's for each product during 2013?

It is also interesting to know the stock level at all DC's during the times a STO from secondary DC's has been denied and postponed. To know which OQ's that has been denied by the Main DC, the following question is needed (question 10).

What is the fixed OQ for each product and DC for each period during 2013?

These questions will answer how often and when an STO from a secondary DC is denied by the Main DC. This information combined with the stock levels may indicate whether actual supply is possible or not.

Situation 3 - Fixed OQ disfavors Main DC

When the stock level is below the OP at secondary DC's the STO for replenishment is sent to the Main DC. By using the same figure as before, Figure 19 below, ADC, APDC and CDC are secondary DC's.

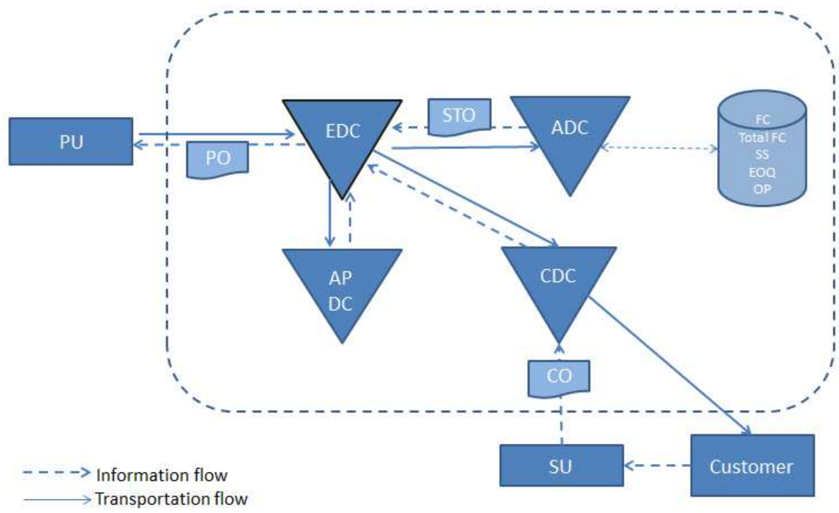


Figure 19 - A description of Situation 3- Fixed OQ disfavors Main DC

An exceptional situation can occur when the stock level at ADC, APDC or CDC just falls below the OP but still, due to the current logic, order an entire fixed OQ. Yet, the Main DC (EDC in Figure 19) gets depleted to low inventory levels but are facing much higher order volumes, than the secondary DC making this STO. As a consequence, the inventory of the Main DC might even become depleted and has to call back quantities with a Backlog STO, described in Situation 1. To know when a Main DC is drained of large amount of inventory and to know if STO's to secondary DC's was urgent enough to be served, following questions are needed (question 15 and 16):

What PO's and at what time have PO's been sent to a PU for each product during 2013?

What is the replenishment time between a PU and DC for each product during 2013?

Situation 4a - Main DC creating a PO instead of checking another secondary DCs first

A PO is created and sent to the supplier when the stock level at a Main DC is below or at its OP. In a certain situation, the demand of certain products at secondary DC's may decrease over time. When this occurs, there may be situations where the desired product is available in another DC and the Main DC does not necessarily need to send a new PO. However, in the stock transfer generation logic, the Main DC does not consider stock levels at secondary DC's and therefore sends the PO anyway. This situation will continue feeding the system with inventory, which will increase the total inventory to unnecessary high levels of a product. To identify if quantities from secondary DC's can be used instead of placing a new production order to the PU, following questions are stated (8 and 15):

What STO's has been sent between all DC's for each product during 2013?

What PO's and at what time have PO's been sent to a PU for each product during 2013?

To know the sales at each DC, question 12 is stated:

What are the CO volumes for each product and DC during 2013?

To identify when a secondary DC has unnecessarily high stock levels, while this stock could be used in a Main DC, question 13 is asked:

What is the stock level of each DC for each product during 2013?

Situation 4b - Secondary DC creating a STO instead of checking other secondary DCs first

This exceptional situation is similar to situation 4a above but with the difference that the secondary DC is creating a STO before tracking stock levels at the other DC's. The consequence is the same as for 4a, and will therefore affect the inventory and thereby increase the costs. To identify such a situation, the sales at each DC, the STO's sent between DC's, inventory levels at each DC's when it occurs is needed (question 8, 12 and 13):

What STO's has been sent between all DC's for each product during 2013?

What is the stock level of each DC for each product during 2013?

What are the CO volumes for each product and DC during 2013?

6.3. Continuing questions at a general level

These questions are needed at a general level in order to verify the data being analyzed.

20. *What is the FC and total FC for each product and DC for each period, during 2013?*
21. *What frequency group does the product belong to?*

6.4. Summary of the chapter

Table 7 below summarizes the questions that were created in this chapter. The table presents in which part and specific situation the question is used, if the question is only stated once.

Table 7 – A summary of the questions stated in Chapter 6

	Question	Part	Answered in
1	*What is the transport cost between PU's and DC's for each product?*	1 and 2	7.7.1
2	*What is the transport cost between DC's for each product?*	1 and 2	7.7.1
3	*What is the handling cost at each DC's for each product?*	1 and 2	7.7.2
4	*What is the duty cost for shipments imported to each DC and for shipments exported from each DC, for every product?*	1 and 2	7.7.3
5	*What is the inventory carrying cost per product in stock for each product and DC?*	1 and 2	7.7.4
6	*Which DC is the Main DC for each product and PU?*	1 and 2	7.2
7	*What is the SA for each product and DC during 2013?*	1 and 2	7.5.7
8	*What STO's has been sent between all DC's for each product during 2013?*	1 and 2	7.6.2
9	*What is the OP for each product and DC for each period during 2013?*	1 and 2	7.5.3
10	*What is the fixed OQ for each product and DC for each period during 2013?*	1 and 2	7.5.4 and 7.5.5
11	*What is the SS for each product and DC for each period?*	1 and 2	7.5.2
12	*What are the CO volumes for each product and DC during 2013?*	1 and 2	7.6.3
13	*What is the stock level for each product and DC during 2013?*	2 (Situation 1 and 4)	7.5
14	*What are the priorities of the STO's occurring during 2013?*	2 (Situation 1)	7.6.4
15	*What PO's and at what time have PO's been sent to a PU for each product during 2013?*	2 (Situation 3 and 4)	7.6.1
16	*What is the replenishment time between a PU and DC for each product during 2013?*	2 (Situation 3)	7.6.2
17	*What is the replenishment time between DC's for each product during 2013?*	2 (Situation 2)	7.6.1
18	*How many Backlog STO's are sent after each other during 2013?*	2 (Situation 1)	7.6.5
19	*At what times have the STO's from secondary DC's been denied and postponed for each product during 2013?*	2 (Situation 2)	7.6.2
20	*What is the FC and total FC for each product and DC for each period, during 2013?*	Validation	7.5.1
21	*What frequency group does the product belong to?*	1	7.4.2

7. Empirics

This chapter aims to present the empirical data describing the design of the distribution system and data requested in the problem specification in Chapter 6.4 and Table 7. Since some of the data is too large to present in the report, a description of how the data was obtained will only be written in those cases. The chapter begins with the description on how the current Main DC distribution set up is decided, with the opportunities available today followed by a description of secondary DC's and classification of products. A section will also concern the supply path and logic used at SMS today, including terms and concepts. The chapter is divided by the different elements and costs used to calculate, model and analyze for Part 1 and Part 2 in the later Chapters 8 and 9.

7.1. Theoretical definition of the distribution system

The business strategy, method of supplying materials for the defined scope is MTS, see Chapter 4.2.7. After the CDP, the desired lead time to the customer is 24 hours. The CDP is located at the DC. This means that the DC's must have a satisfying stock level to be able to provide the customer when a CO is received. The system of the distribution used by SMS is called an OP system, see Chapter 4.2.6.

7.2. Main DC

The Main DC for a given product is the DC/DC's that get the product delivered directly from one PU. The Main DC then supply the secondary DC's with products. For a given product, the DC's supplied by a PU is assumed to be a Main DC and the DC's supplied from a DC was assumed to be secondary DC's. For the assortment chosen, only a single Main DC is supplying the other DC's for each product. This information is retrieved with the data of the actual supplier for each product at each DC from the company's ERP-system.

7.2.1. Initial decision of Main DC

The initial supply chain set for a product is decided in projects, which contains a decision of main DC and PU. This decision is not taken by SMS. Therefore they cannot affect anything in the initial choice of Main DC. The DC distribution set up decision is embedded in the set supplier step. Since the DC distribution set up is highly affected by the decision of PU, the two decisions are made in combination. The DC distribution set up is made on a case by case basis and is decided based on numerous factors.

Example of the most common factors affecting the initial decision of DC distribution set up:

- Possible candidates
  - Alternative possible combinations of PU's and Main DC's for the new product
  - PU with available capacity and technology
- Market
  - Expected sales at each DC
- Costs
  - Distance between Main DC candidates and PU set to produce the new product
- Set up of similar products

When the initial supply path is set up and the product is released, the planning function is taking over the responsibility of choosing a Main DC distribution set up minimizing the cost of distribution set up.

7.2.2. Main DC switch

The planning function is responsible of following up how the actual sales match the expected sales for each product. During large deviation in the different regions between actual sales at the DC's and the expected sales the products supply path is flagged by a report generated by the ERP-system (see Table 8). The planners then consider if a Main DC switch should be done on a case by case basis.

Table 8 – Sales deviation criteria when a Main DC set up is flagged according to Eurenius *et al* (2014)

Product group	Flag possible Main DC switch if:
Inserts	Order intakes and order lines to Main DC < 30 % of total sales for given product and Order intakes and order lines to a secondary DC > 50% of total sales for given product
Tools	Order intakes and order lines to Main DC < 30 % of total sales for given product and Order intakes and order lines to a secondary DC > 50% of total sales for given product
Round Tools	Order intake to a secondary DC > 50% of total sales for given product

The Main DC switch with the included changes in the supply set up must be done for each of the products individually. When a Main DC switch is done, the new Main DC inherits the value of EOQ and SS, manually done by the planner. The parameters are then recalculated each period. For the new secondary DC, previously the Main DC, a new value of OQ and SS is needed to be estimated. The calculations are made as described in Chapter 7.2.2.

7.2.3. Strategy of multiple Main DC's

In a Multi-Main DC strategy, the PU delivers to two or three Main DC's instead of only one. The criterion to use the Multi-Main DC strategy is when the estimated OQ for more than one DC exceeds a certain threshold value (EOQMAX[5]). Estimated OQ's are generated per Main DC candidate based on the Main DC candidates Total FC. The threshold value EOQMAX is a fixed parameter value for every product, set by the PU. This means that if the estimated order volumes can supply more than one Main DC candidate, multiple Main DC's should be used for this product.

7.3. Secondary DC

A secondary DC for a given product is the DC that gets the product delivered from the connected Main DC for that given product.

7.3.1. Shipping to a DC via another DC

Some PU's cannot deliver to all DC's directly, even if choosing an unfeasible Main DC for a product from a certain PU is desirable. The reason is as simple as there is currently no particular route between these nodes. In this case, the PU can deliver to this DC via another DC. The transshipping DC will then just work as a transshipment node and a new order will be instantly created sending the product to the intended Main DC. In the current supply path strategy, transshipping to a DC via another DC is only used if the PU cannot ship to the Main DC directly. This concept is at SMS denoted as cross docking[6]. This does mean that an extra handling cost, described in Chapter 7.7.2, will be added.

[5] SMS threshold value of the minimum OQ for adding multiple Main DC's to the distribution set up.

[6] In theory, cross docking means that the product is not sent to long term stock and instead transshipped to intended destination (Langevin & Riopel, 2005).

Investigating new transport costs alternatives of new non-existing routes is kept out of scope and interest. But even if this is the current situation, it is still interesting to use the possibility to ship “directly” to a DC.

7.4. Classification of products

Depending on the life cycle state on the product is, which frequency group the product belongs to and how expensive the cost of the production, the products are handled differently. This is done to achieve the lowest cost possible and not having to finance for unnecessary activities but also to be able to differentiate service levels. The classifications mentioned below are the ones used for the products in the scope of this study.

7.4.1. Life cycle state

The life cycle state (LCS) classifies the current state of the product life cycle. The LCS is decided by the product manager and cannot be changed by SMS. The LCS is divided in five groups, which determine the pricing and handling of the product, both in stock and at the market which indicated how to handle the product during its life cycle. The different grades of LCS are defined below with values and explanation:

LCS 10 - The product is only registered in the system but not for sale (registered product)

LCS 20 - A product which is released on the market and for sale (released product)

LCS 30 - A product that will be phased out at a defined time in the upcoming future (phasing out)

LCS 40- The product is no longer produced but is selling out of what is left in stock (no replenishment from PU)

LCS 90 - A product that is no longer in stock, produced and are no longer in the system (merely logged as obsolete)

7.4.2. Frequency groups and production costs groups

Products are divided in two different groups based on order frequency and production costs. This is calculated by the amount of orders received for the specific product. These values are updated every period since it is used in the calculated of SS and was obtained by their ERP-system, for each product during 2013.

FREQ 10 - High frequent product

FREQ 20 - Medium high frequent

FREQ 30 - Medium low frequent product

FREQ 40 - Low frequent product

The classification of production cost is divided in two groups (PK) and is also updated every period due to the use in calculations of SS:

PK 10 - Less expensive product

PK 20 - Expensive product

7.5. Stock parameters

For every DC at every period a recalculation of OP, SS, FC, Total FC and OQ are made automatically in the system. The EOQ for Main DC stocks are not updated automatically every four weeks. The EOQ at a Main DC needs to be updated manually.

This was retrieved from the ERP-system by retrieving the initial stock level in the beginning of each month during the delimited time period of 2013.

7.5.1. Sales forecast and Total forecast

The sales forecast (FC) is based on historical order intake from the last 24 periods. Total forecast (Total FC) is a parameter based on the calculated FC. In the Main DC is the Total FC equal the FC in all secondary DC's. The Total FC in a Main DC is based on its FC and the FC of all the DC's it supports with products, see Figure 20. This information was obtained from the ERP-system. The FC was presented as a mean value for each product and DC during 2013

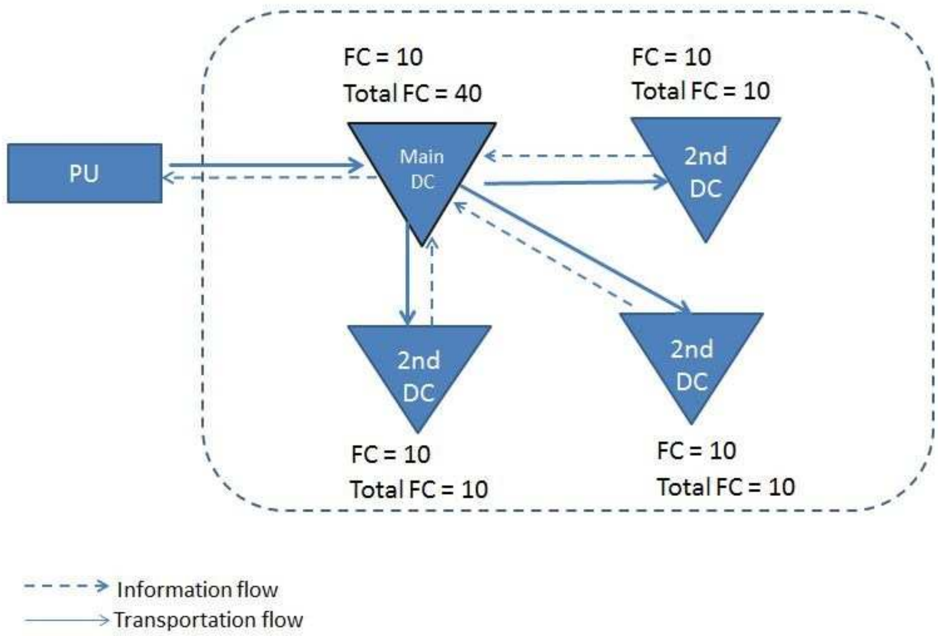


Figure 20 - An example of how FC and Total FC is determined

7.5.2. Safety Stock

In order to cover the variations in demand and supply, a safety stock (SS) is used. There are two uncertainties included in the calculation: the uncertainty in the FC and the uncertainty in supply lead time.

As mentioned in Chapter 7.2.2 is the value of SS inherited when a Main DC switch is made but has to be recalculated for the new chosen secondary DC. The formula used when calculating the SS is shown in equation 2a below:

$$SS = 1{,}25 * \text{MAD} * \text{Security factor} * \text{Exposure factor} * \text{Exposure constant} * \text{Lead time}^{0{,}65} \quad (2a)$$

$$\text{Exposure factor} = \frac{\frac{\text{Annual Total FC}}{52}}{\text{OQ}} * \text{Leadtime in weeks} \quad (2b)$$

The MAD is the mean absolute deviation from the FC and the security factor is a factor based on the desired service level of the product. The exposure constant is a security constant based on the frequency group of the product. The lead time is the time between order and replenishment and is measured in whole periods, where each period is four weeks.

The used SS in the total cost analysis is the mean value for each product and DC during 2013, achieved from the ERP-system.

7.5.3. Order point

The order point (OP) for each DC varies depending on the product. The OP level is calculated to be enough to cover the weekly FC during the lead time in weeks without consuming the SS levels, see equation 3. The OP was obtained from the ERP-system for each product and DC during 2013

$$OP = SS + \frac{Total\ FC}{week} * Lead\ time\ in\ weeks \tag{3}$$

7.5.4. Economic order quantity

The Wilson formula is used to calculate the economic order quantity (EOQ) for replenishment orders to a PU from a Main DC (see Chapter 4.2.6). The EOQ is set by the central Supply Chain Planning function and manually recalculated 4-6 times a year by the planner and rounded to cassette size. In the case of a Main DC switch, the new Main DC inherits the EOQ from the old Main DC and the old Main DC gets a new OQ instead.

7.5.5. Secondary DC order quantity

When calculating the order quantity (OQ) for the secondary DC’s, a predefined quantity is set based on the FC and which frequency groups the product belongs to. The OQ equals one or two months FC rounded to cassette size, described in Chapter 7.5.6, depending on the frequency group (equation 4).

$$OQ = \begin{cases} 1 * FC\ if\ frequency\ group\ is\ 10\ or\ 20 \\ else\ 2 * FC \end{cases} \tag{4}$$

This formula is used for items with LCS equals to 20, which are all products in scope.

