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# EVALUATION OF SEA FREIGHT DISTRIBUTION

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A case study from an aftermarket perspective



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Go Pack! Boat Guys Out!

Lund, Spring of 2017



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## **ABSTRACT**

### **Title:**

Evaluation of sea freight distribution – a case study from an aftermarket perspective

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### **Background:**

Within research, it has been stated that transportation cost is a large part of logistics cost which is a large contributor to supply chain costs. To reduce transportation cost, choosing the appropriate transportation mode is an important decision both on a strategic and tactical level. There are several models and approaches when choosing transportation mode, including several factors and variables. Choosing the variables and factors varies for all companies. Sandvik Stationary Crushes (Sandvik SC) is a business unit within the Sandvik Group that is experiencing high logistics cost and no previous freight strategy. The business unit has identified transportation mode choice as a cost reducing opportunity. The focus of this thesis is to reduce transportation cost by a unit cost freight model that chooses the transportation mode for replenishment of aftermarket products within Sandvik SC's global distribution network.

### **Purpose:**

The purpose of this thesis is to develop a shipment profile for replenishment orders with a sea freight perspective.

### **Research Questions:**

1. How can a company determine what transport mode to use in the distribution network with the objective to minimize freight cost?
2. What factors are important to consider when changing transportation mode from air to sea freight?

### **Method:**

The study has a systems approach to the problem and apply a case study on a case company. To understand the problem and situation for the case company, literature review, data gathering, interviews and observations have been carried out. With the gathered information, a simulation model based on linear programming has been developed. The output of the model is that it chooses which transportation mode, air or sea freight, that implies the lowest transportation cost between global distribution centers. Furthermore, a sensitivity analysis has been carried out to test the validity of the model. The results and the implications of the results have been analyzed and discussed from a sea freight perspective. Additionally, the

actions taken by the case company, on recommendation from the study, together with real results are compared with the results from the simulation model.

### **Results:**

The result from the model show that a significant number of items should be shipped with sea freight rather air freight for replenishment order between global warehouses. The change of transportation mode implies great cost savings for the case company.

### **Conclusions:**

The study concludes that the unit freight cost model reduces cost by changing transportation mode. When choosing transport mode there are other factors than costs to consider for sea freight, such as; reliability, transit time and implementation processes. These factors need to be taken in consideration for the cost saving opportunities to be successful. Actual cost figures from the case company prove that the results from the model are applicable in practice, but with the other factors to consider as well.

### **Keywords:**

sea freight, transportation mode, distribution network, simulation, aftermarket perspective

# **SAMMANFATTNING**

## **Titel:**

Utvärdering av distribution med sjöfrakt – en fallstudie från ett eftermarknadsperspektiv

## **Författare:**

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## **Handledare:**

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Jamie Heath, External Logistics Manager, Sandvik

## **Bakgrund:**

Det är känt inom forskning att transportkostnader är en stor del av logistikkostnader som i sin tur är en stor bidragande faktor till supply chain kostnader. För att reducera transportkostnader kan val av fraktmedel vara ett strategiskt beslut att se över. Det finns många modeller och tillvägagångssätt när man ska välja fraktmedel, alla beroende av olika variabler och faktorer. Att välja dessa faktorer varierar för företag och beroende på vilken industri man är verksam i. Sandvik Stationary Crushes är en affärsenhet inom Sandvik koncernen som i dagsläget har höga logistikkostnader och saknar en tydlig strategi för att transportera produkter. Detta examensarbete syftar på att reducera transportkostnader genom att tillämpa en fraktkostnadsmodell som väljer den billigaste metoden.

## **Syfte:**

Syftet med detta examensarbete är att skapa en skeppningsprofil genom att tillämpa en kostnadsmodell med fokus på sjöfrakt.

## **Forskningsfrågor:**

1. Hur kan företag gå tillväga för att välja fraktmedel med målet att minska kostnader?
2. Vilka faktorer är viktiga att överväga när man byter från flyg- till sjöfrakt?

## **Metod:**

Detta examensarbete har ett holistiskt synsätt till problemet och använder en fallstudie på ett företag för att undersöka problemet. För att förstå problemet i sig och för fallstudieföretaget, har litteraturundersökningar, datainsamling, intervjuer och observationer utförts. Med all insamlad data har en simuleringsmodell baserad på linjärprogrammering konstruerats. Modellen väljer mellan flyg- och sjöfrakt och tar det medlet som är billigast för att frakta produkter inom Sandvik SC's globala distributionsnätverk. En känslighetsanalys har utförts för att testa modellens giltighet. Resultaten och effekterna av resultaten har analyserats med ett fokus på sjöfrakt. Till sist jämförs verkliga resultat från Sandvik SC med resultaten från modellen för att bevisa att modellen stämmer överens med verkligheten.

## **Resultat:**

Resultatet från modell visar att den största andelen produkter ska skeppas med sjöfrakt för påfyllnadsorders mellan Sandvik SC's globala distributionscenter. Förändring från flyg till sjöfrakt kommer enligt resultaten innebära stora kostnadsbesparingar för Sandvik SC.

## **Slutsats:**

Studien påvisar att kostnadsmodellen för att välja fraktmedel kan användas för att reducera transportkostnader. Att välja fraktmedel innebär inte bara att ta hänsyn till kostnader, utan man måste också se över ledtider, pålitlighet och hur implementeringen påverkar verksamheten. Dessa faktorer måste vara undersökta för att kostnadsbesparingarna ska bli så stora som man hoppas. Vidare, verkliga resultat från Sandvik SC efter implementation av modellen, visar att kostnadsbesparingarna är likvärdiga med resultaten från modellen.

## **Nyckelord:**

Sjöfrakt, transportalternativ, Distributionsnätverk, Simulering, Eftermarknad

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# 1 INTRODUCTION

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*The first chapter presents the background to this study and describes the problem to why this study was carried out. Additionally, it introduces the case company for the study, the focus area and delimitations. The chapter ends with an overview of the disposition of the report.*

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## 1.1 Background

Increasing competitive advantage and being cost efficient through supply chain management is a critical success factor for all business environments. To do so, the quality and selection of the supply chain design needs to fit the products flowing through the distribution network in order to reach excellence in supply chain management (Lovell & Stinson, 2005). The concept of “one size does not fit all” for supply chain designs has long been recognized and is still valid (Lovell & Stimson, 2005). Therefore, it is important to select a good supply chain design for the company specific products.

Within supply chain design, the distribution and transportation of products is core for the supply chain strategy. Transportation is key in achieving an efficient supply chain and transportation costs represent a large spend for the supply chain and companies (Gilmore, 2002). Not only is transportation a major cost for companies, but it is also important as it is directly linked with customer satisfaction, financial cash flows, efficiency and a competitive advantage ( Lovell & Stimson, 2005). Therefore, it is important to do it right. Transportation can be done using different modes, all of which are associated with different costs, lead times, reliability, risks etc.(Lumsden, 2012). Transportation modal choice has therefore grown from being a simple option to a strategic decision for creating a good supply chain design.

Choosing the right transportation mode implies understanding industry characteristics and aligning it with the right transportation mode (Ke, Windle, Han & Britto 2015). This means understanding factors for each transportation mode and what factors needs to be prioritized. In the struggle to gain competitive advantage, more companies are considering changing transport mode. Transport mode selection has become increasingly complex including performance variables, service levels, rates and costs. Historically, it was a process of selecting transport mode followed by choosing a carrier. Today, due to a more complex business environment and more research theories, choosing the right transportation mode has become more complicated. Various approaches and models exist, based on more factors and variables (Meixell & Norbis, 2008). However, cost is still a primary factor to consider when choosing transport mode.

## 1.2 Problem Discussion

For companies with global supply chains, the total logistics costs is a large part of total supply chain costs (Zeng, Rossetti, 2003). Reducing the cost is important as higher costs implies a higher price to customers or a lower margin of product for companies. One way of reducing total logistics costs is to reduce transportation cost, which represents a large part of the total logistics cost ( Ke et al., 2015). Therefore, choosing the right transportation mode is important as it can reduce the transportation cost.

Chopra and Meindl (2012) describe transportation modal choice as “*a strategic important decision for global supply chain management*”. As a strategic decision, choosing the right



transport mode is difficult task. Described by Ke et al. (2015), one method to choose the right transportation mode is to align transportation strategy with the industry characteristics and its products. However, aligning transportation strategy with industry characteristics is easier said than done. It implies many factors to consider, some of them: costs, product characteristics, customer requirements, financial impact, risks etc, -all of which are difficult for large companies to determine. When achieved, the right transportation and distribution methods contribute to gaining competitive advantages (Meixell & Norbis, 2008).

An organization that experiences high logistics cost is the business unit Sandvik Stationary Crushers (Sandvik SC), part of the large global company Sandvik AB. Their logistics cost represents 15% of their cost of goods sold. In a comparison with other Sandvik BUs and competitors the same number was 5 - 8%. This is the percentage they strive to reach. For Sandvik SC, the high logistics costs and inefficient distribution network has affected the profit margin on their products, which has reduced revenue and lead to a loss of competitive advantage, pinpointing the statements made by Lovell and Stimson (2005). The main reason for the high logistics cost have been identified as the lack of freight strategy within the distribution network.

When choosing transportation mode for stock replenishment orders from global distribution centers to their regional warehouses, there has been little strategy and no thought of aligning transport mode with neither product nor industry characteristics. Different transportation modes have been used for all types of products leading to unreliable lead times, high transportation costs and poor customer service. Therefore, developing a strategy to choose transport mode for replenishment orders have become a part of a new change program taking place in Sandvik SC.

Using product segmentation and transportation mode analysis, Sandvik SC aims to achieve better supply chain design and gain a competitive advantage. This study sets out to reduce freight costs by simulating a unit cost transportation model to choose transportation mode for the products within the two product groups spare parts and wear parts.

### 1.3 Research Purpose and Questions

This thesis sets out to investigate what Sandvik SC can do to make the decision regarding what mode of transportation to use in the distribution network, and what impact potential mode changes will have for the firm.

**Purpose:** The purpose of this thesis is to develop a shipment profile for replenishment orders with a sea freight perspective.

**Research Questions:** The study sets out to answer the following research questions:

- *“How can a company determine what transport mode to use in the distribution network with the objective to minimize freight cost?”*
- *What factors are important to consider when changing transportation mode from air to sea freight?*

### 1.4 Case Company Description

Sandvik AB is a global company group with headquarters in Stockholm, Sweden. Founded in 1862, in Sandviken, Sweden, the company has grown to a global engineering group with approximately 43 000 employees, sales in over 150 countries and an invoiced sale of 82 billion SEK in 2016. North America, Europe and Asia make up the biggest customer areas, however, the company is represented with customers in all continents and production facilities all around the world. Sandvik is mainly active in the engineering industry selling tools, equipment and services for industries in metal cutting, construction and mining.

A few years ago, Sandvik AB reorganized the organization and divided the company into three business areas; Sandvik Machining Solutions (SMS), Sandvik Mining & Rock Technology (SMRT) and Sandvik Materials Technology (SMT). The purpose of the reorganization was to decentralize the organization, giving authority to each business area to control their own business. With an independent control, the goal was to create a more efficient business to better serve their customers.

SMS's operations are based in tools and tooling systems for industrial metal cutting. SMRT serves the mining and construction industry with tools, equipment, service and technical solutions, and SMT provides high value-added products in stainless steel, special alloys and products for industrial heating. Each business area consists of several product areas (PA) and business units (BU).

(Sandvik AB, 2017).

For this thesis, the focus is within the Stationary Crushes within SMRT, seen in figure 1.

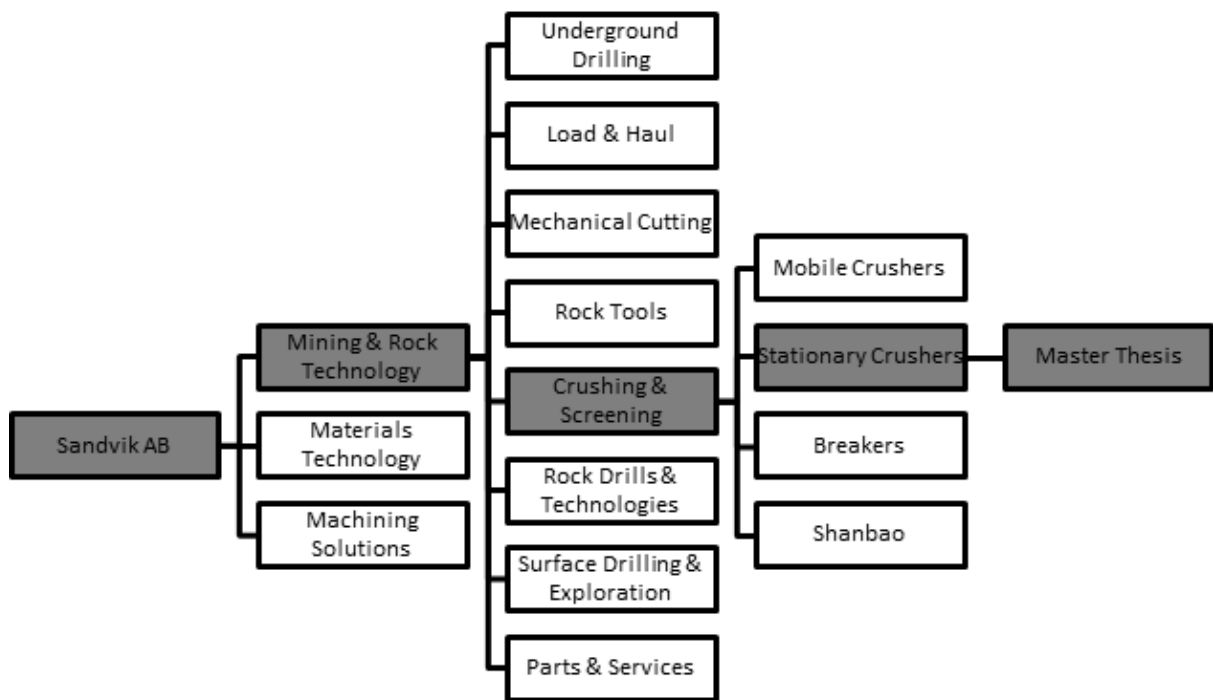


Figure 1 - Tree structured chart over Sandvik AB's organization, illustrating in which areas the focus of the study is within

## 1.5 Project Focus and Delimitation

This study is part of a change program at Sandvik SC, where the objective is to create an efficient supply chain through improved inventory and distribution management. The three focus areas are: inventory management, air freight distribution and sea freight distribution, and each area represents one master thesis carried out by students from Lund Technical University. The three master theses contribute to the overall scope by analyzing each area independently, and the focus for this study is on sea freight distribution.