In this study is the OQ only calculated when a Main DC switch has been made and the old Main DC needs a new OQ to use. Otherwise the fixed OQ has been found in the ERP-system.

7.5.6. Minimum OQ and cassette size

Depending on the product group, OQ for a certain product has a minimum threshold value called the minimum batch quantity (Min OQ). If the calculated OQ is below Min OQ it is automatically rounded up to Min OQ. The Min OQ depends on the product group. The Min OQ for Inserts equals 10 products and equals 1 product for all other product groups in scope.

All SMS products are packed in dispensers, plastic boxes or other packing materials. To make it easier to store the products in the DC’s and to distribute the product from PU to DC and between DC’s, the majority of the items are also packed in boxes (cassettes). When calculating OQ the cassette size is considered. The OQ is therefore calculated according to equation 4 and the system tries to round the calculated OQ to closest multiple of the cassette size. If the FC is smaller than 80 % of the OQ when rounded to cassette size, the OQ will not be rounded to cassette size.

7.5.7. Service level - Stock availability

The service level is measured in stock availability (SA) where the business system detects whether an ordered product is available in the right quantity in stock when an order is received (value 1) or not (value 0). The sum of these values generates a percentage of the SA, which is the service level of the ordered product.

The availability in stock has been received from the same data as above questions, which is the ERP-system. The information of the SA is presented for each order placed in the distribution system, is the date the order was requested, the quantity of the order and the date the order was shipped. This data gives the information if the DC can deliver the requested quantity the same date as the order was placed. The SA is divided in SA0, SA1 and SA7. The number behind "SA" represents the number of days the order is in stock before it can be sent to customers. That is, if a DC sends the order the same day as the order was placed, the system displays a "1" for SA0, SA1 and SA7. If the order is not in stock when it was placed, a "0" is placed in the column of SA0. However, if the order would be sent one day later, a "1" shows in the column of SA1 and for SA7. If the order could not be sent until 7 days later, there is only a "1" under SA7 and "0" under SA0 and SA1.

7.6. Orders

Figure 21 illustrates three different kinds of orders affecting the movement of inventory among the DC's; the PO, STO and the CO, also described in Chapter 1.1. The orders made by customers or DC's (either between DC's or as a PO from a DC to a PU) are, as described earlier in the report, of great importance in order to analyze the system. This following section will describe PO, STO and CO occurring in the scope of this study.

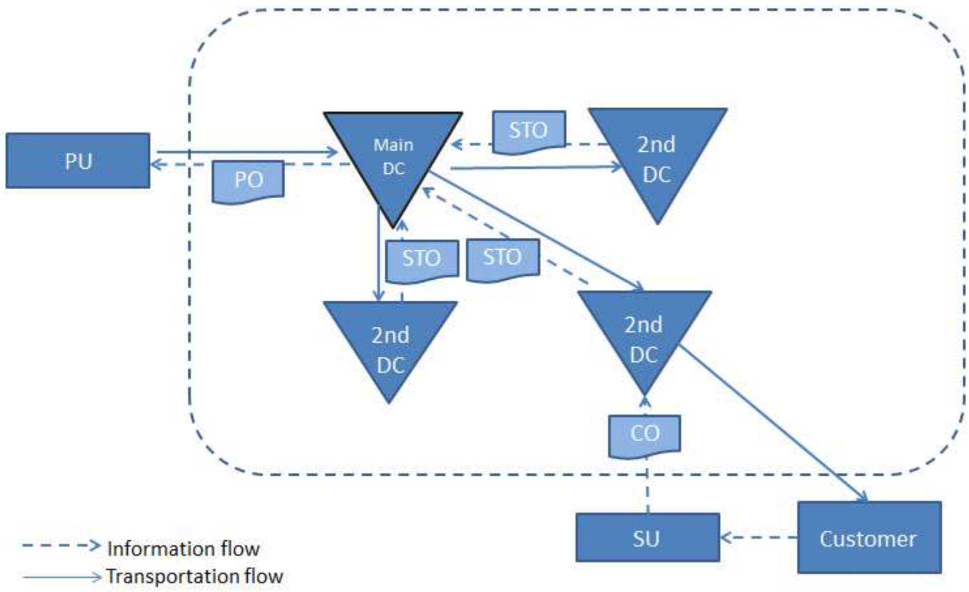


Figure 21 - The figure illustrate the different kinds of orders sent between the DC's

7.6.1. Purchase order

When the stock level of a specific product in the Main DC is at or below the OP, a purchase order (PO) is sent to the PU set up as supplier to the Main DC for this product. The PO always requests a predefined quantity (EOQ). The PU will then replenish the product in various replenishment times (3-

8 weeks) depending on the product. When a PU receives a PO, the PO turns into a production order when accepted at PU. The replenishment time is individually set for each product. Since Part 2 will not change the current Main DC set up and the products will be simulated individually, the product replenishment time obtained from the ERP-system will be used. Due to the large amount of products all different replenishment times from PU to DC will not be presented in a table in the report.

7.6.2. Replenishment stock transfer order

A stock transfer order (STO) is sent to the Main DC when available stock in a secondary DC is less than OP. The STO is always sent in a predefined quantity (OQ). The STO order is only sent if the delivering DC has 10% of its FC left after delivering the order. Otherwise, the order is reserved and not sent until the Main DC is supplied by a PU.

All STO's with information of November and December 2013 of each STO's product, arrival date, priority and DC's involved in the shipment, is obtained from the ERP-system.

Times where STO's are denied of each STO is obtained from the ERP-system during November and December 2013. Information about denied and postponed STO's are obtained in terms of order date and shipment date. If the difference between order date and shipment date of the STO deviates from the average process time the STO is assumed to have been postponed.

Replenishment times for secondary DC's where received from the DC DW Report of 2013 and in consultation with the Transport and Shipping Manager with colleagues at Santrade Ltd. The transport time in days between DC and DC is presented in Table 9.

Table 9 - Transport time from DC to DC according to DC DW Report 2013 in days

		From			
		EDC	ADC	APDC	CDC
To	EDC	X	3.68	2.42	7.18
	ADC	2.85	X	3.23	6.67
	APDC	2.41	3.23	X	3.85
	CDC	3.56	4.68	2.71	X

The replenishment times in above table are registered average durations between the time the order has been sent and the time the order is at the shelf of the DC at the final destination. The reason why the time differs between the different destinations depending on which direction the shipment is done, is because of the different transport agreement between the DC and the carrier.

An estimated STO process time between an order and shipment were added to the replenishment time to compensate the time between the orders receiving to its shipment. This compensated time has been estimated to 0.5 days. The replenishment time including the order process time is presented in Table 10.

Table 10 - Replenishment time including order process time from DC to DC in days

		From			
		EDC	ADC	APDC	CDC
To	EDC	X	4.18	2.92	7.68
	ADC	3.35	X	3.73	7.17
	APDC	2.91	3.73	X	4.35
	CDC	4.06	5.18	3.21	X

7.6.3. Customer order

The SU's handles all the contact with the customers. The customer order (CO) is sent to the DC that the SU is linked to. The DC sends the ordered quantity of the ordered product to the customer and sends an invoice to the SU handling the contact with the customer. The SU sends the invoice to the customer. The data relating to CO's received from the company's ERP-system also consist of data of which product that was requested, the supplied DC, the requested- and shipped date, the quantity of the order, the associated SU and customer market. The volume of the CO was then achieved by summarizing all CO's for each product and DC.

7.6.4. Priority of customer orders and stock transfer orders

There are two kinds of orders that might conflict; the CO and the STO. To avoid confliction, the system uses a priority list where 7 correspond to the highest priority and 0 as the lowest priority. A CO has the highest priority (priority 7) and will pass the queue of lower priority orders while STO's have the lowest priority (priority 0). This means that the available stock left, after satisfying all orders of higher priority, must be enough to cover the STO for the STO to be shipped. When a DC receives orders of the same priority, the first order received is prioritized. The priority levels of the STO's are urgent and non-urgent. An urgent STO is a STO with a waiting CO which will be described in Chapter 7.6.4. A non-urgent STO is a regular STO generated when a secondary DC's stock level falls below OP.

7.6.5. Stock transfer order logic in a backlog situation

A backlog situation occurs when available stock of a product is insufficient to supply a CO received at a DC (Backlog STO). The DC then looks for available stock in the other DC's in a specified search priority. A Backlog STO is sent to the DC with the highest search priority which has available stock. The Backlog STO has the same priority as a CO (priority 7) at the requested DC. The size of the Backlog STO always equals the quantity that is missing in the enquiring DC. Note that even if the first DC at the priority list has a part of the requested quantity it would not send it. That means that the DC that first has the whole requested quantity can send the products to the enquiring DC. The same specified search priority is used both in a Main DC and in a secondary DC when a backlog situation occurs.

If an STO shipment is on the way, a Backlog STO is not sent if the quantity of the STO is enough to cover all waiting CO's. The specified search priority, regardless of product, is defined as:

1. EDC (Netherlands)
2. APDC (Singapore)
3. ADC (US)
4. CDC (China)

Figure 22 below illustrates an example of a backlog situation. A CO is received at CDC but the CO exceeds available stock and a backlog situation occurs. CDC uses the specified search priority to find available stock. EDC has the highest search priority but has no available stock. CDC turns to APDC which has the second highest search priority but does not have available stock either. Finally CDC checks ADC which has available stock. A Backlog STO is sent to ADC and gets the same priority as a CO at ADC. The size of the Backlog STO is the exact amount that is missing to satisfy the CO at CDC.

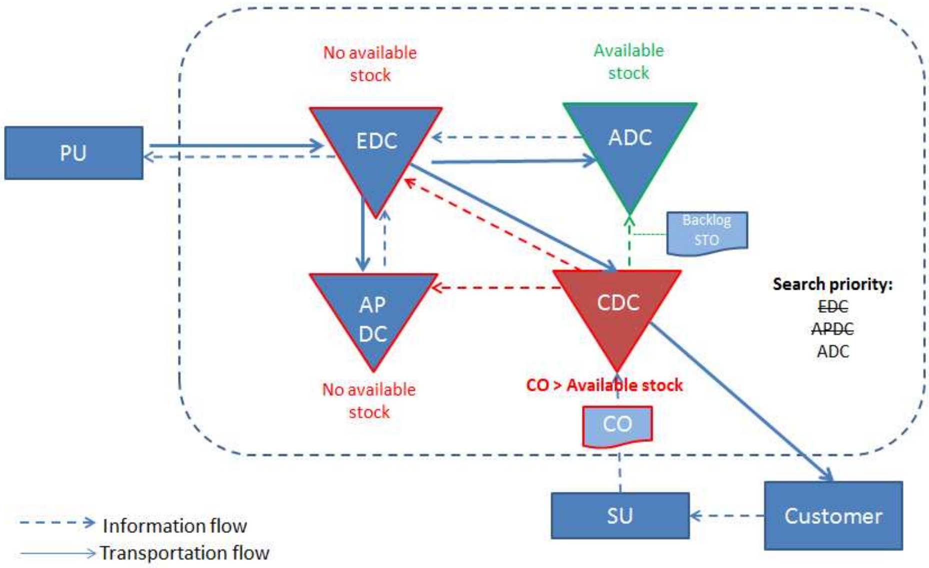


Figure 22 - An example of a backlog situation, where CDC has insufficient stock

Data of STO's contains arrival date, departure date, released quantity and priority. All orders with an urgent priority equal the Backlog STO's. Products with high amounts of Backlog STO's are identified and analyzed further in Part 2.

7.7. Costs

The different cost elements in scope are as earlier described: transport, handling, duty and inventory related. The below subchapters are consequently the basis of the total cost analysis. All costs are shown in EUR.

7.7.1. Transport costs

In order to find out the transport cost, questions were asked to the Transport and Shipping Manager at EDC together with colleagues at all DC's, to create a matrix of transport costs. The presented transport costs in Table 11 and Table 12 are estimated by the total cost of transport during 2013 divided by the total weight transported between origin and destination during 2013, and is measured in cost per weight unit (kg). The cost is therefore complemented with the weight of each product and the transport size of each shipment, which are obtained from the ERP-system. The weight and the transport size are then multiplied with the cost-matrix below to determine the transport cost of each transport. The transport size is estimated to equal the order quantity at the destination DC. All shipments of products in scope are transported by air.

Note that this transport cost, according to the directive 3, cannot be presented by its real costs. The transport costs are therefore presented with value 1. The transport cost between PU's and DC's per weight unit (kg) and presented in Table 11. Note that some transports between a PU and DC needs to be transshipped via another DC (marked with *).

Table 11 - Transport cost between PU and DC (EUR/kg)

		To			
	PU name	EDC (4)	ADC (7)	CDC (8)	APDC (9)
From	Semine Inserts	1***	1***	1***	1
	Pune Tools	1	1	1***	1
	Fondettes Tools	1	1*	1*	1*
	Fondettes Inserts	1	1*	1*	1*
	Westminister Inserts	1**	1	1**	1**
	Gimo Inserts	1	1	1*	1
	Gimo Tools	1	1	1*	1
	Langfang Tools	1	1***	1***	1
	Mebane Tools	1**	1	1**	1
	Langfang Inserts	1	1***	1***	1

*Shipment via EDC, transport cost equals the transport cost between PU to EDC and EDC to the DC (table 11)

**Shipment via ADC, transport cost equals the transport cost between PU to ADC and ADC to the DC (table 11)

***Shipment via APDC, transport cost equals the transport cost between PU to APDC and APDC to the DC (table 11)

Transport cost between DC's (question 2 above) can be seen in Table 12. All costs are shown in EUR.

Table 12 - Transport cost between DC's (EUR/kg)

		To			
		EDC (4)	ADC (7)	CDC (8)	APDC (9)
From	EDC (4)	0	1	1	1
	ADC (7)	1	0	1	1
	CDC (8)	1	1	0	1
	APDC (9)	1	1	1	0

Since the transport cost is depending on the forwarder, the included cost elements differ due to the transportation mode. Examples of cost embedded in the transportation cost are following mentioned by De Clercq (2014): fuel surcharge, remote area, residential address and correction of address, brokerage fee, non-conveyable and non-stacking. Note that the above mentioned costs are based on the volume predicted to be sent between above nodes since the cost tariffs between Sandvik and shippers are negotiated. If there are high volumes of products shipped between an origin and destination, the transport cost per kg are generally negotiated to be lower than between other nodes where the transported volumes are lower.

7.7.2. Handling cost

The cost of handling occurs each time a shipment of products enters a DC and leaves a DC. This means that the handling cost in this study is simplified and does not depend on the weight of the product or the amount of products in a shipment. The handling cost only depends on the number of shipments/transports entering and leaving the DC. The handling costs at PU's are assumed to stay the same no matter of which DC's it supplies and are therefore kept out of scope. All handling costs are shown in EUR, see Table 13.

Table 13 - Handling cost for shipment entering and leaving the DC (EUR/Shipment)

	Inbound	Outbound
EDC	2.17	1.07
ADC	1.45	0.66
CDC	0.08	0.08
APDC	0.19	0.19

Seen in Table 13, EDC and ADC have proportionally high handling cost compared to CDC and APDC. This could be because the handling cost has been requested to each DC separately where different methods determining this cost might have been used.

As mentioned in Chapter 7.3.1, there is an additional handling cost as a result of transshipment via another DC for certain PU's. Description of how each DC is supplied by a PU, if chosen to be the Main DC, is summarized in Table 14.

Table 14 – Description of how each PU's can supply each DC

	To			
PU name	EDC (4)	ADC (7)	CDC (8)	APDC (9)
Semine Inserts	**PU ships via APDC**	**PU ships via APDC**	**PU ships via APDC**	Directly from PU
Pune Tools	Directly from PU	Directly from PU	**PU ships via APDC**	Directly from PU
Fondettes Tools	Directly from PU	**PU ships via EDC**	**PU ships via EDC**	**PU ships via EDC**
Fondettes Inserts	Directly from PU	**PU ships via EDC**	**PU ships via EDC**	**PU ships via EDC**
Westminister Inserts	**PU ships via ADC**	Directly from PU	**PU ships via ADC**	**PU ships via ADC**
Gimo Inserts	Directly from PU	Directly from PU	**PU ships via EDC**	Directly from PU
Gimo Tools	Directly from PU	Directly from PU	**PU ships via EDC**	Directly from PU
Langfang Tools	Directly from PU	**PU ships via APDC**	**PU ships via APDC**	Directly from PU

Mebane Tools	**PU ships via ADC**	Directly from PU	**PU ships via ADC**	Directly from PU
Langfang Inserts	Directly from PU	**PU ships via APDC**	**PU ships via APDC**	Directly from PU

SMS have different reasons of shipping products via another DC to some Main DC candidates. One example is a high transport cost rate given by the carrier due to a small total volume of the flow in certain routes. This cost is summarized for the DC's that need transshipment appears in Table 15.

Table 15 - Handling cost for transshipment for each shipment between each PU and DC (EUR/shipment)

		To			
	PU name	**EDC (4)**	**ADC (7)**	**CDC (8)**	**APDC (9)**
From	Semine Inserts	0.38***	0.38***	0.38***	-
	Pune Tools	-	-	0.38***	-
	Fondettes Tools	-	3.24*	3.24*	3.24*
	Fondettes Inserts	-	3.24*	3.24*	3.24*
	Westminister Inserts	2.11**	-	2.11**	2.11**
	Gimo Inserts	-	-	3.24*	-
	Gimo Tools	-	-	3.24*	-
	Langfang Tools	-	0.38***	0.38***	-
	Mebane Tools	2.11**	-	2.11**	-
	Langfang Inserts	-	0.38***	0.38***	-

*Shipment via EDC, handling cost occurs in EDC

**Shipment via ADC, handling cost occurs in ADC

***Shipment via APDC, handling cost occurs in APDC

7.7.3. Duty costs

More about the customs and duty in the regions respectively can be found in Appendix 2.

The data is obtained with a literature study and by interviewing the Customs & Trade Affairs Advisor at Santrade Ltd and the Business Controller OTD and Planning. EDC is located in Schiedam in Netherlands and uses Schiphol Airport. Netherlands are within the customs union of EU and therefore the EU custom fees apply to shipments to EDC. The tax rates for industrial high-speed steel drills are 2.7% of the total invoice value of the shipment. The total invoice value of the shipment is the sum of the shipment value and the total transport cost.

The tax rate of 2.7% for machine tools for drilling, milling and metal cutting was verified with a search in the Swedish Custom Agency's customs search engine Taric.

ADC is located in Cincinnati in Ohio, US with Cincinnati Airport as the nearest Airport.