The objective of the study is to establish a shipment profile, i.e. by using a simulation model decide on which transportation mode each product should be distributed with through the distribution network. The model takes product characteristics into consideration and selects the best transportation mode. The best mode is based on the lowest unit transportation cost for replenishment orders from two global warehouses in Europe to five regional warehouses around the world.

The problem statement was provided by Sandvik SC prior to the study, and therefore several directives have been set.

- Focus is on replenishment orders for products from the two global warehouses C1 and 07 to the regional warehouses C2, C3, C4, 63 and 67.
- Products in scope are wear parts and spare parts.
- Only the transit cost of products is considered.
- Feasible transportation modes are sea and air.
- Focus on 40ft full container loads.
- A fixed schedule is set-up by Sandvik SC with a weekly frequency for replenishment orders.

## 1.6 Report Structure

In table 1, a short summary of the structure of the report is described.

*Table 1 - A breakdown of the report including the name and number of the chapter with a brief description of each chapter.*

Chapter	Titel	Description
1	Introduction	The first chapter introduces the background to this study and the problem description. It also presents the purpose, research questions and the case company.
2	Methodology	This chapter introduces methodologies and the chosen scientific approach for this study. Followingly, it introduces the strategy taken along with the methods to collect and analyze data. The methodologies taken ensures the credibility of the study
3	Theoretical Framework	The theoretical framework presents theories for distribution, transportation, total logistics cost and simulation. The framework is necessary to understand and analyze the problem which the report will refer to.
4	Background to Sandvik SC	In order for the reader to understand the problem and solution, background of Sandvik SC is needed. This chapter focuses on presenting the parts that make up Sandvik SC's distribution network. It also informs the reader of the freight strategy used for 2016.
5	Empirical Study	This chapter describes the model used to choose transport mode and reduce cost. It explains the data needed and the process of segmenting data and is concluded with showing the credibility of the model by comparing it with real financial figures provided by Sandvik SC.
6	Results	The results are presented in three parts: The new shipment profile, the cost savings suggested by the model and the actual savings after implementation seen at Sandvik SC
7	Analysis	This chapter analyses the results from the study from four different perspectives; the new shipment profile, the stability of the model, the reliability of the model and the internal effects seen at a company that changes mode of transportation.
8	Discussion and Recommendation	This part sets out to discuss the study and its connection to the two research questions. Moreover, the chapter gives recommendations to ensure the future success for Sandvik SC.
9	Conclusion	Chapter nine concludes the study by connecting theory to the case company Sandvik SC and gives a short recap of the findings in the study.
10	References	An alphabetical list of all references used in the study based on the Harvard reference system.

## 2 METHODOLOGY

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*This chapter sets out to explain different research methodologies and inform the reader of what scientific approach and research methodologies that have been applied to this thesis. Furthermore, the chapter includes what type of data that has been used, the study's research execution and a discussion regarding the credibility of the study.*

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Methodology sets the foundation to how a research study is to be carried out. It establishes the frameworks and principles of how to approach the research, and what methodology the researcher chooses should be aligned with the objectives and characteristics of the study (Höst, Regnell and Runesson, 2006)

### 2.1 Scientific Approaches

To ensure the credibility of the research, the right scientific approach should be chosen. According to Arbnor and Bjerke (1996), the chosen scientific approach should be reflected in the problem and the project purpose, and how one views the reality and what type of data is analyzed should also be in line with the chosen scientific approach.

#### 2.1.1 The Analytical Approach

The analytical approach is built on the assumption that the reality has a summative character, which implies that the “sum of the whole is the sum of the parts”. Arbnor and Bjerke (1996) describes this as to the extent that if a researcher has enough knowledge in regards to the different parts, these parts can be combined to get knowledge about the entire picture,  $2+2 = 4$ . Consequently, quantitative data is common when using the analytical approach, and whenever qualitative data is used, it must be guaranteed that the data is objective (Gammelgaard, 2004)

#### 2.1.2 The Systems Approach

The systems approach is developed from the analytical approach, and differs in terms of its holistic view. By that, Arbnor and Bjerke (1996) means that for the systems approach, the sum of the parts does in fact not equal the sum of the whole,  $2+2 \neq 4$ . The researcher's task is to thus to be holistic and take all parts into consideration and improve their relations to each other to develop the entire system (Gammelgaard, 2004.). The systems approach uses both qualitative and quantitative data. but when using qualitative data, the researcher should ensure that the objectiveness of the data.

#### 2.1.3 The Actors Approach

The actors approach, does not view reality as parts, but rather as social connections that together build up the result (Arbnor & Bjerke, 1996). The actors approach does not care for explanations as the previous approaches do, but instead focuses on understanding how the individuals interpret reality. Due to this way of analyzing reality, the actors approach focuses on qualitative studies to understand these social connections.

#### 2.1.4 The Selected Approach

The aim for this project is to establish a model for how Sandvik SC best should distribute their goods from the two global distribution centers in Europe out to the different regional warehouses. In order to do so, a holistic view of the current and future supply chain network must be taken to ensure that the entire network is looked upon. The study must focus on

unique units such as product groups, facilities and transport modes, but also how the relationship between them will be and how they affect each other.

When reflecting on what kind of data is used, the conclusion is drawn that the both types of data is used, but most it is of a quantitative nature. The qualitative data used is not to be interpreted on a personal level due to the researcher's position in the project, which makes for an objective view of it is to be taken. Further, how different parts of Sandvik SC' distribution network will interact and depend on each other plays a key role in the result of the study, and must be taken into consideration. In this study, it is therefore believed that the result of the reality will be described not only by the different parts of it, but also how they interact with each other, which is in line with the systems approach. Further, Churchman (1968) argues that the ideal research strategy when using the systems approach is a case study, and that simulations preferably can be used when improving systems solutions, both of which are suitable and will be applied for this study. Furthermore, Gammelgaard (2004) argues that in the systems approach, the researcher should be very close to the object to best improve the system in reality, which also is the case for this study.

With all these factors in mind, the conclusion is that the systems approach is the most suitable scientific approach for this study, and is therefore the selected scientific approach.

When applying the systems approach, there are, according to Arbnor and Bjerke (1996), two ways of planning and implementing a study; the goal-means orientation and the trial-and-error orientation. The goal-means orientation defines goals for both the study and the system in the initial phase of the study. The approach is thereafter to seek the means that will permit the study to reach and fulfill the defined goals. In comparison, the trial-and-error approach doesn't have a set goals to the problem defined in the beginning. Solutions are gradually developed during the process of the study.

For this study, a problem and a system is already defined by the case company. Therefore, the goal-means orientation is the most suitable option. The orientation of the study is to seek the means to fulfill the goals stated by the case company.

This correlates with Figure 2, which illustrates a problem defined in practice, in this case by the case company. To understand the problem and the system, an empiric study is performed where the existing system is described and analyzed, shown in the top left corner of figure 2. Thereafter, a proposal for change is based on conclusions from the systems analysis and relevant theory. Finally, the proposal is presented as a solution to be implemented in practice.

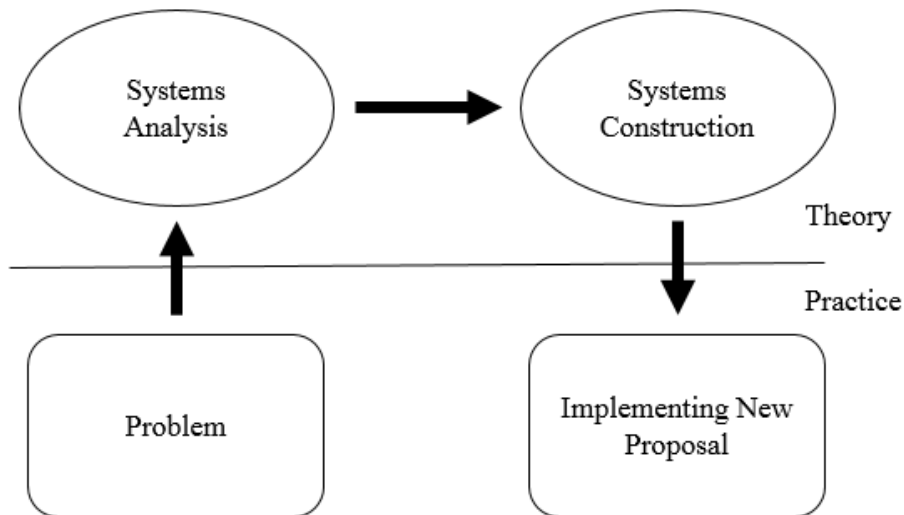


Figure 2 - An illustration of the approach to the study at the case company. (Arbnor & Bjerke, 1997)

## 2.2 Research Methodology

### 2.2.1 Inductive and Deductive

According to Holme and Solvang (1997), there is a great need of systematically capture social relationships and empirical observations into a theoretical point of view. The authors mention two main approaches; inductive or deductive methods, also referred to as the proofing versus the discovering methods.

The inductive method builds up the result from conclusions made from empirical studies and observations, hence called the proofing method. Ghauri and Grønhaug (2002) describes that the inductive process starts with assumptions that later are transformed into conclusions that can generate final theory. When describing the deductive research method, hypothesis and conclusions are drawn from logical reasoning. By using logical reasoning, result might, just like in the inductive method, not be hundred percent true, but at least they are logical (Ghauri & Grønhaug, 2002).

### 2.2.2 Qualitative and Quantitative Methods

Research methods relate to collecting data in an appropriate way to obtain the information needed to answer the stated research question or problem.

There are two main types methods when collecting and analyzing data for a research study; quantitative and qualitative methods (Ghauri & Grønhaug, 2002).

Even though the two methods share the same objective of obtaining the right data, their ways of doing so have considerable differences. The quantitative method convert information that is countable or possible to classify to make statistical analysis, data such as numbers, weights or costs (Höst et al., 2006). Focus is on measurable and objective facts such as hard values, measurements and structured answers to get a high precision in the result. (Ghauri & Grønhaug, 2002).



When using the qualitative method, the researcher’s understanding and interpretations make the base for the analysis. (Holme & Solvang, 1997).

As said by Ghauri and Grønhaug (2002), the dissimilarity between the two methods is not only about quantification, but rather on the level of reflection and knowledge of different perspectives through the research project. The result of the analysis in a qualitative research is therefore, in contradiction to a quantitative, based on the competence and experience of the researcher, due to the mix of both rational, explorative and personal thoughts and interpretations.

**2.2.3 The Selected Methodology**

When selecting which method to use, it is important that the selected method is well in line with the research problem and its purpose (Holme & Solvang, 1997). In many research projects, there is no clear choice of which method to use, and even though most research projects emphasize on one of the two research methods, they are often combined in the same study to complement each other and to answer the research question in the best possible way. (Ghauri & Grønhaug, 2002). When deciding whether this study was of a deductive or inductive approach, the conclusion was that there has been a balance between the two of them.

The study started with a deductive approach, where a literature review built the base for the knowledge and information. However, the further into the study the research came, the more of an inductive approach was taken, where a lot of qualitative data was collected from observations and open-ended questions. The approach taken in this study is illustrated in figure 3.

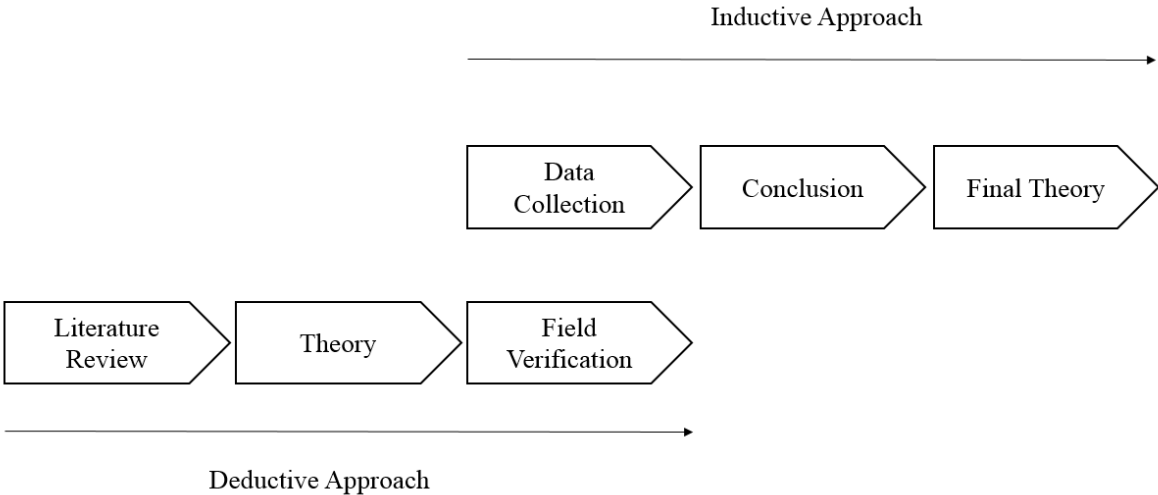


Figure 3 - A breakdown of deductive and inductive approaches and where in the study they are applied.

Taking a balanced approach between inductive and deductive to a research study within supply chain management is strongly encouraged by Golici, Davis and McCarthy (2005), who argue that *”researchers who exclusively choose one approach may delimit the scope of their inquiry and, thereby, their ability to consistently and effectively contribute to the body of supply chain management knowledge”*.

When analyzing what type of data that will be used to answer the research question, the conclusion is that both quantitative and qualitative data has been used.

When using a quantitative research method, the researcher has a larger distance to the data source, that usually consist databases, surveys and strictly structured observations. During a qualitative research method, the researcher is close to the data source, which often is in the form of conversations, unstructured interviews or observations from the real situation (Holme & Solvang, 1997). In this study, the quantitative data came from the Sandvik CS's different databases and from both existing and potential freight forwarders datafiles. Further, a big part of the data was collected from semi-structured interviews and observations, both from people and situations at Sandvik CS, but also from suppliers and external stakeholders.

This can be connected back to the systems approach, where data analysis regarding the different units will be quantitative, but regarding the relationships between the units both data and analysis will be of a qualitative nature, where semi-structured interviews regarding for example human factors will provide the information needed, and personal experience and reflections will build up the analysis.

## 2.3 Research Strategy

### 2.3.1 Research Strategies

According to Yin (2006), there are five main research strategies; experiment, survey, archival analysis, history and case study.

**Experiment:** an empirical investigation under controlled conditions with the purpose to identify root-causes and influence of specific factors.

**Survey:** to obtain data in order to view something comprehensively, in detail and at a certain point of time

**Archival analysis:** to study original documents in a specific field

**History:** to study the past when researcher must rely on primary, secondary, cultural and physical artifacts as main sources of data because no person is alive to describe a situation

**Case study:** focuses on one, or a few, instances of a particular phenomenon to with a view to providing in-depth knowledge of that particular instance

In order to choose the most appropriate strategy, three conditions are to be answered:

- Form of research question
- Requires control of behavioral events
- Focuses on contemporary events

(Denscombe, 2010; Yin, 2006).