APDC is located inside the Airport Logistical Park (ALPS) next to Changi Airport of Singapore. ALPS is a FTZ and therefore are no customs fees or Goods and Service Tax applied for shipments from a DC to APDC.

CDC is located within the zone of Pudong Airport, Shanghai in China. Pudong Airport is one of the FTZ's and therefore is no shipments from a DC to CDC are subject to any custom fees or value added tax. Custom fees and value added tax only apply when a shipment enters the customs border of China.

Due to the fact that the reasons for custom and duty is to protect markets and export it, is encouraged to make markets grow no duty costs for export are assumed to apply to shipments between DC's. The duty and tax for import is presented in Table 16 according to the Customs and Trade Affairs Advisor (2014) with colleagues at Santrade Ltd, Wan *et al* (2014), United States Trade Office (2014) and Swedish Customs Agency (2014).

Table 16 - Summary of customs and tax of import to each DC, van Nijnatten (2014) and Wan *et al* (2014)

DC shipment is sent to	Customs and tax of import
EDC (Schiedam)	2.7%[7]
APDC (Singapore Airport Logistical Park)	Free trade zone
ADC (Cincinnati)	Drawback duty (Refund)
CDC (Shanghai Pudong Airport)	Free trade zone

7.7.4. Inventory related costs

The product value and landed cost factor for the given assortment, also called the stock standard cost (SSC), was obtained from the ERP system for each DC and product. This SSC was furthermore presumed to be the same for each product due to the change in the DC ownership, Santrade (Olofsson, 2014). The weighted average cost of capital (WACC), stock handling cost and the estimated cost of insecurity were asked to the Business Controller OTD and Planning stationed in Switzerland, who provided the interest rate of 22%. The calculation of this interest rate of 22 % is the same interest rate used in the Wilson formula, used by Sandvik according to Olofsson (2014) seen in Table 17.

Table 17 - Cost components included in the stock interest rate

Cost component	
WACC	10 %
Stock handling cost	11 %
Insecurity cost	1 %
Total stock interest rate	22 %

The WACC weighs the Cost of Equity and the Cost of Debt to arrive at the average cost of capital for Sandvik. Cost of Equity is the return the owners of the company require, and it is calculated by taking the current risk free return available on the market, and adding the risk premium the market currently requires for Sandvik. Cost of Debt is the average interest rate Sandvik currently is paying for borrowed funds. Due to the new ownership of Santrade, the interest rate of 22 % will be applied for all DC's.

[7] The transport cost for the part within the EU is not subjected to this tax and is deducted from the total transport cost which is a part of the total invoice value.

8. Part 1 - Total cost analysis

This chapter will describe the model created to analyze Part 1, based on the theory described in Chapter 3, 4 and 5. The solution method for Part 1 is as described in the problem specification, a total cost analysis. The chapter starts with a description of the mathematical formulation of the total cost analysis followed by how each cost have been analyzed in order to achieve the result.

8.1. The mathematical formulation of the total cost analysis

The data and information for the different cost components was retrieved by questions stated in Chapter 6.1 and presented in Chapter 7. As described in Chapter 3.5.2, Figure 10, the result of the activity phases leads to the total cost model in order to achieve the aim of this study. That means that the current set up must first be modeled to be used as a comparison scenario if a change of the set-up is made.

8.1.1. Modeling the current set up

The problem modeling is defined with following labels, Table 18.

Table 18 - Defined labels for the problem modeling of Part 1

Amount	Description
$i \in I$	The set of Main DC's candidates
$j \in J$	The set of secondary DC's
$k_i \in K$	The set of PU's
Variable	**Description**
EOQ_i^p	Average replenishment OQ for product p for Main DC candidate i
OQ_{ij}^p	Average OQ of product p for DC j with Main DC candidate i
ss_{ij}^p	Average SS level of product p in DC j with Main DC candidate i
FC_j^p	Average FC of product p for DC j
$FC_{TOT}{}_i^p$	Average Total FC of product p for Main DC candidate i
q_{pi}	Average amount of producs in stock of product p in all DC's withMain DC candidate i
T_{ij}^p	Estimated sum of transports of product p between Main DC candidate i and DC j
$T_{k_p i}^p$	Estimated sum of transports of product p between PU k, producing product p, and Main DC candidate i
Parameter	**Description**

C_p^i	Total set up cost for product p with Main DC candidate i
w_p	Weight of product p
p_{value}	Product value and landed cost factor (Standard Stock Cost, SSC) for product p
d_j^p	Order intake of product p in DC j, seen as the demand for the product p in DC j
$c_{interest\ rate}$	Stock interest rate at 22% for all DC's
$c_{ij}{}^{transport}$	Cost of transport per weight unit between Main DC candidate i and DC j
$c_{k_p i}{}^{transport}$	Cost of transport per weight unit between PU k, producing product p, and Main DC
$c_{k_p i}{}^{duty}$	Costs of duty for transports between PU k, producing product p, and Main DC candidate i
$c_{ij}{}^{duty}$	Costs of duty for transports between Main DC candidate i and DC j
$s_{k_p i}^{duty}$	Part of transported distance liable to tax between PU k, producing product p, and Main DC candidate i
s_{ij}^{duty}	Part of the transported distance liable to tax between Main DC candidate i and DC j
$c_{inbound}^{j}$	Inbound handling cost at DC j per received shipment
$c_{outbound}^{j}$	Outbound handling cost at DC j per sent shipment
$c_{inbound}^{i}$	Inbound handling cost at Main DC candidate i per received shipment
$c_{outbound}^{i}$	Outbound handling cost at Main DC candidate i per sent shipment
$x_{k_p i}^{j}$	$\begin{cases} 1 & \text{if PU k, producing product p, must transship at DC j to supply Main DC candidat} \\ 0 & \text{if PU k, producing product p, can supply Main DC candidate i directly} \end{cases}$
Objective function	**Description**
Minimize C_p^i	Find Main DC candidate i with the lowest total set up cost for product p

With above definitions, the problem can be formulated as:

$$\min C_p^i = \left\{\begin{matrix} \text{Transport costs PU DC} + \text{Transport cost DC DC} \\ + \text{Handling cost PU DC} + \text{Handling cost DC DC} \\ + \text{Duty costs PU DC} + \text{Duty costs DC DC} \\ + \text{ Inventory costs} \end{matrix}\right\}$$

Equation 5 will estimate the total cost of transports from the PU to the Main DC candidate:

$$\text{Transport cost PU DC} = T_{k_p i}^p * w_p * c_{k_p i}{}^{\text{transport}} * EOQ_i^p \quad (5)$$

The transport cost of Main DC candidate i to supply itself equals zero, as described in Table 12, Chapter 7.7.1. Equation 6 will estimate the total cost of transport from the Main DC candidate to all DC's

$$\text{Transport cost DC DC} = \sum_{j=1}^{4} T_{ij}^p * w_p * c_{ij}{}^{\text{transport}} * OQ_{ij}^p \quad (6)$$

As described in Chapter 7.7.1, the transport cost depends on the weight of the product and the number of transports made. The sum of transports is estimated by using equation 7 and 8.

$$T_{k_p i}^p = \frac{\sum_{j=1}^{4} d_j^p}{EOQ_i^p} \quad (7)$$

$$T_{ij}^p = \frac{d_j^p}{OQ_{ij}^p} \quad (8)$$

If shipment via another DC is made additional inbound and outbound handling will occur at this DC. The total cost of handling shipments from the PU to the Main DC candidate is estimated with equation 9a:

$$\text{Handling cost PU DC} =$$

$$= \{\text{Transshipment cost} + \text{ Inbound handling cost Main DC} + \text{Outbound handling cost Main DC}\}$$

$$= T_{k_p i}^p * x_{k_p i}^j * \left(c_{\text{inbound}}^j + c_{\text{outbound}}^j\right) + T_{k_p i}^p * c_{\text{inbound}}^i \quad (9a)$$

Outbound handling occurs at all DC's, including for the supplying shipments from the Main DC candidate. Inbound handling occurs at the secondary DC's. The total cost of handling shipments from the Main DC candidate to the other DC's is estimated with equation 9b:

$$\text{Handling cost DC DC} =$$

$$= \{\text{Outbound handling cost at all DC's} + \text{ Inbound handling cost at secondary DC's}\} =$$

$$\sum_{j=1}^{4} T_{ij}^p * c_{\text{outbound}}^j + \sum_{\{j=1,\ j\,!=i\}}^{4} T_{ij}^p * c_{\text{inbound}}^j \quad (9b)$$

Chapter 7.7.2 described the handling cost as an expense that arises when a shipment with products enter and leave a DC, depending on the numbers of shipments (see equation 9a and 9b). As also mentioned in Chapter 7.3.1, some PU's cannot ship to all DC's directly and need to ship via another DC. In this case, in addition to the increased transport cost, the transshipment will also cause additional handling costs at the transshipment node. The total handling cost will therefore also consist of the handling cost of any required transshipment needed for the suggested set up, which can be seen in equation 9a.

The description of how the duty cost is obtained is defined in Chapter 7.7.3. The calculation is not only based on the amount of transports or the value of the shipped product, but also the distance outside the point of customs liable to import tax. The transport cost for the distance inside the border of import is duty free (equation 10 and 11).

$$\text{Duty cost PU DC} = T_{k_p i}^{p} * p_{value} * EOQ_i^p * c_{k_p i}{}^{duty} + \{\text{Transport cost PU DC}\} * c_{ij}{}^{duty} * s_{k_p i}^{duty} \quad (10)$$

$$\text{Duty cost DC DC} = \sum_{j=1}^{4} T_{ij}^{p} * p_{value} * OQ_{ij}^{p} * c_{ij}{}^{duty} + \sum_{j=1}^{4} T_{ij}^{p} * w_p * c_{ij}{}^{transport} * OQ_{ij}^{p} * c_{ij}{}^{duty} * s_{ij}^{duty} \quad (11)$$

The total duty cost is summarized by equation 10 and 11.

According to directives and as described in Chapter 7.7.4, the interest rate is set to 22 % for all DC’s. The inventory cost, equation 12, is calculated on the product value, interest rate and the stock level at each DC.

$$\text{Inventory costs} = p_{value} * c_{interest\ rate} * q_{pi} \quad (12)$$

The average stock level, equation 13, is the sum of the mean amount of products in stock based on SS and EOQ.

$$q_{pi} = \sum_{j=1}^{4} \left(ss_{ij}^{p} + \frac{OQ_{ij}^{p}}{2} \right) \quad (13)$$

The total inventory cost is the sum of equation 12 for all DC’s

8.1.2. Modeling alternative Main DC set up’s

To investigate how alternative set up with a Main DC switch would affect the total cost of the whole distribution flow, each alternative was created. The scenarios (described in Figure 10) were created by having each DC act as the Main DC for all products respectively. The total cost of transport, handling, duty and inventory was then calculated for all alternatives respectively. The cheapest alternative set up for each product were then collected and is the optimal solution in the aspect of the lowest total cost with the same service level.

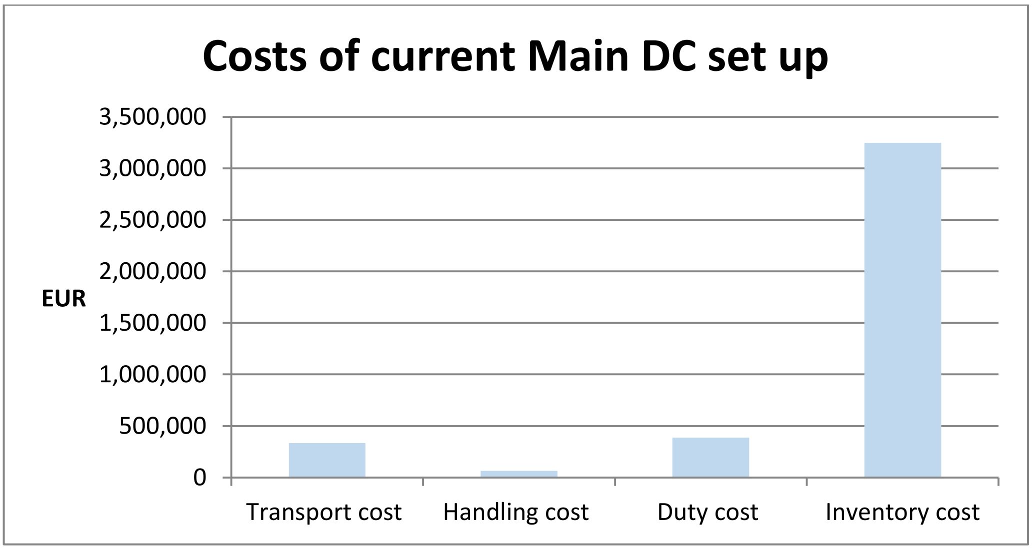
As described in Chapter 7.2.2 some parameters are being inherited in case of a Main DC switch and some are automatically being recalculated by the ERP-system in the period following after the Main DC switch. If a Main DC switch is made, the new Main DC will inherit the same EOQ and SS as the old Main DC. The SS and OQ of the old Main DC turning into a secondary DC are recalculated according to Chapter 7.5.2 and 7.5.5. The estimated OQ for the new secondary DC is based on its FC and which frequency group the product belongs to. If the estimated OQ is below Min OQ the OQ is set to Min OQ. By inheriting the EOQ and SS from the current Main DC to the Main DC candidate it’s assumed that the service level is unaffected by a Main DC switch.

8.2. Analysis of model output

This section will summarize the output of the total cost model for Part 1. The analysis is made on an assortment of 2071 products and does not consider products using a Multi- Main DC strategy (Chapter 1.4). An analysis is made of how the cost components relate to each other and affect the total cost. Each cost component is separately described below.

8.2.1. Comparison of transport-, handling-, duty- and inventory costs

To illustrate the different cost factors effect on the total cost, a comparison of the size of the different cost factors are made. This is done by summarizing the total costs of each cost factor generated from the total cost model illustrated in a Graph. The total cost in the current set up is illustrated in Graph 1.



Graph 1 - The share of the total cost in all current Main DC set up

As it can be seen in Graph 1, the inventory cost is the largest cost factor of the total cost of the average set up. The duty- and transport cost are of almost equal size. The handling cost has a very small impact on the total cost.

However, it's important to consider all cost factors when deciding the Main DC set up. To illustrate the danger of not considering all costs, all set ups has been optimized by only considering one cost component at a time when deciding which DC should be set as the Main DC. The sub optimal solutions generated from this method give an understanding how the cost components are related to each other and affected by the decision of Main DC. This analysis has been made by letting the total cost model only consider minimizing one cost component at a time.

Transport costs

The transport cost is directly linked to the number of shipments, the size of the shipments and the weight of the product. The transport cost varies depending on the origin and destination. The transport cost per weight unit is generally lower for EDC. The transport cost per weight unit for CDC is the highest, while ADC and APDC is somewhere in the middle. A PU have different transport cost per weight unit to the different DC's. Since some products in the given scope are of very low weight the transportation cost plays a minor role in their set up costs. A few products are of a high weight which make the transport cost play a much larger role.

If an optimization would be done by only considering the costs of transports, the cost that increases when minimizing the transport cost is handling and duty. The model has focused on minimizing the number of shipments of products with high weight or high transportation costs to markets with high actual sales. The handling cost increases due to the variation of handling cost between the DC's is out of consideration. The reason why the duty cost increases while minimizing the transport cost is because the model only is considering the weight of a product, but not the product value which also affects the Duty cost. Sub optimizing on transport cost also leads to heavy products being sent to EDC despite higher sales in another DC, due to the lower transport cost per weight unit in EDC.

Handling costs

As described in previous section, handling generates a fixed cost for transports in- or out from a DC without any relation to the product value or the shipments size. Handling cost measure the cost of activities and is also affected by the additional cost of cross docking products. The handling cost increases as the amount of transport increase and correlates with the transport costs. The handling cost is low in comparison to other costs and a low effect on the total cost when changing the Main DC. Since the handling cost is lower in Asia, sub optimizing the handling cost will vastly increase the transport cost due to a higher transport cost per weight unit in APDC and CDC. The inventory cost will also increase due to the high share of the sales in other regions which would increase the total inventory level.

Duty costs

Duty when shipping to a Customer or a SU is assumed to be paid either way and is kept out of scope. However, additional duty exists in EDC as products are passing through in the distribution set up. Since the duty costs are based on the number of shipments multiplied by the order quantity and the value of both the product and the transport and a high demand exist at EDC, the Duty has quite a large effect on the total cost. This makes it interesting to analyze how the other cost factors would be affected in the model if only the duty cost would be minimized.

The only increase of costs when separately minimizing the duty cost is the inventory cost. This could be for the reason that the cheapest choice of Main DC will only depend on minimizing import to the duty obligated DC's, which is only EDC. That means that the model has only been focusing in locating the Main DC where the transportations to EDC from outside the EU are reduced regardless of where the sales are greatest and henceforth the increase of inventory related cost.

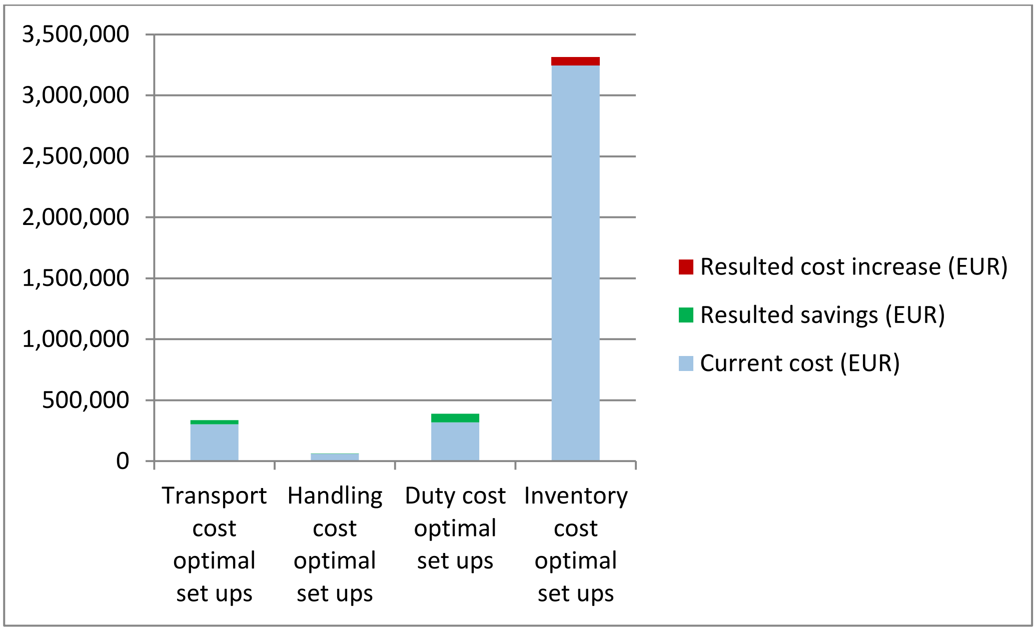
Inventory costs

The inventory cost is calculated in a similar way as the cost of duty and is based on the product values and the quantity of products in stock multiplied by the stock interest rate of 22 %. This inventory cost has the largest effect on the total costs.