Table 2 describes these conditions and illustrates how they correlates with each main research strategy.

Table 2 - The structure for choosing the research strategy with the conditions for each strategy (Yin, 2006)

Strategy	Form of Research Question	Requires Control of Behavioral Events	Focuses on Contemporary Events
<b>Experiment</b>	How, Why	Yes	Yes
<b>Survey</b>	Who, What, Where, How many, How much	No	Yes
<b>Archival Analysis</b>	Who, What, Where, How many, How much	No	Yes / No
<b>History</b>	How, Why	No	No
<b>Case Study</b>	How, Why	No	Yes

To define the research questions is the first and the most important step in a study. One reason for that is because it gives guidance on what research strategy to use (Yin, 2006). The research questions need to include both essence and form. Essence describes what the research is about and form addresses the questions “who”, “what”, “where”, “why” and how”.

The second step is to answer the questions if requires control of behavioral event and focuses on contemporary events. When all conditions are stated, the appropriate strategy can be chosen. Worth noting is that the response to the conditions can overlap between the strategies, giving several options.

### 2.3.2 The Selected Strategy

The selected research strategy for this thesis is the case study. The strategy is chosen because the scope of the thesis is to focus on a few phenomena of a supply chain and gain in-depth knowledge of the situation. Answering the questions how and why is align with the provided problem definition. A case study requires no control over behavioral events and focuses on contemporary events which fits the process for this thesis. In agreement with Yin (2006), a case study is preferred when studying actual events because it includes two empirical methods, contemporary observations and interviews with people in the events. The combination of the conditions and the empirical methods for a case study makes it a suitable research strategy.

### 2.3.3 Case Study Approach

A case study focuses on one, or a few, instances of a phenomenon with a view to providing an in-depth knowledge base in that particular instance. There is an obvious greater opportunity for researchers to delve into the detail and to understand and discover things that might not have been possible when looking at the wider spectrum (Denscombe, 2010). It is a spotlight focused on individual instances rather than a wide spectrum. One logic behind concentrating efforts on one case rather than many, is that there may be insights gained from looking at the individual case that can be allied to the whole. Insights that would have been difficult to distinguish by looking at many phenomenon (Denscombe, 2010). With that in mind, since it's a study focusing on one phenomenon, the results may not always be applicable to other cases and difficult to generalize (Eisenhardt, 1989). To generalize from a case, Denscombe (2010) argues that researchers need to define characteristics of the case study so it can be compared to other cases similar of its type, both by presenting its uniqueness but also that it's part of a broader class of things.

Another strength with the case study approach is that it allows researchers to use variety of sources, a variety types of data and variety of research methods as part of the investigation. Many different points of interest are considered (Denscombe 2010).

The case study approach consists of four different case study designs, according to Yin (2006). When determining what type of design, the researcher needs to determine if the study consists of either one or more cases for the study. A single case design is a good method when looking at a representative case. The purpose is to capture and describe the circumstances of that project and then research if it is applicable to similar types of cases. (Yin,2006) It gives great depth and can test well formulated theory. However, it can be proven difficult to generalize from the case. The multiple case design is commonly used in larger research projects when a study consists of several different cases. The group of cases can have unique attributes to either one or more theories that together represent a bigger spectrum making it easier to generalize. However, multiple case design requires more resources. (Voss, Tsikriktsis & Frohlich, 2002)

Within both types of design, the researcher also needs to determine if one or more units of analysis are to be considered. A single unit of analysis only considers one system, organization or business and gives a holistic view, whereas the multiple-analysis considers views from business units and individuals. (Yin 2006) Together, the level of design and analysis create for types of case study designs, shown in table 3.

Table 3 - The four different types of case studies proposed by Yin (Yin, 2006).

	<b>Single-Case Design</b>	<b>Multiple-Case Design</b>
<b>Single unit of analysis (Holistic design)</b>	TYPE 1	TYPE 3
<b>Multiple units of analysis</b>	TYPE 2	TYPE 4

### 2.3.4 The Selected Case Study Approach

A type 1 case study design was chosen for this study, and the unit of analysis is one type of transportation mode for a business unit; sea freight distribution for the Sandvik SC. The study focuses on a single case and from a holistic view interprets the situation, without involving more units of analysis. A reason for choosing this method was because that it can be shown as a representative case, that for future research can be applied to similar of its kind. As the resources are seemed as a constraint, doing a multiple case design was not possible

## 2.4 Data Collection

There are two types of data, secondary and primary data. Primary data help the researcher to get the requested information from an external source, such as the internet, journals or books. Secondary data is data not compiled by the researcher, and is needed when there is no valid secondary data available, or when the researcher needs specific data for the study and thereby

must collect the data by own means. Naturally, there are different aspects on what data source is the best. An advantage for using secondary data is the time saved when gathering the data, while an advantage for primary data is that the researcher gets the data needed for the specific study. (Ghauri & Grønhaug, 2002).

There are different ways of collecting data, appropriate for different purposes and circumstances. Since this thesis is built on a case study, the primary data was mainly collected through interviews, observations, surveys and from Sandvik CS databases. Secondary data came from theory gathered in the literature review and additional data provided by Sandvik CS.

### **2.4.1 Interviews**

Interviews require a real interaction between the respondent and the researcher, and according to Ghauri and Grønhaug (2002), interviews are considered to be the best method to collect data. Höst et al. (2006) argue that there are three main interview techniques; unstructured, structured and semi-structured.

An unstructured interview could be described as an explanatory conversation within specific areas, but without specific questions. Structured interviews can be compared to a survey, where strict questions are asked in a way where the respondent has no or very little room for explanatory or unstructured answers. Semi structured interviews are also covering target areas like unstructured interviews, but they usually contain some strict questions to give more in-depth understanding of the subject. (Höst et al., 2006). Voss, Tsiriktsis and Frohlich (2002) discuss the importance of having a good research protocol when doing interviews, either as a tape recording or notes, to ensure the validity of the data collected through the interview.

In this study, several interviews have been held. All interviews have been of a semi-structured nature, where certain topics have been covered and both open and strict questions have been asked. It has been important that the respondent has been allowed to answer freely since qualitative personal opinions and experiences have been valuable for the project, while at the same time strict questions have been asked to ensure that the required information has been collected. Most of the interviews took place during meetings, both formal meetings with external participants from outside Sandvik SC and informal daily meetings. Because of the nature of the meetings, neither set lists with interview questions have been used nor recording devices. However, during the interviews, important information and data was noted to ensure that no important details were missed. Since the interviews were always held by both researchers, the data collected from the interviews were always compared to ensure no important information was missed or misinterpreted before used in the study.

A list of the people interviewed during the thesis is presented in appendix 1.

### **2.4.2 Observations**

Observations is a good way to, by looking, hearing and asking collect information about how processes function and how situations are in life. The advantage of observations is that the information gathered is direct and comes from a natural setting, while the biggest disadvantage is that it can be difficult to translate observed situations into scientific information. In this translation, it is of highest importance that the result is validated to ensure that it reflects the observed information in a reliable way. (Ghauri & Grønhaug, 2002)

According to Holme and Solvang (1997), the observation can be divided into either open or hidden, meaning that if the observation is on people, the observed persons are either aware of the observer or not. The authors argue that the result from a hidden observation might reflect reality in a better way, but that there might occur some ethical issues with those kinds of observations. In this study, the observations have mostly been open, where the researchers have walked around the facility in Svedala and observed and asked both blue collar workers and “regular staff” of how their processes work. Additionally, observations in Sandvik SC’s warehouse and production facility have been a good way of gathering knowledge about the characteristics of the products and company specific procedures, which otherwise would be hard to get. Observations have also taken place during bigger meetings, both internal Sandvik meetings and with meetings between Sandvik staff and external companies. During these meetings, data has been collected through listening and observing, and notes have been taken to collect important information. Examples of the data gathered from these meetings included transportation mode specifics, current sea freight industry trends and Sandvik’s internal goals and struggles.

### **2.4.3 Triangulations**

Triangulation is defined as using several different perspectives to view items of interest. The several perspectives mean that researchers can use different methods, different sources of data and different researchers for the study. The reason for using this method is that it enables researchers to investigate different positions, thereby gaining a better understanding of what is being investigated. (Denscombe 2009)

For this study, two types of triangulation are being used; methodological and data triangulation. Methodological triangulation is defined as using different methods to allow comparison between the findings. Thereby, enabling the findings to be either questioned or complemented to each other. Data triangulation means that data is validated by using the same data from several different sources (Denscombe 2009). In this study, quantitative and qualitative methods are used, giving the study a broader perspective. Also, data from Sandvik SC is compared with the same data from their suppliers to check if data from different sources is the same.

## **2.5 Research Execution**

The execution of the study was divided into a three-step model, that started with building a foundation of the situation and industry, and was followed up by a second phase that focused on collecting and mapping data of the current situation needed to build the logistics model. The last phase consisted of simulation, scenario analysis and evaluation of the results given from the model. Writing the report was included in all phases to ensure the activities made during the project were included in the report.

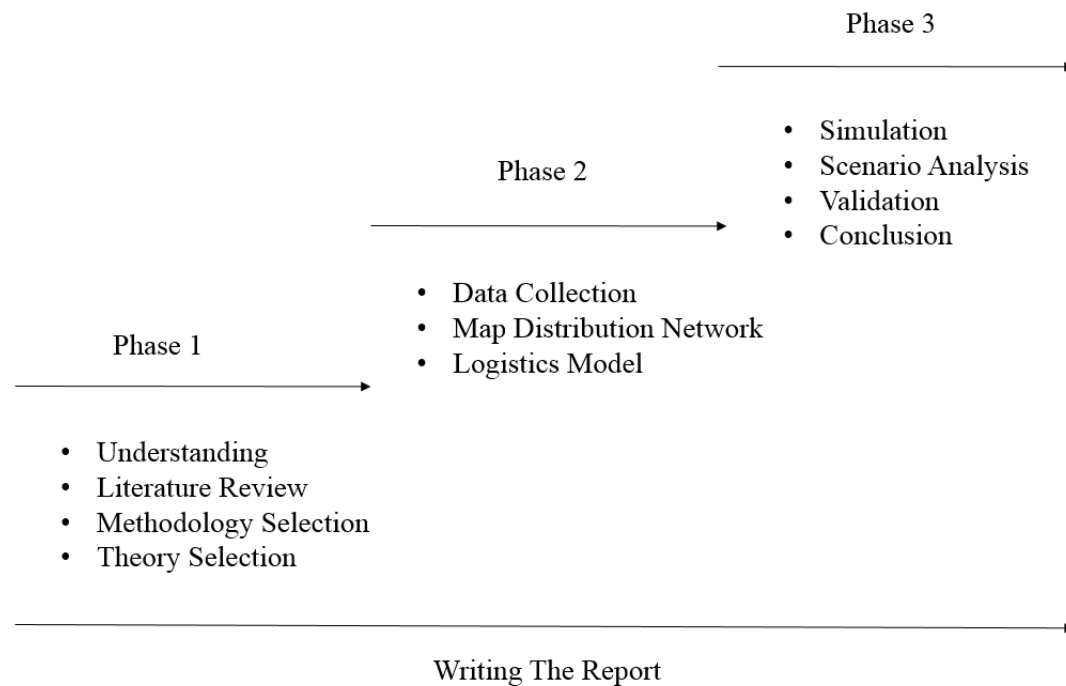


Figure 4 - A breakdown of the processes into three phases during the study. The activities for each phase is presented to give further clarity

### Phase 1:

The study began with an introduction of Sandvik SC and the current situation and ambition with the project with a focus on their freight and distribution network. Discussions with Sandvik SC employees together with a thorough literature review created the foundation of our understanding of the research problem and industry situation. After having understood the objective with the study, research methodologies and theory areas were selected. During phase 1, it was concluded that a simulation model based on linear programming had to be created to reach the purpose and to answer the first research question “*How can a company determine what transport mode to use in the distribution network with the objective to minimize freight cost?*”

### Phase 2:

Data collection through the methods mentioned in section 2.4.1-2.4.4. The freight data needed to for the model is listed in table 4. When the data was collected, the logistics model could be built.

Table 4 - The needed freight data for the model divided into factors for each the four categories.

Category	Factor
<b>Total logistics cost</b>	Transportation cost
	In-transit holding cost
<b>Modal Characteristics</b>	Lead time
	Loading capacity
	Reliability
	Service level
<b>Physical attributes of transported goods</b>	Shipment size
	Product/package characteristics
	Product value
	Product weight
	Product Volume
<b>Route Characteristics</b>	Transportation distance
	Demand
	Frequency

### Phase 3:

During the last phase, simulations of the logistics model were made to get different results and scenarios that later were analyzed and validated. When the best scenario was found, conclusions could be drawn and suggestions were made.

## 2.6 Credibility

Credibility is important in case study research, and assures that conclusions are well supported and focused on the chosen research subject, and that the results are generalized (Höst et al., 2006). Credibility can be divided into two dimensions; reliability and validity (Voss, et al., 2002)

### 2.6.1 Validity

Validity is about the connection between the researched object and what is measured, and can be divided into the three dimensions; construct validity, internal validity and external validity (Voss, et al., 2002). Construct validity is the degree of which correct measures have been used for what is researched, which can be ensured by using multiple sources during the data collection and by using triangulation to see the object from different views. Internal validity is about how certain conditions can be related and derived from each other. Time-series analysis and pattern matching or explanation building can be used to test internal validity. External validity is about knowing if the findings from the study can be generalized beyond the case study in focus (Yin, 1994).



### **2.6.2 Reliability**

Reliability is about to what extent the research can be repeated with the same results (Yin, 1994), and to achieve high reliability it is crucial for the researcher to be accurate and careful in the data collecting and analysis (Höst, et al.,2006). This can be ensured well documentation during the research, preferably by using a thorough case study database and case study protocol (Yin, 1994).

### **2.6.3 Credibility in This Study**

In this study, multiple data sources have been used to collect the quantitative data, which has come from different units within Sandvik in the form of databases, but also from external carriers through surveys. Before using any of the data, the numbers have been compared and analyzed to ensure validity of the data, both with the other thesis projects and the supervisors at Sandvik SC. Additionally, the qualitative data was collected through different methods and sources. Therefore, both the quantitative and qualitative data is assumed to be of a high construct and internal validity.

Because this is a single case study, the external validity can be assumed to suffer since the exact results from this study will be hard to replicate in other research projects. However, in accordance to Yin (1994), a solid theoretical base can complement the external validity, which in this study was the base during phase 1 in the project execution.

The results and output from the model of Eindhoven has been compared with the results from the air freight project to ensure the results are aligned and that the same products should go with the same mode in both studies. When those two models proved the same results, the credibility for the wear parts model increased. The comparison of results with the other project figure as a triangulation, and improved both studies credibility.