The inventory cost are often low for products with many order intakes in all DC's as the turnover in such cases are high no matter on the Main DC set up. The inventory cost has a much larger effect for products with a high value. Since the same stock interest rate are used in all DC's due to the new ownership of Santrade, minimizing the Inventory cost will choose a Main DC with the highest share of the sales to reduce the OQ and SS of secondary DC's. As the OQ and SS decrease the average inventory level will decrease which decrease the inventory cost. However, sub optimizing the inventory level will be at the expense of an increased amount of transports, handling activities at the DC's and Duty is increased due to the generally high share of sales in EDC, which is liable to import duty.

Transport-, duty- and handling costs set against inventory costs

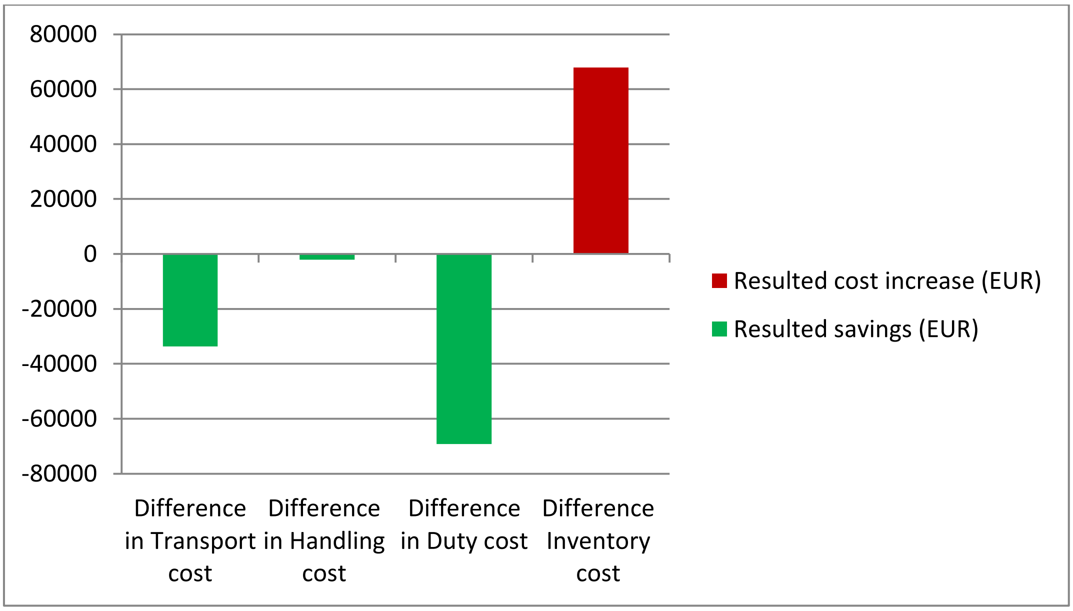
To avoid a sub optimal solution a tradeoff between the transport-, duty- and handling cost versus the inventory cost must be made. The graphs (Graph 2 and Graph 3) below illustrate the total cost of the distribution flow if the total cost model optimizes the costs of transports, duty and handling.



Graph 2 - The total cost when optimizing the costs of transports, duty and handling

In Graph 2 the cost of current set up is compared with an optimization of changing the Main DC set ups only to minimize the of the Duty-, Transport- and Handling cost. Switching Main DC's by just considering these costs will increase the inventory cost.

Graph 3 clarifies the various cost increases and decreases from Graph 2.

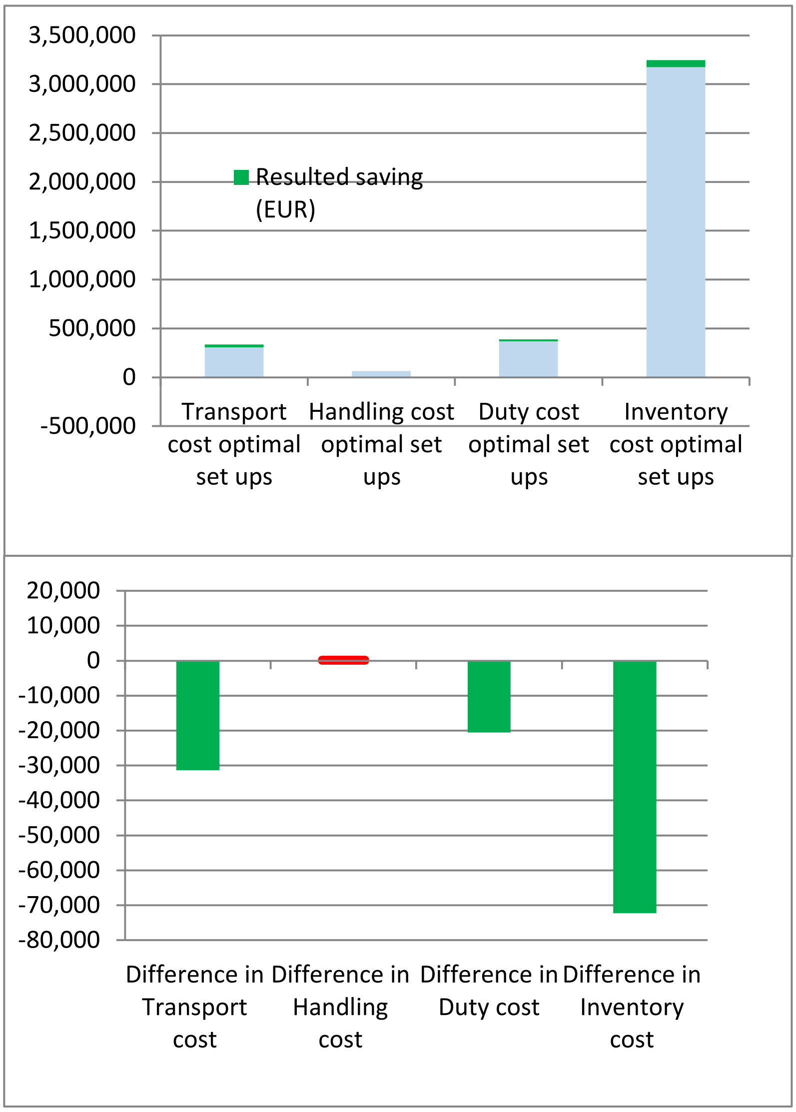


Graph 3 - Savings and cost increases when optimizing the costs of transports, duty and handling

As seen from above graphs the only cost increase is in inventory costs. The sum of savings in transport, handling and duty is higher than the cost increase of inventory. However, the total cost can be decreased further. As the transport-, handling- and duty costs are decreased, it is on the expense of an increased inventory cost. Optimizing the inventory will get the opposite effect where the inventory cost will be decreased on the expense of an increased transport-, handling- and duty cost.

The optimal set up

The optimal set up is a tradeoff, where the optimal set up considers the effect of all cost factors. The share of the total cost in an optimal set up is shown in Graph 4.



Graph 4 - The total cost of an optimal set up

Seen in Graph 4, the optimal set up would have a slightly larger handling cost but a lower total cost. The difference in costs between the optimal set up compared to the current set up is 123 870 EUR of potential savings on an assortment of 2071 products. The exact proportion of the potential savings in comparison to the current set up cost not is presented, as a request from SMS.

8.2.2. Analyzing the effect of weight and SSC

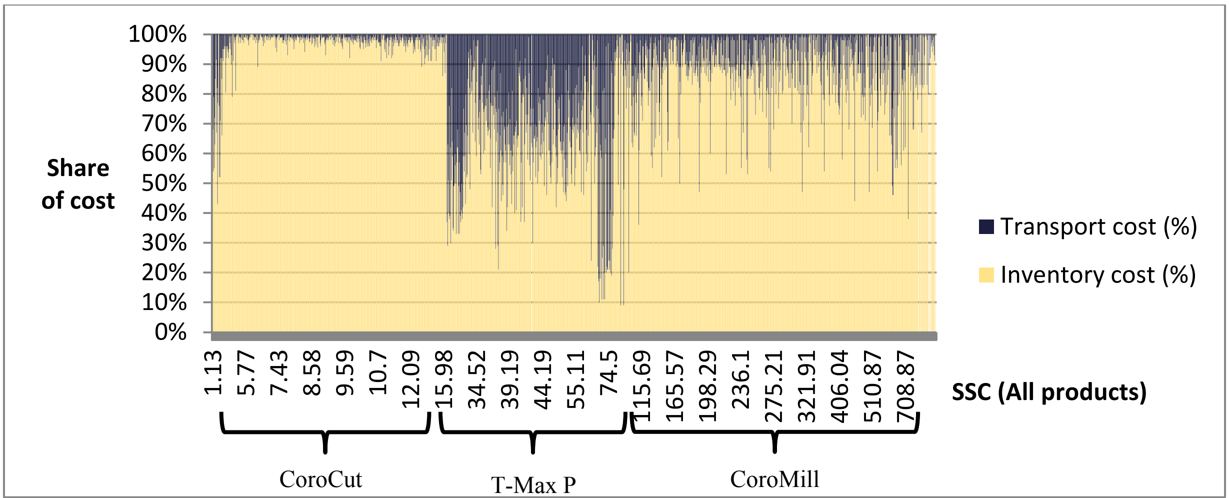
The inventory cost is generally much larger than the transport cost. However, both the weight and SSC have a great impact on these cost components, and therefore on the total cost of the distribution flow. To investigate the effect weight and SSC impacts the cost of a Main DC switch, the parameters are compared against the inventory- and transport cost.

Weight and SSC

The products weight affects the cost of the transport. A product with a higher weight generally creates a higher transport cost compared to a product of lower weight, due to the use of an estimated transport cost per weight unit.

The SSC of a product affects the cost of inventory and duty. A product with a higher SSC generally generates a higher inventory cost due to a higher total value in stock affected by the stock interest rate. A product with a higher SSC value generally generates a higher duty cost due to a higher total value of the imported product liable to import tax.

However, the inventory cost of all the products in the scope of this study is always much larger than the transport cost. An indication of a correlation between the SSC and the product weight could be seen in the given assortment. As the weight of the product increase, so does the SSC. If this would be the case, the share of the inventory cost compared to the transport cost would be stable for the whole assortment. However, after studying all products SSC with the transport cost and the inventory cost clear variations could be seen. A comparison between the inventory- and transport cost for all products SSC can be seen in Graph 5.



Graph 5 - Comparison of the Transport cost and the Inventory cost for all products with current set ups

Graph 5 contains the transport cost compared to the inventory cost for all different products in the studied assortment with their SSC. When the products get sorted after their SSC three clear intervals can be seen. Surveying the data, these intervals were proved to represent the different product families as shown in Graph 5.

The products with the lowest SSC are represented by inserts (CoroCut, mentioned in Chapter 2.1.1). The product weight is very low for these products which lead to a low transport cost, despite a low SSC. The products with a SSC between 15 EUR and 135 EUR are mostly represented by tools from the product family T-Max P (Chapter 2.1.2). These products represent holders which generally have high weights but varying SSC. This explains the large variation in the difference in transport and inventory cost for these products. The products with the highest SSC are mostly represented by milling cutters (CoroMill, mentioned in Chapter 2.1.2). Milling cutters are expensive products and therefore these products have a high SSC. Therefore, the inventory cost is generally higher than the transport cost for this product family.

This means that the variations between the product families affect the total cost of the Main DC set up differently. For increased high accuracy in the choice of Main DC set up, the product family with its weight and product value should be considered.

8.3. Analysis of key factors affecting the total cost

All alternative Main DC set up's (EDC, ADC, CDC or APDC) are estimated for each product and the Main DC set ups with a lower total cost compared to the current set up is identified. Before the analyses of the key factors are made, the current flagging method first needed to be examined.

8.3.1. Current flagging method

As described in Chapter 7.2.2, SMS are in the current system using a flagging method to guide whether a Main DC switch is worth considering or not. The current flagging method uses generic threshold values of the share of sales at the current Main DC and the secondary DC with the highest amount of sales, to flag potential unsuitable set ups.

After a consultation with supervisor at SMS, the analysis have used criteria's of all possible savings to an alternative solution must be at least 500 EUR to make a Main DC switch worth wile (that is per product). Another criterion is that the proportional savings also must be more than 10 % of the total cost, to create a margin for uncertainties in the input data. These criteria and the total cost model resulted in 57 unsuitable[8] Main DC set up's. The unsuitable set ups have cheaper set ups that all together could save 78 296 EUR per year.

Table 19 presents the result of using the current flagging method and modifications of the current method. The table shows how many products that would be detected, flagged correctly[9], flagged incorrectly[10] and how many optimal set ups that are missed according to the optimal solution obtained based on the total cost model. Products flagged incorrectly are assumed to make the planner distrust the flagging result, load unnecessary work to the planner or even stress the planner to make a bad decision. As can be seen in Table 19, the current method flag a large amount of products and misses a fair share of candidates with a cheaper alternative set up. To illustrate the inefficiency of this method, different threshold values are tested and presented in Table 19.

Table 19 - Evaluation of flagging methods using generic thresholds of the share of the total order intake

Method [share of order intake at current Main DC (less than) ; share of order intake at the secondary DC with the highest sales (larger than)]	Flagged	Correct	Incorrect	Missed	Optimal set ups [Main DC switches with savings larger than 500 EUR]
Current (< 0.3, >0.5)	428	40	380	17	57
Low, High (<0.2, >0.6)	315	21	76	36	57
Very low, Very high (<0.1,>0.7)	183	21	55	36	57

8 An unsuitable set up is a Main DC set up with an alternative Main DC set up that has at least 10% lower total cost of at least 500 EUR

9 A correct flag is made on a product which has an alternative cheaper set up, according to the total cost model

10 An incorrect flag is made on a product with no cheaper alternative set up, according to the total cost model

High, Low (< 0.4, >0.4)	566	44	97	13	57
Very high, Low (<0.5, >0.4)	743	51	89	6	57
Optimistic flag (<0.6, -)	973	56	917	1	57

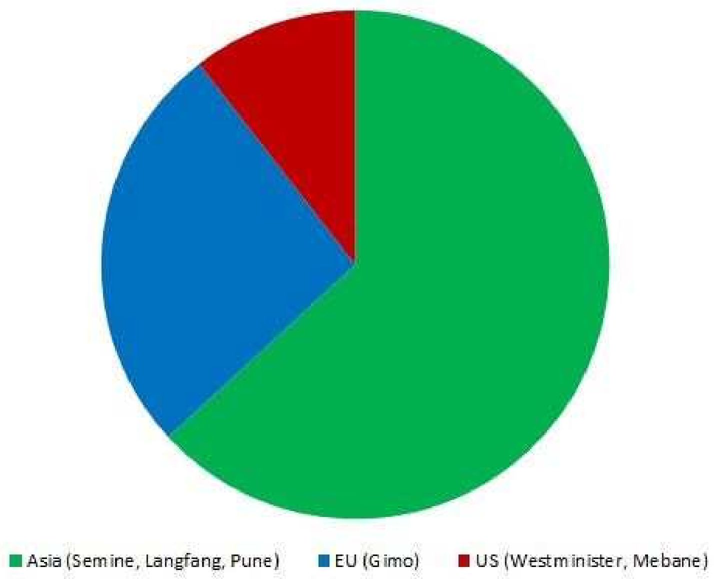
Changing the threshold values will affect the amount of flagged set ups. However, a large amount of incorrect flagging will always be made and some Main DC switches according to the optimal solution will always be missed.

By observing Table 19 it can be assumed that it is not enough to consider the share of sales in the Main DC and the secondary DC's. This is because the flagging method detects a total of 428 but only finds 40 correct solutions of the 57 optimal ones.

8.3.2. Location of PU's for unsuitable Main DC set up's

Although today's flagging method can be adjusted for better accuracy, the criteria's will still never give all optimal solutions without missing anything. And since the flagging method only considers the expected sales, it may be interesting to examine criteria that consider additional factors and thereby increase the accuracy of flagging unsuitable set ups. This has been done by analyzing from which PU these unsuitable Main DC's is supplied and therefrom investigate any correlations.

The analysis of this was shown that the majority of the unsuitable Main DC set ups is due to a location of PU linked to an unsuitable Main DC. Graph 6 shows the producing PU's that currently has the unsuitable Main DC set ups.



Graph 6 - The allocation of PU's generating wrong Main DC set up's

What you clearly can translate from Graph 6 is that the majority of the unsuitable Main DC set ups is being supplied by a PU located in Asia. Typical cases in unsuitable Main DC set ups from the studied assortment are summarized in Table 20.

Table 20 - Summary of typical unsuitable Main DC set ups

	Assumed reason for using the current Main DC set up	Possible saving factor	Reason of high cost
PU in Asia			
EDC	Largest share of sales	Duty cost.	The cost for duty is more than twice as large if EDC is Main DC as another DC. As the whole quantity of products made in Asia for all DC's must be taxed for import to EDC before distributed to the other DC's.
APDC	Larger sale quantities were predicted in Asia	Inventory cost	The share of sales is much less in APDC
PU in EU			
EDC	Larger sale quantities were predicted in Europe. Low transport cost between the PU in Gimo to EDC.	Inventory cost	The share of sales is larger in ADC
APDC	Largest share of sales	Transport cost	Heavy products and high transport cost between Gimo and APDC. Even if the largest share of sales is in APDC, the savings in transport cost have a larger effect on the total cost.
PU in US			
EDC	Largest share of sales	Duty cost	The total sales of all DC's must be imported to EDC and therefore creates high duty costs. This is despite a lower total inventory cost of using EDC as Main DC.
ADC	Larger sale quantities were predicted in the US. Low transport cost between the PU's in US to ADC.	Inventory cost.	The share of sales is larger in EDC. And despite the high duty costs when sending the whole quantity to EDC (same reason mentioned earlier), the high SSC on products has a larger effect on the inventory costs then the costs of duty.

8.3.3. Increased accuracy flagging method considering location of the PU

To suggest a flagging method with increased accuracy the threshold values have been adjusted after the location of the PU, the current Main DC and where the unsuitable set ups have been found in the total cost model on the studied assortment. Since the analysis is based on events happened for the products in scope are these threshold values not guaranteed to be valid on other assortment. It could though work for other products, but that is not analyzed in this study.

Narrowing the thresholds will increase the accuracy but reduce the amount of detected unsuitable Main DC set ups. The threshold values and the result of the increased accuracy flagging method can be seen in Table 21.

Table 21 - Increased accuracy flagging method considering the location of the PU, the current Main DC and the share of sales in the current Main DC

	Method [share of order intake at current Main DC (less than)]	Flagged	Correct	Incorrect*	Missed	Optimal set ups [Main DC switches with savings larger than 500 EUR]
PU's in Asia						
	EDC < 60%	12	8	4	0	8
	ADC	0	0	0	0	0
	APDC < 15%	79	22	57	6	28
PU's in EU						
	EDC < 5%	31	1	30	6	7
	ADC < 45%	14	1	13	0	1
	APDC < 55 %	17	6	10	1	7
PU's in US						
	EDC < 45 %	5	4	5	0	4
	ADC < 5 %	45	0	25	0	1
	APDC < 45 %	3	1	2	0	1
Total	Increased accuracy method	206	43	146	13	57

* Note that an incorrect suggestions also might have an alternative set ups with cheaper alternative Main DC set ups, however not within the limits of 500 EUR and 10% savings of the total cost.

The suggested thresholds are created with the desire to increase the amount of correct suitable Main DC switch candidates as possible, decrease the amount of flagged products and flag as few incorrect suggestions as possible. However, optimal set ups will still be missed and a large amount of products will be flagged unnecessarily.

9. Part 2 – Evaluation of distribution logics

This chapter will describe the model created to analyze Part 2, based on the theory described in Chapter 3, 4 and 5. The modeling of Part 2 is as described in the problem specification and is performed as a simulation model in Arena. The chapter begins with a situation and cost analysis based on historical conditions followed by a brief description of the simulation model construction. New logics are implemented in the model with identical sales conditions.

9.1. Assortment studied

As described in Chapter 3.5.2 and Figure 16 the analysis of Part 2 started with an analysis of order data to find traces of the exceptional situations described in Chapter 6.2.3. To study the distribution and movement of products the stock level combined with orders at different times had to be considered. The exceptional situations are a series of events over time and to study all products in the given assortment would time consuming and require an unmanageable amount of data. Therefore specific products were chosen to be studied further. The products chosen were products with measured problems in the distribution that could be seen in the order data.

Identification of the individual products to study, in order to gain knowledge of the exceptional situations mentioned in Chapter 6.2.3, is summarized in this chapter.

9.1.1. Situation 1-3

Situation 1, 2 and 3 were assumed to leave a trace of a high amount of Backlog STO's, since all three situations end up sending Backlog STO's as described in Chapter 7.6.5. A product with no Backlog STO's measured was assumed to have sufficient stock levels to a higher degree and therefore not subjected to the Situation 1-3 to the same extent. This assumption was made to minimize the risk of studying products where situation 1, 2 and 3 did not occur at all.

Data of Backlog STO's could only be obtained for the last two periods. To find product candidates demonstrating Situation 1, 2 and 3, all products is sorted after its amount of Backlog STO's and the total shipped quantity of these Backlog STO's. Products with a total PO quantity and total initial stock level less than 80% of the Actual sales[11] and total final stock level in all DC's, is assumed to have inaccurate data and is not investigated further. Products with a large difference in the yearly FC and Actual sales is assumed to contain high amounts of Backlog STO's due to inaccurate Stock parameters created by an inaccurate FC and not investigated further.

The stock transfer situation for individual products was studied numerically date by date in order evaluate the performance of the current logic. Information about the products initial stock level, PO's, STO's, Backlog STO's and all CO's is combined to study the movement of products. The initial stock level is the available quantity in stock during a specific date. The orders sent in the system past this date changes this stock level. The reasons orders are created are surveyed and alternative system decisions that could have been done are studied.

In addition, a simulation model was built in Arena with the capacity of simulating the movement of products for one product id at a time. The simulation model was built to illustrate how the logic

[11] Actual sales are assumed to be the Total yearly CO intake (Sum of the quantity of all CO's addressed to the DC during 2013)

handles the exceptional situations and to gain understanding about the current system logic. The same products were individually simulated in the Arena model.

Modeling the distribution set up in Arena

Simulation terms are described in Chapter 5.2. The model is deterministic based on historical CO's, OQ's, OP's and a defined logic. That means that the model uses no elements of probability or randomness. The simulation model of the distribution set up is constituted by the following components:

- **Entities:** Entities describe all flows and movements of material in the simulation model. Individual entities exist for each flow between each origin and destination and are released upon the signal of rewritable variables. Entities in the model are given a transportation time equal to the entire lead time. Therefore the model will illustrate the processing time in the PU as a slowly moving transport. Entities also represent the flow of Orders. No shipment is sent without first receiving an order.
- **Queues:** Queues are only created for flows. If an order cannot be satisfied with available stock in the Main DC, this order will be held in a queue until there is available stock. Backlog STO's are not queued. If there is no available stock in any of the other DC's at all, the Backlog STO will not be served and will be held until there is available quantity.
- **Resources:** No resources are used in the model. The model assumes that the system has infinite capacity and transports will always deliver right on the lead time from a PU. All DC's and all transports have unlimited capacity.
- **Attributes:** All Sales entities are given an attribute of the time of when the actual historical CO of 2013 was received. The Sales entity is also given an attribute of the actual sales order quantity that changes the available stock level at the given time. If there is unavailable stock, the sales order quantity is sent as a Backlog STO to any of the other DC's
- **Variables:** Multiple variables are used. Variables used are Stock levels, Backlog order levels, OP levels, OQ levels and signaling variables for all DC's. Signaling variables are variables signaling when stock levels fall below OP, when to send a shipment and when replenishment is received. The Stock level variables changes value when a shipment is received. The OP and OQ level variables are changing every period based on historical data. The Backlog order level variables are changing if there is unavailable stock or if a Backlog shipment is received. Signaling variables are used to hold orders (Entities) until the Stock level falls below OP at a DC.

9.1.2. Situation 4

Described in Chapter 6.2.3, Situation 4a and 4b occurs when the Main DC's and the secondary DC's does not consider the other DC's inventory level before sending a PO and a STO. If the situation has occurred it's assumed to leave a trace of unnecessary production quantities and unnecessary inventory levels in secondary stocks, due to the continuous feeding of inventory and the fact that the system does not consider the stock level at secondary DC's. The stock level of all products was studied. Table 22 defines the assumed factor of unnecessary costs due to Situation 4.

Table 22- Summary of unnecessary inventory levels due to Situation 4

Factor of cost	Definition
Unnecessary inventory levels	The average turnover stock kept in secondary DC that exceeds the yearly demand at the same DC

Situation 4 is assumed to create unnecessary stock levels in secondary DC's as demand for a certain product in a certain DC decreases or is replaced with another product. As the system logic is not checking secondary DC's and instead keeps feeding the system with products, traces of product quantities lying around untouched in secondary DC's is assumed to exists as unnecessary stock.

All available stock above the SS level not sold during the entire year is assumed to be unnecessary stock and is illustrated in Figure 23. To determine each products unnecessary stock the Average Stock level at secondary DC's minus its SS and Total yearly Actual sales.

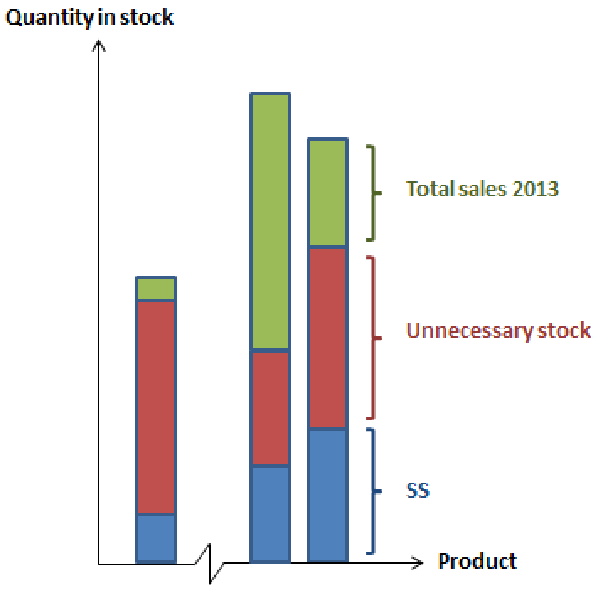


Figure 23 - Illustration of the stock level in a secondary DC and what is defined as unnecessary stock

The unnecessary stock illustrated in Figure 23 above leads to a large unnecessary inventory cost per year due to a larger total inventory level. The unnecessary stock also creates additional costs of producing at PU's earlier than necessary, even if the current total inventory level is more than enough to cover the present and future demands of all the DC's. The cost of production is however kept out of scope.

9.2. Analysis of models

This chapter summarizes observations and analysis made of collected data and the models in Part 2.

9.2.1. Exceptional situations

An Arena simulation model was created to model the exceptional situation 1, 2 and 3. Using products with historical high levels of Backlog STO's in the simulation models, all products modeled recreates less Backlog STO's than measured in reality. According to the model which uses historical stock parameters, CO's and transport times, the regular STO's can satisfy the demand more efficiently in the model than in reality. However, the model assumes that PO's and STO's are always delivered in time and in the entire amount of the ordered quantity which might generate an optimistic output. The exceptional situations are recreated in the model but in a smaller extent and do not match reality according to measured Backlog STO's. Suggested reasons are that in reality the replenishment from the PU could not match the entire EOQ, the standard lead time from production was exceeded, the transport times according to the DC IW report was exceeded or additional transfer orders were placed manually. Backlog STO order data could only be obtained from November and December, which means that these orders cannot be validated with the events during the whole year. Even if the model does not recreate the exact events that occurred in reality, the logic still exemplifies realistic system decisions. Therefore, a few observations made in combination with surveying order data and stock levels could still be of interest.

Observations of Situation 1 – Multiple Backlog STO's sent after each other in a backlog situation

Backlog STO's occurs for a few of the simulated objects. However, the model does not recreate as many Backlog STO's as the historical orders from the last two periods suggest. The reason can be the large fluctuations of the real delivered quantities compared to the OQ and EOQ always delivered in the model. The delivered quantity of the products simulated is generally lower according to the measured PO's, compared to the model output. Another reason is believed to be the inaccuracy in the shipped quantities and dates of the measured STO's, Backlog STO's, CO's and PO's. The STO's, Backlog STO's, CO's and PO's shipped and the change of the inventory levels between the periods according to the data is inaccurate and does not give an accurate match in the change of the stock level between the two last periods. The Backlog STO's occurring in the model before the last two periods cannot be validated with historical orders and therefore cannot be assumed to be real events.

One reoccurring similar observation could be made in the modeled logic. The observations are made on systems were the production and the DC's perfectly can live up to the ordered quantities and delivery times. In the observation all DC's are below OP, and were the DC's during the replenishment time are apportioning what is left by sending Backlog STO's to each other.

In addition to the simulation, the current Backlog STO's logic was studied in numerical examples. Tests were made by increasing the Backlog STO quantity. Larger Backlog STO quantities can reduce the amount of multiple Backlog STO's after each other; however it is as likely to create additional Backlog STO's by causing a backlog situation for another DC. To avoid causing a backlog situation for another DC, the system must consider the Backlog STO supplying DC's stock level, when it will be replenished and predict its future sales. If the Backlog STO supplying DC is a Main DC, the system must also consider its secondary DC's stock levels, sales and OP's before increasing the Backlog STO quantity to avoid putting another DC in a backlog situation.

Observations of Situation 2 – Fixed OQ disfavors secondary DC

Since the model assumes perfect delivered quantities and that the PU's are always delivering on time, the Main DC often has available stock and the secondary DC's are rarely denied replenishment. The model assumes that all orders are delivered in time and has a much shorter replenishment time for secondary DC's then for the Main DC supplied by the PU. In the observations made when the Main DC deny replenishment for the secondary DC, the system does sometimes put the secondary DC's in a backlog situation. However, due to the shorter replenishment time of the secondary DC it is also often replenished before running out of stock. In many observations the Main DC has a higher demand and by denying secondary DC's replenishments it's keeping itself out of a backlog situation. However, the observations in the last two periods do not match the historical STO's and Backlog STO's and cannot be assumed to be real events. The observations made before the last two periods cannot be validated with historical orders and can therefore not be assumed to be real events.

In addition to the simulation, numerical examples were studied. The advantage when the Main DC is denying secondary DC's replenishment due to low inventory at the Main DC is that the Main DC itself is avoiding a backlog situation. The drawback is that it might put the secondary DC in a backlog situation. The Main DC could avoid putting the secondary DC in a backlog situation by accepting partial quantities of the OQ; with a risk of the Main DC getting emptied and ending up in a backlog situation. A system logic were the Main DC has the ability to send partial quantities of the Main DC, when the Main DC will be replenished by the PU and predict all DC's future sales. For the Main DC not to risk putting another secondary DC in a backlog situation, additional information is needed to predict the actions of the other secondary DC's. Since the Main DC is supplying other DC's, the system must also acknowledge the OQ, OP and predict the sales of all other secondary DC's.

Observations of Situations 3 – Fixed OQ disfavors Main DC

No observations of the secondary DC disfavoring the Main DC were found in any simulation. The reason is that situation is very unlikely if the Main DC has a high FC and replenishment from a PU is delivered in time, and all simulated objects has the highest FC in the Main DC. The Main DC always denies replenishment to the secondary DC if the stock level at the Main DC would be less than 10% of its FC, after the potential STO shipment. Since the OP is set to cover the FC during the replenishment time of the PU without falling below SS, a system with no problems in production is very unlikely to have a Main DC stock level falling below 10% of its monthly FC without receiving replenishment.

The numerical simulation created from historical orders, stock levels and stock parameters were studied. The situation is more likely to put the Main DC in a backlog situation if the Main DC has a low FC and the secondary DC has a high FC which leads to a high OQ. However, if the secondary DC has a higher FC then the Main DC the Main DC set up is likely to be unsuitable and in need of a Main DC switch.

This situation is avoided as long as the system has the highest FC in the Main DC, the Main DC has accurate OP, the secondary DC's has accurate FC's and therefore accurate OQ's and if the PU can deliver within its promised lead time.

Even if the situation is unlikely to put the Main DC in a backlog situation due to the hold back level of 10% of the Main DC's FC and the high FC's at the Main DC's in the studied candidates, the situation is always reducing the Main DC's stock level. This will accelerate the consumption of the Main DC's stock level to drop to its OP and will trigger the Main DC to send a PO to the PU. However, this phenomenon is described in Situation 4.

Observations of Situation 4 – The total inventory level at all DC's is not considered when ordering replenishment

Observation of Situation 4 was only made numerically. The situation is linked to the logic of the Main DC's OP always triggering the Main DC to send a PO the PU, even when there are large quantities of the product available at other DC's. The situation is also linked to the logic of the secondary DC's OP always triggering the secondary DC to send a STO to the Main DC, without even considering the stock level and predicted sales at other DC's. If stock levels not needed at other DC's was considered in the system, the PO's and STO's could be postponed or avoided, by using existing stock. Many observations of the system overloading the system could be made numerically. Of all 2071 products, 265 products were found with unnecessary stock levels at the secondary DC's with the criteria mentioned in Chapter 8.3. A Main DC checking if unnecessary stock exists in a secondary DC and relocating unnecessary stock levels where it's needed before sending a PO could remove these unnecessary stock levels. A secondary DC checking if unnecessary stock exists in other DC's before sending an STO could also remove these unnecessary stock levels. If unnecessary stock levels would be relocated where it's needed, PO's, STO's and production could be postponed and the total inventory level of the product could be reduced. A system detecting unnecessary stock levels must consider the current stock level, the SS and predict the sales at the secondary DC's. If the system can identify products in secondary DC's with a current stock level high enough to cover both the DC's SS and a high share of its yearly FC, the system can identify unnecessary stock. If unnecessary stock is found, it can relocate the stock where it's needed. Otherwise, the estimation of unnecessary stock might be inaccurate with the risk of moving too high quantities and putting the secondary DC in a backlog situation.

9.2.2. Cost of exceptional situations

The following section is used to analyze and quantify the cost of the exceptional situations and potential savings with potential alternative logics. The discussed change of logics is based on previous research in Chapter 5.1.

Potential savings in Situation 1 - Multiple Backlog STO's sent after each other in a backlog situation

As all Backlog STO's are sent individually and never consolidated, every shipment requires resources of handling the shipments at the DC's. Chapter 5.1.1 discusses proactive and reactive transshipments. The current backlog logic is reactive to the stock level and handles reactively when the CO is larger than the available stock level. In an alternative logic, the Backlog STO's could be consolidated by increasing the Backlog STO quantity proactively as long as it does not put another DC in a backlog situation. Sending shipments individually leads to high costs of handling each shipment at the DC's. The cost of handling is small in comparison to other costs and can be seen in Chapter 7.7.2. The cost of transports in Chapter 7.7.1, and is paid per weight unit. Therefore consolidating Backlog STO shipments will not reduce the transport cost since the same weight will be transported.

Consolidation of Backlog STO's by increasing the Backlog STO quantity could increase the SA for the following CO's, as additional quantities will be available at the DC. This will reduce the costs linked to unavailable stock. An increased SA is an objective for SMS. An increased SA will lead to decreased costs. However, the exact cost reduction due to an increased SA is not investigated in this study.

Potential savings in Situation 2 – Fixed OQ disfavors secondary DC's

When a Main DC disfavors a secondary DC, the secondary DC is denied replenishment. This might put the secondary DC in a backlog situation. An alternative logic where the Main DC can send partial quantities of the OQ when possible, with enough knowledge not to risk ending up in a backlog situation itself, would decrease the risk of putting the secondary DC in a backlog situation. This is described as partial pooling in previous research, see Chapter 5.1.2. This will create additional handling of additional shipments of STO's. The transport cost will be unchanged, since the same weight is transported and transports are paid per weight unit. The potential decrease in costs are linked to avoiding a backlog situation for secondary DC's and mentioned in Situation 1 above. Avoiding Situation 1 will lead to an increased SA which is an objective for SMS.