### 3 THEORETICAL FRAMEWORK

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*This chapter introduces five different theoretical frameworks. It starts with Distribution Network Design which serves as the foundation for the study. Secondly, the chapter describes the different transportation modes and because the focus for this study is on sea freight, the third chapter provides deeper knowledge of the sea freight industry. The last two theories discussed set out to give a deeper knowledge about the formula for logistics cost and the process of linear programming in combination with simulation*

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#### 3.1 Distribution Network Design

According to Chopra and Meindl (2013) distribution is “*the steps taken to move and store a product from the supplier stage to a customer stage in the supply chain*”. The term distribution network refers to the chain of which the goods are moved and stored. The movement of goods is done with transport modes while the storing is using different types of warehouses. The performance of a distribution network can be evaluated by the two dimensions *customer needs* and *the costs of meeting customer needs*, thus entailing that the main decision when designing a distribution network is how much value the company can afford to give its customers. Before deciding how the distribution network should be planned, it is therefore important to understand the supply chain objectives to ensure the strategy of the distribution is in line with the firm’s overall strategy and ensure customer satisfaction. This means that a company with a cost leadership strategy should have a distribution network focusing on lowest total cost (Chopra & Meindl, 2013).

Due to globalization of economic activities and rapid development of both information technology and customer service requirements, a strong distribution network has become important and can be seen as a key point in a firm’s success since it affects both customer service levels and supply chain costs directly (Melo, Nickel and Saldanha-da-Gama, 2009).

When designing the distribution network, the customer values that will be influenced include response time, time to market and product reliability and variability. The costs that these changes drive are primarily costs for transportation, inventory, information, facilities and handling (Chopra & Meindl, 2013). Furthermore, Meixell and Norbis (2008) identified six factors that influenced the transport mode choice when reviewing literature of transportation mode choice. Three of which this study aims to focus on. They are:

- Cost
- Transit Time
- Reliability

In figure 5, a generic supply chain network is visualized, with goods flowing from production through the network to the end customers.

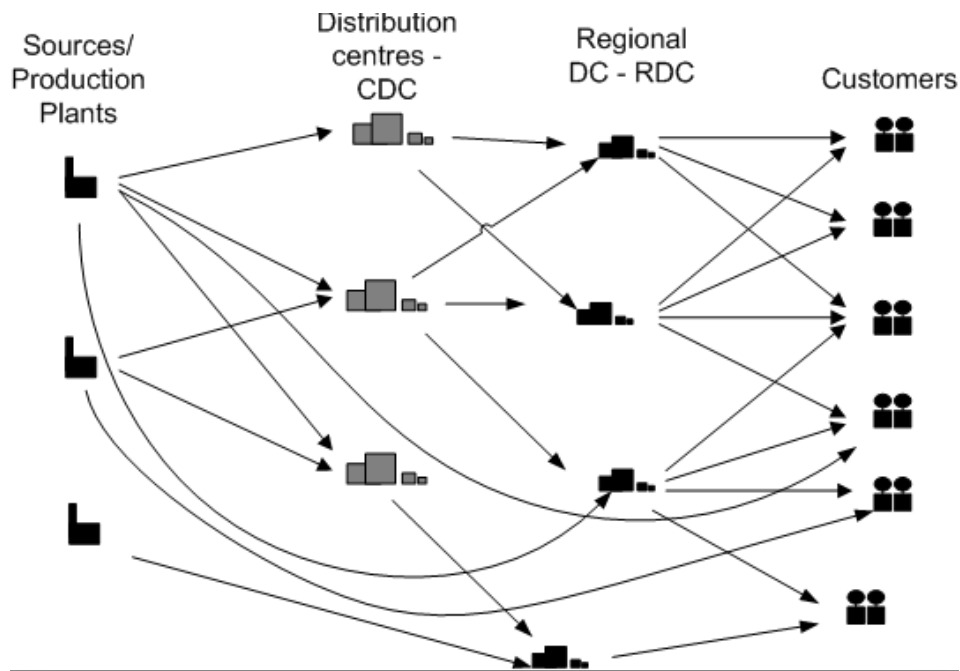


Figure 5 - An example of a generic distribution network

Melo et al. (2009) inform that the decisions regarding the distribution network design can be divided into three levels depending on their time horizon; strategic, tactical and operational. Strategic level decisions are based on long term decisions such as facility locations and their capacities and how the goods should be distributed throughout the network. Tactical and operational level decisions are for instance transport mode choices, vehicle routing, inventory decisions and capacity planning.

Chopra and Meindl (2013) argue that the total logistics cost is the sum of inventory, transportation and facility costs for a supply chain, and figure 6 below visualizes how the response time and total logistics cost vary with the set number of facilities. The authors further argue that firms should have at least the number of facilities that minimizes the total logistics costs, and if the customers require even shorter response time, more facilities could be used if economically viable.

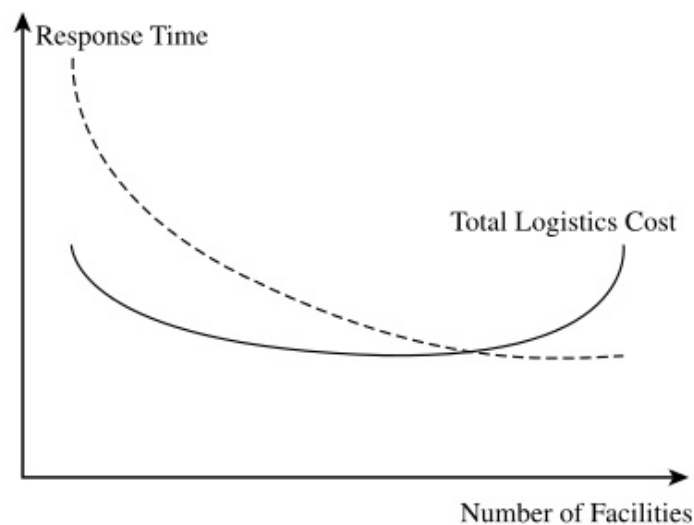


Figure 6 - The relationship between response time and number of facilities (Chopra & Meindl, 2013).

Several external factors influence the decisions when designing a supply chain distribution network, and some of them are listed and described below:

**Macroeconomic factors:** These are external factors that cannot be controlled by the individual firm, and include tariffs and tax incentives, exchange rates and freight and fuel prices. Tariffs imply duties that must be paid when goods are distributed across borders, and companies strive to have a lot of manufacturing plants if there are high tariffs to save money, or might even decide not to serve that market. Tax incentives are reductions in tariffs set by governments as an incentive to increase trade.

Changes in exchange rates can have enormous impact on a firm's financial numbers, and the risks can be hedged by financial instruments or to set up production facilities where the main markets are, and thus have both costs and revenue in the same currency. When fuel and freight costs change, companies with distribution networks built on long transportation routes can be severely affected. These fluctuations can be hard to foresee, but can be dealt with by hedges or long term contracts on the commodity market.

**Infrastructure factors:** Infrastructure play a big part in a distribution network, and the absence of it can harden the freight tremendously. Infrastructure elements that should be taken into considerations are among several; availability of sites and labor, highway access, distance to airports and seaports and local utilities.

(Chopra & Meindl, 2013).