Potential savings in Situation 3 – Fixed OQ disfavors Main DC

The situation of a fixed OQ from the secondary DC's disfavoring the Main DC can theoretically put the Main DC in a backlog situation since its consuming additionally on the Main DC's stock level. An alternative logic would potentially decrease the costs that are linked to avoiding a backlog situation as mentioned in Situation 1. However, no alternative logic for Situation 3 has been evaluated. The reason no alternative logic is evaluated is due to the observations that the current hold back level of 10% of the FC at the Main DC makes this situation unlikely.

Potential savings for Situation 4 - The total inventory level at all DC's is not considered when ordering replenishment

The situation of ordering replenishment from the supplier, even when unnecessary stock levels exist is a cost bearer to SMS. The current system logic allows products lying around in secondary DC's for an unlimited time if not sold or transferred manually. This is a cost to SMS in various aspects. After a certain time products become unusable and must be discarded. These products will not generate any revenue which is a lost profit, and the cost of producing these articles is completely wasted. For products were the sales are phasing out, current existing stock levels at secondary DC might be sufficient to cover the final demand of all DC's. The system will replenish the Main DC as soon as it's below OP. Using unnecessary stock levels at secondary DC's, the last produced batch could have been avoided entirely. By using proactive transshipments, described in Chapter 5.1.3, stock could be relocated at to DC's where it's needed before total sales are known.

In addition to these cost, the cost of keeping inventory is a yearly expenditure linked to an unnecessarily high stock level due to the unnecessary stock described in Chapter 9.1.2. Unnecessary stock was identified in 265 out of 2071 products. By using the product value's and the stock interest rate on all identified unnecessary stock found in secondary DC's, the cost of keeping this inventory is estimated to 20 990 EUR per year. However, a system logic transferring unnecessary stock to the DC's where it's needed will lead to more shipments, which will lead to a higher amount of products being transported and increase handling of shipments at the DC's. This will increase the transport cost and the handling cost. If the relocation is made of stock not needed at the secondary DC's the SA will be kept unchanged.

10. Sensitivity analysis

As described in Chapter 3.5.3, the sensitivity analysis is made to analyze how sensitive the model is to varying the input data. The sensitivity analysis should give an indication of how valid the result of the models is, even if the input data is inaccurate. The chapter is divided into Part 1 and Part 2.

10.1. Part 1 – Sensitivity of total cost model

The total cost model in Part 1 is created and tested on an assortment of 2071 products. However, the input cost parameters are assumed to be generic and applicable for a larger assortment.

To measure how sensitive the model is to the different input data, each cost parameter is modified in order to analyze the changes in the results. An input parameter with high sensitivity needs high accuracy, as it highly affects the result. An input parameter with low sensitivity is not as likely to affect the result with a low accuracy. However, no input cost parameters can be neglected in the model for a valid result.

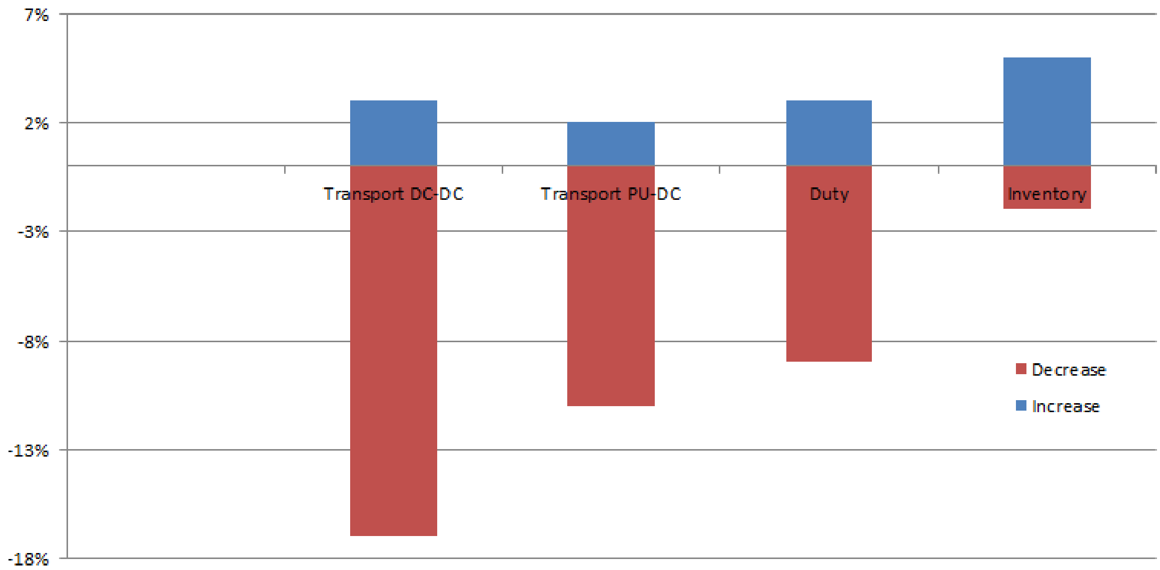
10.1.1. Sensitivity of cost elements

The 57 unsuitable set ups found with the total cost model (described in Chapter 8.3) was decided to be our model output. The input data was changed gradually in order to analyze when a change in the input data would not change the output.

The sensitivity will in this chapter be measured on the following input data:

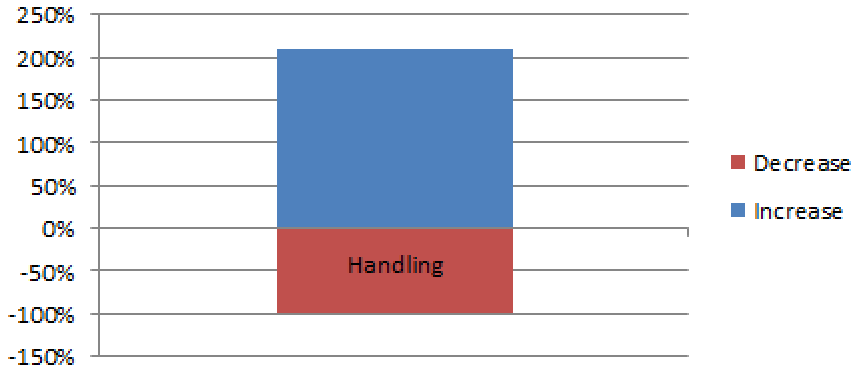
- The estimated transport cost per weight unit between all origins and destinations
- The estimated handling cost at each DC
- The estimated stock interest rate
- The cost of duty

A proportional increase and reduction of each input data have been analyzed and are presented in Graph 7. The graph shows all costs except for the handling cost as the handling differ too much compared to others. The individual sensitivity of the handling cost can be seen in Graph 8.



Graph 7 - The sensitivity of the costs of transport, duty and inventory

As seen in Graph 7, the transport cost between DC's as well as between PU and DC is the costs that are the least sensitive to a proportional decrease of the current input data. The most sensitive output of a change in the input data is the inventory cost.



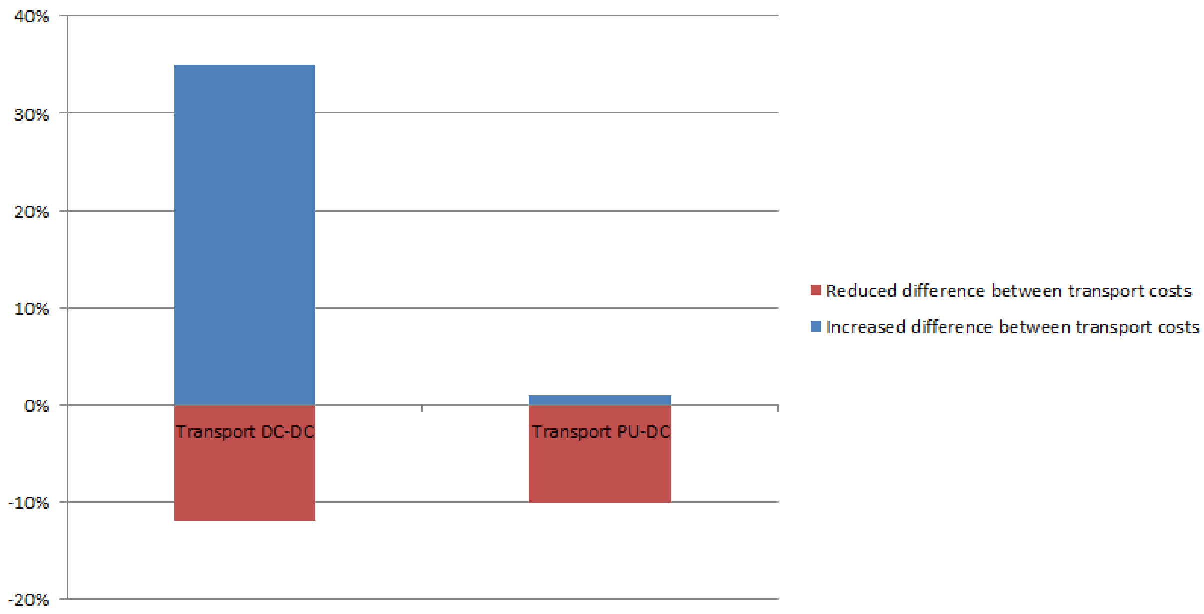
Graph 8 - Sensitivity handling cost

The handling cost seen in Graph 8 is very insensitive to changes of the input data. The reason is that the handling cost (as mentioned earlier) has such a small impact on the total cost model.

As large variations exist in the transport cost depending on the origin and destination (Chapter 7.7.1) a further investigation of the individual impact of changing this input data was made. The sensitivity of the individual impact was done by either amplifying or smoothing the differences between the input transport costs per weight unit. The analysis has been done in two ways:

1. An increased differential between the costs by letting the costs above the average cost increase by a certain percentage and the cost below the average cost decrease with the same percentage
2. A decreased difference between the costs by letting the costs above the average cost decrease by a certain percentage and the cost below the average cost increase by the same percentage.

This analysis demonstrates that increasing the cost difference between the DC's means that it becomes more crucial which DC to choose and consequently the set up as it differs significantly between the cheapest and most expensive. If the difference between the transport costs between the origin and destination reduces it also provides less impact on the total cost. In this case, the amount of unsuitable set ups due to high transport cost decrease as the transport cost for all alternative set ups becomes more even. Note that the Graph 9 only refers to the transport cost since the handling cost is assumed not to be interesting, for the same reason mentioned below Graph 8. The result of this sensitivity analysis of the individual input transport cost impact is shown in Graph 9.



Graph 9 - Sensitivity analysis of equalizing the transport cost

As seen in Graph 9, the transport cost between PU and DC is more sensitive if the difference of transportation cost between PU and DC is increased than if the difference in cost would increase for the transportation between DC's.

10.2. Part 2 – Evaluation of system logics

Evaluation of the system logics is done in a simulated environment, where the results and output of the model is interrelated with the input data. This chapter contains a sensitivity analysis to measure how sensitive the model output is to the model input.

10.2.1. Sensitivity of probability, randomness and the choice of simulation candidates

The model contains no elements of probability and randomness. The model completely trusts the input data to be accurate, and models the effects of input data according to the defined logic. Therefore the model is not sensitive to probability and randomness. However, the model is sensitive to the input data. The result is highly sensitive to the choice of simulation candidates in the aspect of the accuracy of the simulation candidates input data.

Sensitivity in estimation of costs

The estimated cost of unnecessary stock in Part 2 is proportionally sensitive to the stock interest rate. An increased stock interest rate will increase the yearly cost of keeping inventory of unnecessary stock. All other costs are kept on a generic level and are not estimated numerically. A change in the modeled logic highly affects the cost of stock availability. The changes in cost with a change of the stock transfer logic are highly sensitive to SMS's actual cost of having unavailable stock.

11. Result

This chapter presents the results arising from the analysis Chapters 8 and 9 for Part 1 and 2 respectively.

11.1. Part 1 – Main DC switch

Since there are numerous factors affecting the total cost in the Main DC set up, no factor alone can predict the lowest total cost with high accuracy. The complementary information that should be used when deciding a Main DC switch are all input parameters in the total cost model.

As a result of the analysis of Part 1, the resulted guidelines require the use the total cost model in Chapter 8.1. But to only use the total cost model is not enough. To reduce the total cost of the supply chain the unsuitable Main DC set ups must be followed up on and changed with a Main DC switch. Otherwise, the total cost model is of no use. The guidelines are summarized in Table 23 below.

Table 23- Guidelines of how to reduce the total cost of the supply chain by changing the Main DC set up

Guidelines
5. Apply the total cost model on the entire/parts of the assortment 6. Identify all products with unsuitable set ups and the cheapest alternative 7. Follow up on results and change as many unsuitable set ups as possible, start with the products with the largest potential reduction in total cost 8. Repeat the procedure occasionally

11.2. Part 2 - DC stock transfer logic

The four exceptional situations, possible changes in the current logic, the risk of changing the current logic and additional information needed to eliminate risk, are summarized in Table 24.

Table 24 – Summary of evaluation of the stock transfer logic and the risks with changing the current logic

Situation	Description of situation	Possible change in logic	Risks with changed logic	Information needed to eliminate risk
1	Multiple Backlog STO's sent after each other in a backlog situation	Increased quantity of Backlog STO's when possible	Larger Backlog STO's could feed the system with additional Backlog STO's	• Stock level of delivering DC • Time of replenishment for delivering DC • Predicted sales of the delivering DC • If delivering DC is a Main DC; same information about secondary DC's
2	Fixed OQ disfavors secondary DC, which is denied replenishment	Allow secondary DC to receive partial quantities of the OQ from the Main DC, when possible	Situation 1 occurs at Main DC	• OP, OQ and Stock level of all DC's • Time of replenishment for Main DC • Predict future sales of Main DC • Predict future sales of all secondary DC's
3	Fixed OQ disfavors Main DC, which is	No change in logic studied	Situation 1 occurs at Main DC	• High FC in Main DC • Accurate OP, OQ and FC

	emptied		Situation 4 occurs	
4	a) Main DC does not check secondary DC stock levels before sending a PO b) Secondary DC empties Main DC without checking secondary DC's stock levels	a) If unnecessary stock exists in secondary DC's, request a stock transfer in the quantity of the unnecessary stock level. If the unnecessary stock levels exceeds EOQ, hold PO to PU b) If unnecessary stock exists in secondary DC's, request stock transfer in the desired quantity as long as it does not exceed the quantity of unnecessary stock	a) Situation 1 occurs at Secondary DC due to inaccurate estimation of unnecessary stock b) Situation 1 occurs at Secondary DC due to inaccurate estimation of unnecessary stock	• Accurate Stock level, SS and FC at all stocks • High margins of predicted sales

The cost with alternative logics is based on observations in the simulation model, reasoning, numerical examples and the exceptional situation identified for the studied products. The change in cost with alternative logics is presented in Table 25.

Table 25 - Estimated potential savings with possible changes

Situation	Description of situation	Possible change in logic	Change in costs in scope
1	Multiple Backlog STO's sent after each other in a backlog situation	Increased quantity of Backlog STO's when possible	• Lower handling cost at DC's
2	Fixed OQ disfavors secondary DC, which is denied replenishment	Allow secondary DC to receive partial quantities of the OQ from the Main DC, when possible	• Higher handling cost at Main DC
3	Fixed OQ disfavors Main DC, which is emptied	No change in logic studied	-
4	a) Main DC does not check secondary DC stock levels before sending a PO b) Secondary DC empties Main DC without checking secondary DC's	a) If unnecessary stock exists in secondary DC's, request a stock transfer in the quantity of the unnecessary stock level. If the unnecessary stock levels exceeds	• Higher handling cost at all DC's • Higher transport cost of moving unnecessary stock • Lower inventory cost, 20980 EUR / year

	stock levels	EOQ, hold PO to PU b) If unnecessary stock exists in secondary DC's, request stock transfer in the desired quantity as long as it does not exceed the quantity of unnecessary stock	

12. Discussion

This discussion aims to address interesting factors that might influence the study negatively. The chapter also aims to note the assumptions and results that affect the output in this particular scope.

12.1. Part 1 - Impacts of delimitations

In the study the assumptions, delimitations and the direct focus of the study can affect the reliability of a general result. As the real system is complex and as a large amount of data and information has been collected, simplifications and delimitations have been necessary to move forward and to accomplish the desired goals of the study. To discuss the reliability of a general result, the impacts of assumptions are questioned in this chapter.

12.1.1. Impacts of using historical input data

As the condition will change over time, using historical data will have an impact on the future costs linked to the decision of a Main DC switch. Since the total cost model cannot be applied on exact future sales, an exact prediction of all set ups with the lowest total can never be guaranteed based on historical conditions. Therefore recent input data is recommended to be used in the total cost model.

12.1.2. Events of 2013 affecting model outputs

During the year of 2013, CDC first became operational in March. The introduction of CDC had a large impact in the data collected and the information during these months deviates from the regularity of the rest of the year. The impact of the introduction of CDC according to the data led to high variations in the stock parameters at all DC's during its first months in operation. The reason could be a type of phasing in the system before the sales and ordering parameters are settled in a steady state. As the total cost model in Part 1 considers the average stock- and ordering parameters of the whole year, this impact is faded in the result. However, the total cost model will represent reality with higher accuracy when applied to more recent data, where all DC's has been in operation through the entire time of study.

12.1.3. The same stock interest rate for all DC's

Since the same stock interest rate has been applied on an assortment during 2013, but the new ownership of Santrade was first implemented during April 2014, the output of the total cost model might have a small deviation in the inventory cost compared to the reality. The set up during 2013 might have had a slightly different inventory cost then what our model suggests. However, since the model is created to support a future decision of a Main DC switch the model was used with the stock interest rate based on today's ownership of Santrade.

12.1.4. Limited numbers of products

The total cost model has been created and tested on 3 % of the products of the entire assortment of SMS, which might have an effect on the formulation of the model. Additional conditions might exist for products of an assortment outside the scope which is unknown when this model was created. If applying the model on another assortment far different to the assortment in the study, the results should be handled with caution and questioned with factors outside this scope. However, the total cost model is a dynamic mathematical model and as long as the input data is correct, the output should be applicable for any similar assortments.

12.1.5. Multi-Main DC set up

The total cost model formulated is not created to estimate the cost of products using a Multi-Main DC set up. If a product with a Multi-Main DC set up is estimated by the model, the estimated cost will be inaccurate. The reason is that the model always assumes that the Main DC always supplies all other DC's. In a Multi-Main DC strategy this will not be the case, since more than one DC is supplied directly from one or several PU's.

12.1.6. Dynamic transport costs due to transport tariff cost negotiation

As the transported flow between an origin and destination increases, the transport cost tariff to SMS given by the external shippers will decrease. The model will not consider the effects that an increased flow will have on the transport cost. Therefore, a large relocation of flows due to a Main DC switch might have a slight effect on the transport cost that the model cannot predict. An example would be the opportunity of having CDC as Main DC. CDC is not set up as a Main DC in current set ups. Therefore the outbound transports from CDC are relatively expensive, since CDC never supplies any secondary DC's. However, by allowing CDC to be a Main DC would increase the outbound flow from CDC and reduce the transport cost for this set up. Therefore any set up where CDC has the lowest total cost as a Main DC is recommended, as this cost will be even lower as future outbound flows will increase.

12.1.7. Various methods when estimating transport- and handling cost

The transport- and handling cost collected from the DC's in this study are all estimated separately by different people. This means that they might have used different methods of estimating the cost of transports and handling. This might affect the output of the model. Since the model is sensitive to the transport cost between PU and DC, it is recommended to create strict and consistent instructions of how this cost should be estimated by the DC's.

12.1.8. How a change in the delimited system affect the entire system

As described at the beginning of the report the studied system is defined to only handle the distribution flow between PU to DC and between DC to DC. We have there assumed that a SU always place CO to the most suitable DC. By suitability it can mean shortest distance for example. This means that we have not analyzed how the changes of the suggestions given by the total cost model will affect the whole system, as this is outside our scope. It is however important to indicate the awareness and discuss this situation for any future implementations.

Since we have used and analyzed real values of CO's with the assumption that the decision of the allocation of these CO's are not affected by a Main DC switch. In the reality a SU belongs to a certain market and sends the CO's to the predetermined DC. However, this allocation of sales changes between the DC's from time to time. This decision is affected by the Main DC set up. If the Main DC set up is changed in a large scale without being considered when reallocating the sales at the SU the cost might be higher than expected. A change in the Main DC switch also affects the reallocation of the production at the PU's. The decision of which PU that should produce what product is likely to be made by considering the Main DC set up. A change in the Main DC set up can undermine decisions made in the allocation of the production.

This means that a change in our system might have an effect on the allocation of the sales and production. The recommendation is therefore to communicate strategies between SU's, PU's and DC in order to keep sustainable and long-term decisions.

12.1.9. The effect on customer service

A change in the supply path is assumed to not affect the customer service. As described in Chapter 7.2.2, the new Main DC will inherit EOQ and SS from the old Main DC. And since these parameters affect the availability of the product in stock (described in Chapter 4.4), it is assumed that the availability is taken into account by the model and therefore the current customer service is kept.

This assumption is not always correct and exceptions will always exist. However, since we never can predict future events with perfect accuracy, assumptions must be made. Depending on future conditions and variations, the customer service will vary. The assumption of inheriting EOQ and SS of the old Main DC will keep us from neither making an optimistic nor a pessimistic estimation of the cost of the current service level. That means that we can never guarantee that the service level will be maintained, become better or worse without predicting the exact future. The only thing that would guarantee a perfect stock availability is an unlimited stock level, which is not an option.

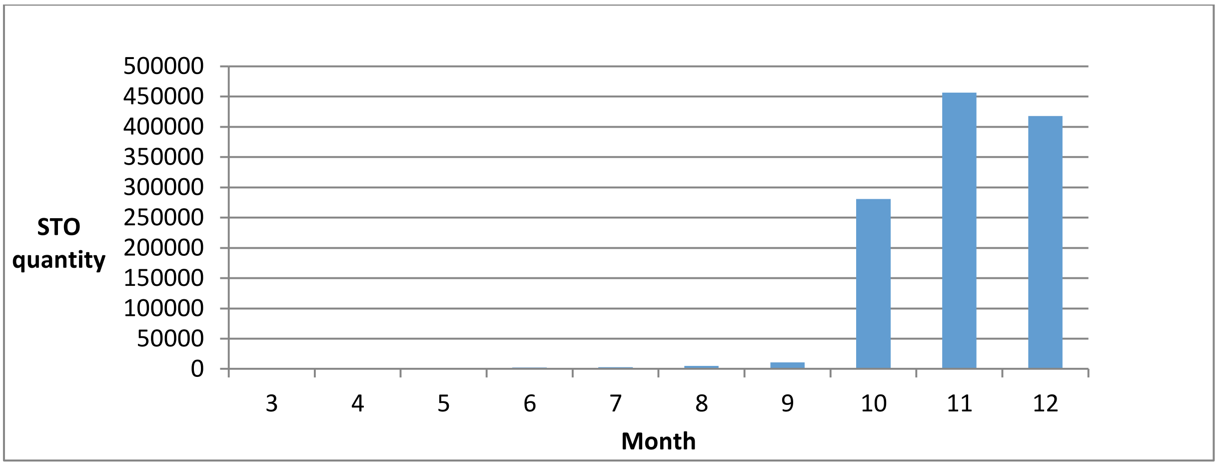
12.2. Part 2 - Discussion of simulation model

The authors have tried to model stock transfer situations by creating a simulation model using historical sales and stock- and ordering parameters. A big difficulty was to create a model handling the large amounts of each product and a large variety of products in a simulation model thought to represent a much larger assortment. Another difficulty when creating this model was to validate the model with the data received. Since that SMS have the possibility to manually change values in the stock transfer logic, for instance order quantities, this may modify the logics in the distribution system. So when differences between the outcome of the simulation model and the real system (described in Chapter 7) occurred, it was difficult to determine whether the reason was due to the manual changes or the stock transfer logic.

Below chapters discusses different factors effecting the simulation of Part 2.

12.2.1. Validation with orders received

PO’s was obtained for the whole year with information when it was received at the Main DC. No time when the PO was sent from the Main DC could be obtained, which made the time stamp of the events difficult to validate due to believed large variation in the lead time from PU’s and the assumed standard stock lead time obtained from the ERP-system. CO’s was obtained with requested quantities and with time stamps of when the order was received and when it was shipped. The CO’s were validated with the total yearly order intake used in Part 1 during the last period of 2013 and was slightly smaller. The missing quantity was believed to be the last few orders missed in the last period. The measuring of STO’s and Backlog STO’s done by SMS was implemented in ERP-system in March of 2013, as seen in Graph 10.



Graph 10 - The total STO quantities of the assortment measured ERP-system during 2013

As seen in Graph 10, the STO and Backlog STO quantities are very low in the beginning of the year and therefore assumed to be unreliable. This has impacted the study since the simulation model in Part 2 could only be validated during the last two months. We also had difficulties validating the STO and Backlog STO orders during the last two periods by comparing the data with CO's, PO's and the obtained momentary extracts of the stock level in the last two periods. Therefore we cannot guarantee the validity of any STO and Backlog STO data received.

12.2.2. Not evaluating theoretically possible extreme scenarios in Part 2

Choosing specific products and recreate the stock transfer situation based on real orders could as an alternative been made by fabricating theoretical possible extreme scenarios. With our choice our observations are tied to real events. This leads to the fact that we might have missed extreme conditions that can occur in theory, which is a risk for SMS. In theory, extreme conditions and coincidences of orders could lead to additional problems with the current logic. As an example, we could not detect Situation 3. Situation 3 can however occur theoretically during extreme conditions. The choice of studying real stock transfer situations was made due to the difficulty in constructing realistic extreme scenarios. To be able to study all possible extreme scenarios, fabricated parameters could have been used. However, when creating a model with fabricated parameters where the situations are reinvented was assumed to be dangerous due to the amount of necessary assumptions that would be necessary. If fabricating the parameters, realistic values of demands and sales must be assumed at each DC. This also leads to fabricating an accurate assumption of the FC. As the FC most likely deviates from the actual sales in reality, this must also be considered. With the FC's, different OQ's could have been estimated with additional assumptions. Further estimation of an initial stock level, tied to earlier sales, transfers and replenishments would require further assumptions. All these assumptions necessary would give us difficulties in trusting fabricated conditions when evaluating the system logics. The study of the logic has only focused on products with high amounts of Backlog STO's and high quantities of Backlog STO's. This has been done with the assumption that the system logic handles products with low or no amounts of Backlog STO's with acceptable efficiency. Besides, a few additional criteria are required before deciding that simulation is worth using. All products chosen are products with high distribution activity and with a large order intake at the Main DC. The reason of choosing products with high activity was with the desire to detect as many situations of interest as possible.

Before implementation, we recommend that any change in the current logic is tested on a broader assortment. A change in the logic can affect other products with differing conditions.

12.2.3. The choice of simulation software

To model the current stock transfer situation, Arena has been used as simulation software. However, a large range of simulation software (Arena) exists which might have been more useful for the formulated problem. The reason to use simulation software was not the opportunity to add randomness, rather the software ability to model discrete events necessary to recreate connected events over time.

The choice of using Arena was mainly because of previous experience within the software and the opportunity to obtain a license. However, Arena is generally created to simulate objects as entities. In our model entities are only used to describe the flows between the PU and the DC's. The reason was the high quantities shipped and stored of each product was too large to describe each article as an entity. The actual quantity in stock, the size of shipments and the change of the stock level are described with variables. Variables are generally used to describe the characteristics of the entire system. Variables are not tied to a specific entity, and therefore a large amount of different variables had to be created. Arena handles variables very well, as long as the entities are sent to the right destination. Nevertheless, of all the simulation software's available today it is most likely other software's existing more suitable for this task.

12.2.4. The effect on customer service

Change of the logic will have an effect on the customer service which is complex to quantify. The cost of a product not delivered within the lead time can be affected by various factors like compensation, additional handling, transports and inventory cost, administrations cost or even a lost income. Decreased customer service and stock availability can also lead to unsatisfied customers, who additionally affects the future sales and these effects are difficult to predict. On the contrary, pleased customers are likely to have positive effects on future sales.

Therefore, any effect a change in the logic will have on the customer service is important to consider. This will affect the changes of our model. If we assume that when a Backlog STO is sent, some customer order in the system is automatically delayed due to the process time of the Backlog STO, we can assume that by decreasing the amounts of Backlog STO's the stock availability will increase. However, all assumptions will have exceptions in a complex system. Yet, no matter how hard we try we can never predict the future with perfect accuracy.

With this said, the logics evaluated in Part 2 has mainly been focusing on the transport-, inventory-, handling- and duty costs in scope. For future research, we recommend a more comprehensive investigation of the change of costs with an increased SA.

12.2.5. How a change in the delimited system affect the entire system

The study has assumed infinite capacity of transports and infinite capacity at the DC's. Even if small changes are made compared to the total handling and inventory at the DC's and the total volume shipped in transports, this delimitation might have additional effects on the DC's and the cost of transports. If the suggested logic leads to increased transports and handling, this might have an effect at the DC's in terms of the DC's in need of increased amounts of resources, additional space at shipping docks and other synergetic effects of increased handling. The effects of assuming infinite capacity of transports might neglect the filling ratio which in reality might lead additional shipments.

13. Conclusion

This chapter presents the conclusions of the master thesis by answering the main issues and confirms that the purpose of the study is correctly responded

The aim and purpose of the study was presented in the introductory chapter that follows:

The aim of this thesis is partly to create a dynamic decision model for Sandvik Machining Solutions distribution flows and partly to evaluate how the stock transfer system logic handle four specific exceptional situations. The purpose is to reduce the total costs while keeping/improving the service level.

13.1. Part 1 – Main DC switch

The conclusion of Part 1 will be presented by answering the stated main questions in Chapter 1:

1:1 - How does the planning function currently decide a Main DC switch?

The planning function is using a flagging method based on expected sales. The different criteria were presented in Table 8.

1:2 - What complementary information could be used to reduce the total costs of the supply chain when deciding a Main DC switch?

Since the current flagging method only considers expected sales, other cost factors such as transport-, duty- and handling cost are needed to reduce the total cost of the supply chain. It is also useful to understand the impact of each cost factor depending on the product concerned. This means that the location of the PU may matter.

1:3 - *How would the new set of guidelines reduce the total costs of the supply chain when deciding a Main DC switch?*

The new set of guidelines, presented in Table 23, will help the planning function to decide when a Main DC switch is needed. Through the guidelines, the total cost model will identify products with unsuitable set up and present the cheapest alternative. By choosing the products with the largest potential reduction, the total cost of the supply chain will be reduced with lowest effort.

13.1.1. Responding to the purpose

By inheriting the EOQ and SS when making a Main DC switch, the service level will be unchanged.

13.2. Part 2 – DC stock transfer logic

The conclusion of Part 2 will be presented by answering the stated main questions in Chapter 1:

- 2:1 - *What is the current logic for DC stock transfers?*

The current logic for DC stock transfers is an order point system described in Chapter 1.1, where orders are triggered as described in Chapter 7.6.

- 2:2 – *How does the current system logics handle the four exceptional situations?*

The current system logic handles the four exceptional situations better than expected in a model assuming perfect precision produced quantities and delivery times. However, high amounts of Backlog

STO's were sent between the DC's. The current logic also allows high stock levels not needed at secondary DC's. This means that the total inventory level is higher than necessary and means an inventory cost larger than necessary.

- *2:3 – How would alternative system logics affect the costs and the service level?*

For Situation 1 we suggest that SMS look in to the possibility of an alternative logic increasing the quantity of each Backlog STO shipment when it's possible without putting another DC in a backlog situation. The system must be complex enough to accurately consider the stock situation of the other DC's.

For Situation 2 we suggest that SMS look in to the possibility of an alternative logic allowing partial quantities of the OQ from the Main DC when possible. This must be done without risking the Main DC ending up in a backlog situation. To allow partial quantities of the OQ to the secondary DC the system must be complex enough to accurately consider the stock situation of all DC's.

For Situation 3 we suggest that SMS work with increasing the accuracy of the OP's, OQ's and FC's as this will avoid the situation. The current logic with a hold back level of 10% of the FC and an accurate OP triggering the replenishment order in time will protect the Main DC from getting emptied and ending up in a backlog situation.

For Situation 4 we suggest that SMS look in to the possibility of an alternative logic relocating stock not needed at secondary DC's. A system logic relocating stock must be complex enough to accurately consider what stock is not needed at secondary DC's. If relocation of stock is done without risking putting any DC in a backlog situation the SA will not reduce. A suggestion could be a system assuming all stock levels at secondary DC's above the SS and the yearly FC could be relocated risk free. This would reduce the total inventory level without decreasing the SA.

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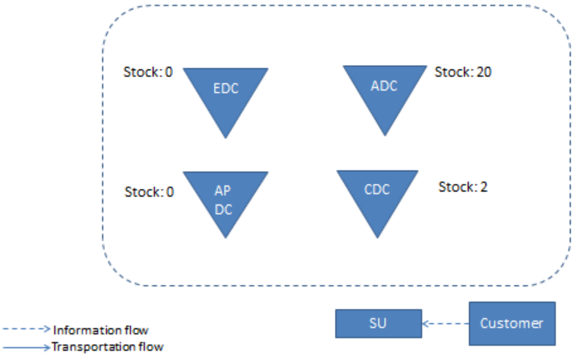
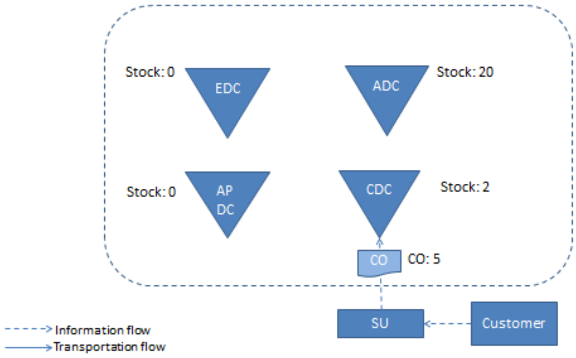
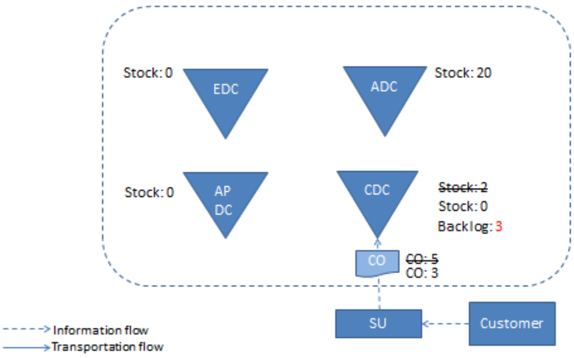
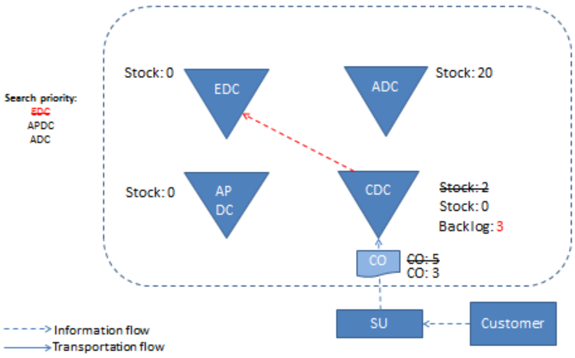
Appendix 1 – Examples of exceptional situations

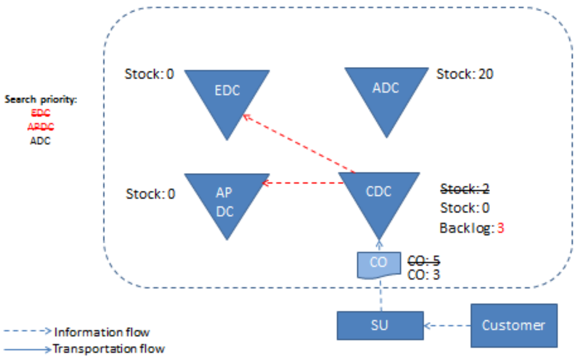
Situation 1 – Multiple Backlog STO's sent after each other in a backlog situation

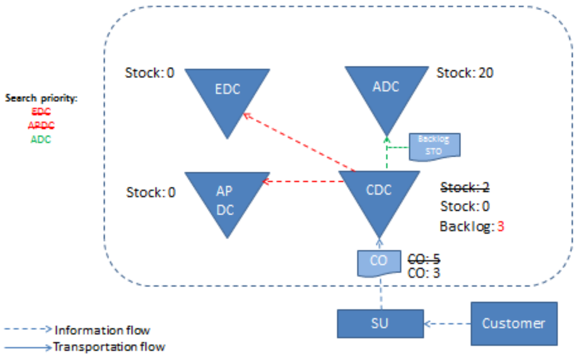




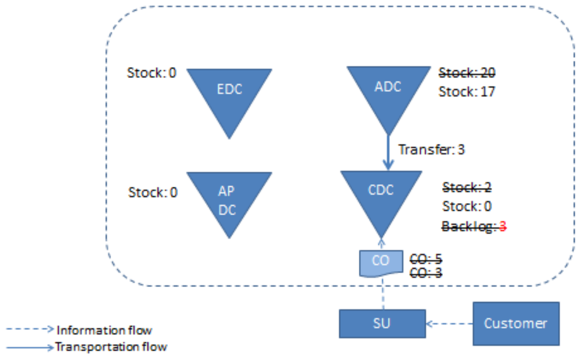








Appendix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ADC
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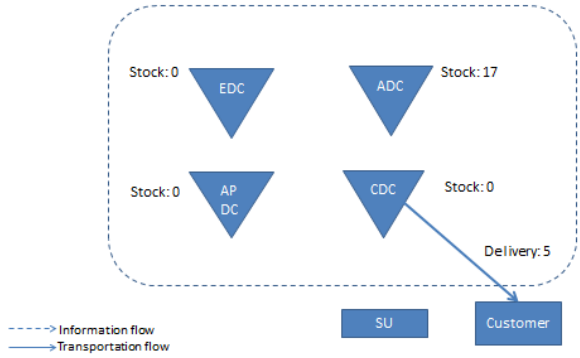
Stock: 17
Transfer: 3
Stock: 0
AP DC
CDC
~~Stock: 2~~
Stock: 0
~~Backlog: 3~~
CO
~~CO: 5~~
~~CO: 3~~
SU
Customer
Information flow
Transportation flow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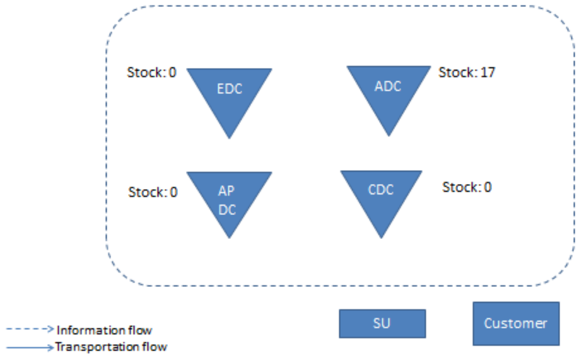
ADC
Stock: 17
Stock: 0
AP DC
CDC
Stock: 0
Delivery: 5
SU
Customer
Information flow
Transportation flow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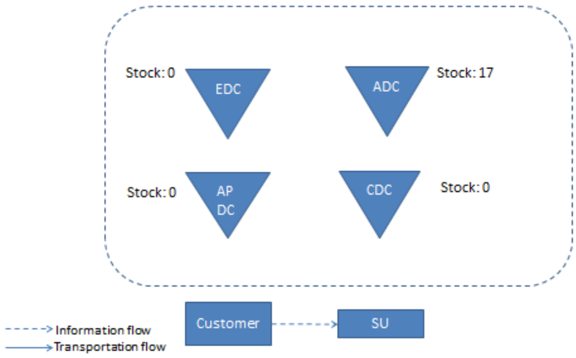
ADC
Stock: 17
Stock: 0
AP DC
CDC
Stock: 0
SU
Customer
Information flow
Transportation flow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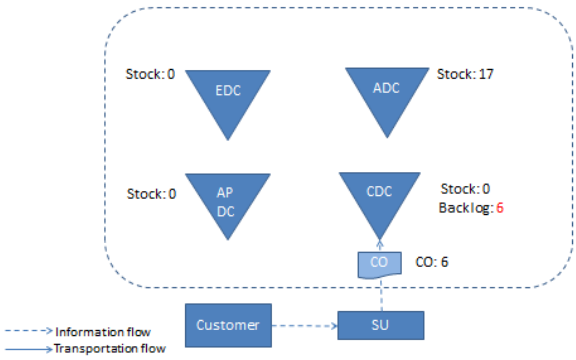
Customer
SU
Information flow
Transportation flow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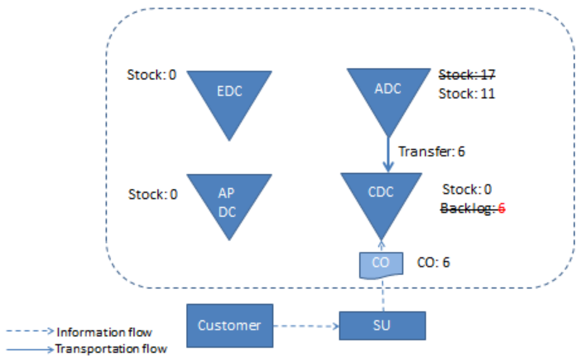
Information flow
Transportation flow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Stock: 0
AP DC
CDC
Stock: 0
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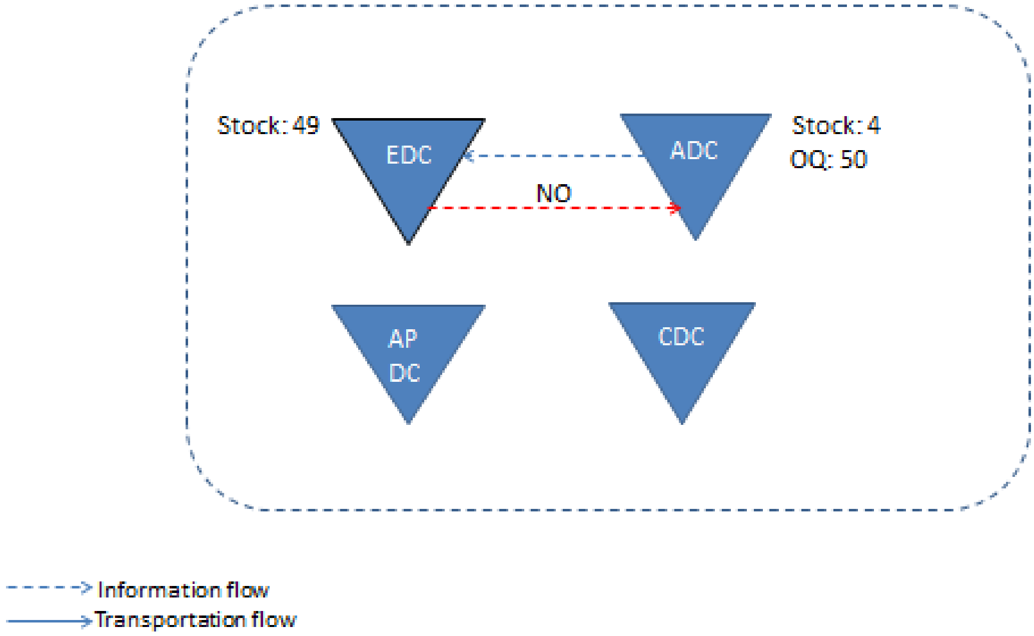
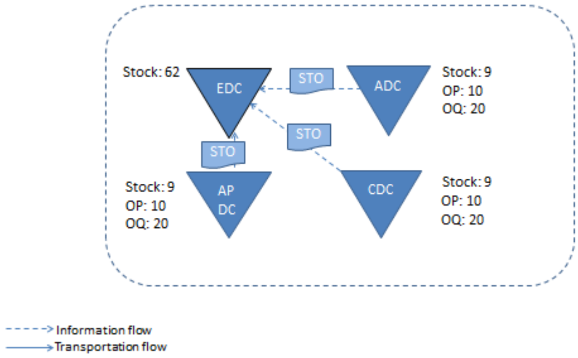
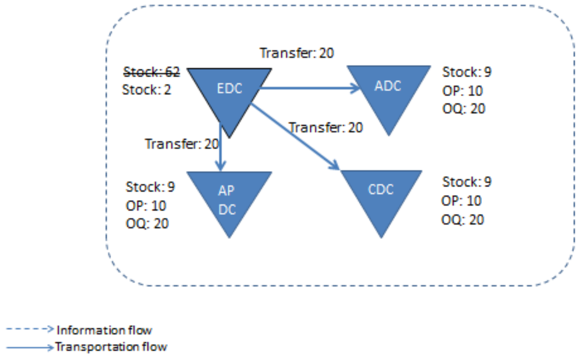
CO
CO: 6
Customer
SU
Information flow
Transportation flow

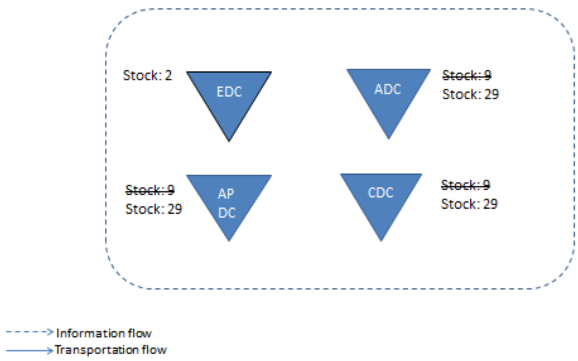
Situation 2 - Fixed OQ disfavors secondary DC

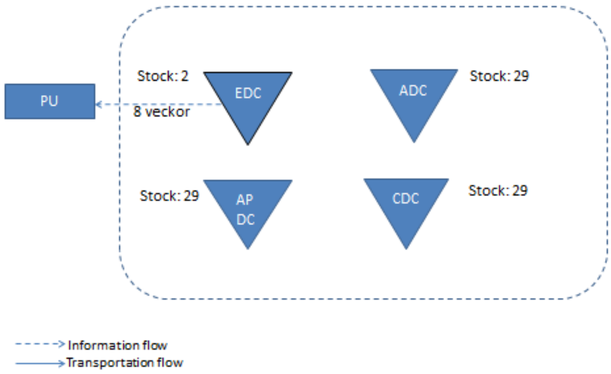


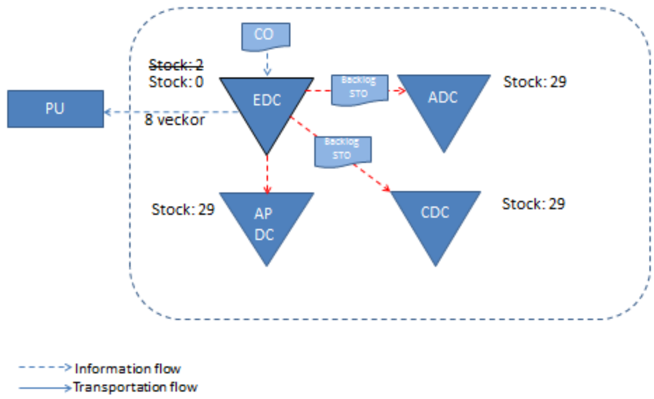
Situation 3 – Fixed OQ disfavors Main DC



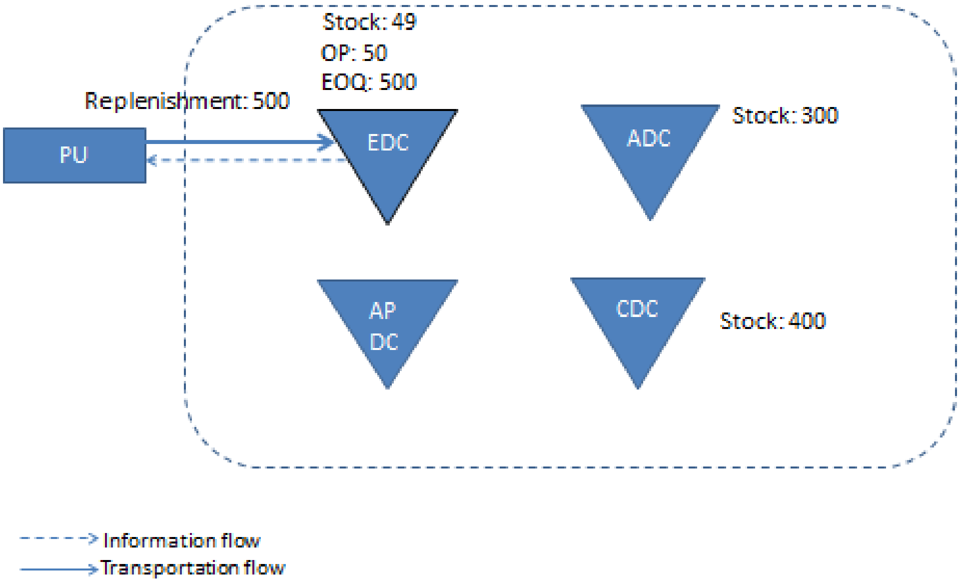




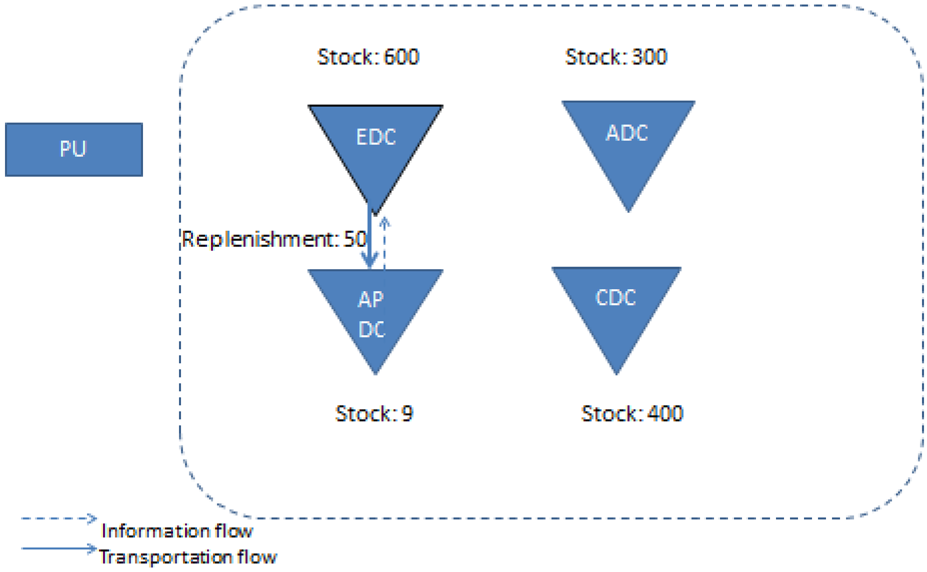




Situation 4a - Main DC creating a PO instead of checking other secondary DC's first



Situation 4 b - Secondary DC creating a STO instead of checking other secondary DC's first



Appendix 2 – Customs and duty

Customs and duty in the European Union (EU)

Horspool & Humphreys (2010) summarize the concept of free movement of goods within the customs union of EU. Inside the EU, no duties or quotas apply to any goods regardless of their origin.

'Once goods originating from a third country have been admitted anywhere in the customs union, they may circulate freely throughout the Member States. '

- Horspool & Humphrey (2010, p. 296)

According to the Swedish Customs Agency, Tullverket (2014), the EU is a customs union and no duties are collected among the member countries. However, each EU member country has the right to confiscate and levy goods under the circumstances of environmental protection, public health or security.

Import customs to the EU from outside the EU

Described by Swedish Customs Agency, Tullverket (2014) is the normal case of commercial import duty for commodity outside the EU to an EU member country. The customs value liable to tax is the selling price set by the supplier with an addition of the transport and insurance cost until reaching the border of EU. According to the Business Controller OTD and Planning (2014) an additional opportunity of a bonded warehouse exist. Mentioned by the European Union website (2011), a product not released in a free circulation but instead is held in a bonded warehouse can be store without duty until put in free circulation. According to the Business Controller OTD and Planning (2014), Sandvik are aware of this possibility but a bonded warehouse is not used in the present and import duty is paid for all shipments outside EU to EDC.

Imports and exports to the US

According to the United States Trade Office (2014), tax rates for imports to the US consist of Most-Favored-Nation (MFN) tax and an additional rate of ad valorem exists for imports from countries with standard trade relations. Import duty rate to America varies depending on the product group.

However, according to Business Controller OTD and Planning (2014) and United States Trade Office (2014), products re-exported from the US are entitled a refund called Duty drawback. This occurs when products are imported to the US but re-exporter to another DC, SU or customer outside the US. The refund is 99 % of the import duty of the re-exported quantity and is refunded to Sandvik.

Free trade zone (FTZ) in China

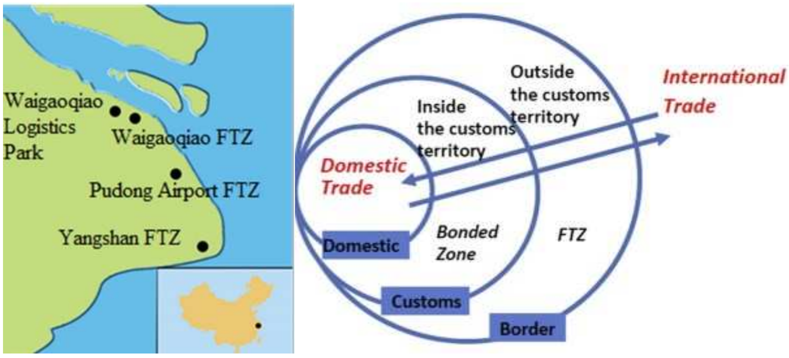
Wan *et al* (2014) mention that China launched the Shanghai Free Trade Zone (FTZ) Program in late September 2013. The implementation of a FTZ in Shanghai is to stimulate trade and to bring increased shipping and finance opportunities to the city. The FTZ launched in China is located in the outskirts of Shanghai and covers the trade zones of Waigaoquia, Yangshan Pudong Airport and Waigaoqiao Bonded Logistics Park. According to Wan *et al* (2014), the FTZ uses liberalized modern logistics to facilitate the free movement of goods.

'The FTZ will not impose customs duties or adopts complex administrative procedures.'

- Wan *et al* (2014, p. 4)

Appendix

The locations of the FTZ's in Shanghai and an illustration of trade zones can be seen in the figure below.



FTZ locations near Shanghai and illustration of trade zones (Wan, et al., 2014)

Free Trade Zone (FTZ) in Singapore

Mentioned by Singapore Government (2014), FTZ in Singapore are zones where duties and tax are suspended when the shipments arrive at Singapore. No duties or taxes apply to goods that are stored in the FTZ. According to Singapore Government (2014), foreign trades will have to work with local freight forwarders or traders to obtain the necessary permits of using the FTZ in Singapore. Singapore Government (2014) also states that products can only be stored in FTZ if they are being transshipped or re-exported. FTZ locations in Singapore are Brani Terminal, Keppel Distripark, Pasir Panjang Terminal, Sembawang Wharves, Tanjong Pagar Terminal & Keppel Terminal, Jurong Port, The Changi Airport Group, Airport Logistics Park of Singapore and the Changi Airport Cargo Terminal Complex.