### 3.1.2 Inventory Holding Cost

Inventory holding cost is measured as a percentage of the value of an item, and refers to the costs that occur if items held in inventory remains unsold, usually on an annual basis. The percentage is the sum of components such as:

- Cost of capital - a financial measure that take the firm's required return on equity and cost of debts into consideration
- Obsolescence cost - an estimation of the rate for which the product's value reduces due to long time to market
- Handling cost - includes incremental receiving and storage costs depending on the quantity of products received
- Occupancy cost - reflects the additional change in space cost due to changed cycle inventory levels
- Miscellaneous costs - the sum of several small cost factors such as costs for theft, damage, tax and insurance charges

(Chopra and Meindl, 2013)

### 3.2 Transportation Modes

According to Chopra and Meindl (2013), transportation refers to “*the movement of product from one location to another as it makes its way from the beginning of a supply chain to the customer*”, and it is an important driver in the distribution network since products seldom are produced and consumed in the same location.

In global supply chains, where different tiers in the chain are spread across the globe, transportation usually stand for twenty percent of the total production costs for manufacturing firms. To select which mode to use when moving products is therefore a key decision for logistics managers which impacts the cost. There are several different modes used for transportation of goods and the decision for choosing the right transport mode is based on several criteria such as costs, service levels, capacity and transit times (Meixell & Norbis, 2008). The tradeoffs logistics manager stand for are responsiveness versus efficiency, i.e. transit time versus costs (Chopra & Meindl, 2013).

For the shipper, i.e. the person who requires the transportation, to decide on which carrier to use, i.e. the party actually transferring the goods (Chopra & Meindl, 2013,) and with what mode the goods should be transferred is therefore not only a matter of costs, but also of a company's overall competitive strategy, since the right selection can increase internal effectiveness and customer satisfaction (Meixell & Norbis, 2008).

The most common transportation modes in global supply chains are road, air, sea and rail, and the different modes of transportation are used depending on the characteristics of the goods, the freight distance, required transit times and available infrastructure (Chopra & Meindl, 2013).

### **Truck**

Trucks carry a big part of the land transportation in most of the world, and is a fast transportation modes that enables door-to-door delivery in a flexible way. Due to its adaptivity to small scale quantities, high service levels, short transit time and low fixed costs, the trucking industry has grown during the last century (Lumsden, 2012).

### **Rail transportation**

Transporting goods on rail is a fast transportation mode for long distances on the same continent or land area that is suitable for freight of heavy and bulky goods. The mode is limited by the rail infrastructure and thereby lack of door-to-door flexibility, which implies that most train transports need to be combined with truck to get to the final destination. Railway transportation has a large loading capacity, and due to large fixed costs in the railway infrastructure, high flow of goods is required to ensure economical transportation (Lumsden, 2012).

### **Air**

Air is the transportation mode with the shortest transit times and highest transportation costs for long distances. Products suitable for air transportation are generally small items with a high value or products that have a very short customer order deadline (Lumsden, 2012). Transporting goods by air is limited to airports, which implies that in almost all cases, transporting goods by air implies intermodality, which means that the goods need to be loaded on another transport mode, usually trucks, to reach the end destination (Chopra & Meindl, 2013). For air shipments, capacity is a constraint because of the low loading volume of an aircraft, where goods either are sent with cargo-airplanes or below the passengers in commercial airplanes (Lewis, 1994).

## **Sea**

Sea freight is usually carried out for large quantities of goods with low value, since sea is the transportation mode with the highest in-transit lead time. Due to the large loading capacity and free route at international oceans, sea transportation is the most cost efficient mode when it comes to transportation cost (Lumsden, 2012). Transporting goods by sea is limited to certain areas and routes due to the need of water lanes, which implies that shorter transportations within the same region seldom are carried out by sea freight (Chopra & Meindl, 2013). Due to a high variability of transported goods, different types of ships exist and are used according to the storing and loading requirements of the products. Examples of how ships are used depending on the transported goods is container ships, which are used to transport containers, and general cargo ships, which are used not only to transport containers, but also with capacity to transport non-unitized cargo. For long distances, sea freight is the transportation mode that is the most energy efficient and emits the lowest amount of emissions (Lumsden, 2012).

### 3.2.1 Comparison of the Different Transportation Modes

Table 5 compares the different transportation modes within different product and service level criteria of which logisticians should align to match the distribution network strategy.

Table 5 - comparison of the different transport modes (Lumsden, 2012).

	Road	Rail	Sea	Air
<b>Transit time</b>	Moderate	Moderate	Long	Short
<b>Transport cost</b>	Low	Low	Very low	High
<b>Reliability</b>	Good	Good	Limited	High
<b>Loading Capacity</b>	Low	Relatively high	Very High	Relatively low
<b>Type of products</b>	All items that fit into a truck.	Bulky, high volume goods	Big, bulky products. Low value	Small, high value items
<b>Distance</b>	Short to medium	Medium to long	Long	Long

Since the focus of this study is on sea freight distribution, the next chapter, 3.3, will provide further knowledge regarding the sea freight industry.

## 3.3 The Sea Freight Industry

Three important factors to consider when using sea freight as the mode for transportation within the distribution network are:

- Lead Times
- Reliability
- Cost

(Lumsden, 2012).

### 3.3.1 Sea Freight Lead Times

The lead time for sea freight depends on point of measure. Harrison and Fichtinger, (2013) describes the two definitions for transit time; Door-to-Door (DTD) and Port-to-Port (PTP). The two definitions are illustrated in figure 7, where PTP is the transit time between the two ports. For customers to the shipping industry, DTD is favored as it includes both land, port and sea movement, all of which are necessary for knowing the whole transit time in the distribution chain. In the shipping environment, PTP is most often used for describing the transit-time (Harrison and Fichtinger, 2013).

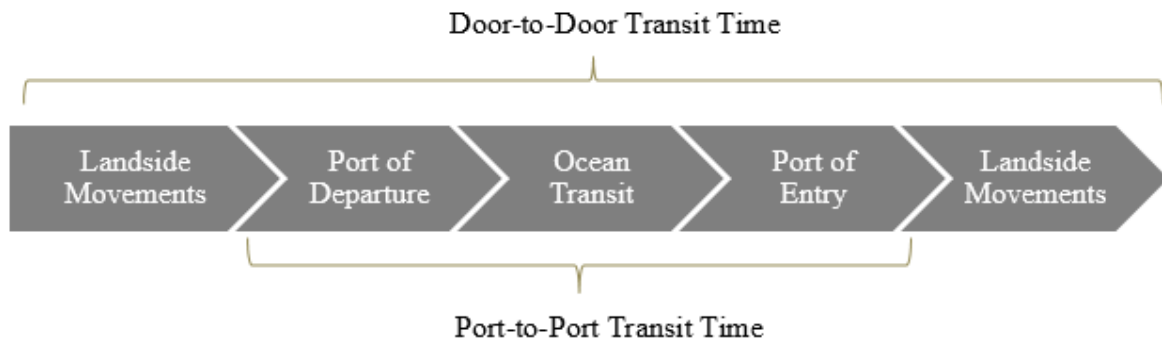


Figure 7 - The different methods to measure transit time (Harrison & Fichtinger, 2013)

Furthermore, the lead times depends on the path taken by the ship i.e. the ship route. A ship route is defined by the sequence of ports that are visited by a vessel from origin to destination (Mulder & Dekker, 2013). A way to increase the efficiency of the sea shipments is to include several links into the routes, which means that several ports are visited during the route, where loading and unloading can take place on the route. To Include multiple links in sea routes increases the loading efficiency of the ships which implies lower transportation costs but also increases the in-transit lead time (Lumsden, 2012).

To reach a high cost efficiency for the loaded goods, large amounts need to be loaded onto the vessels, which for some destination can cause low frequency shipments due to low demand. This can cause low frequency of the shipments in ports with low demand, since the ship needs to wait in the port to be loaded up to a certain level.

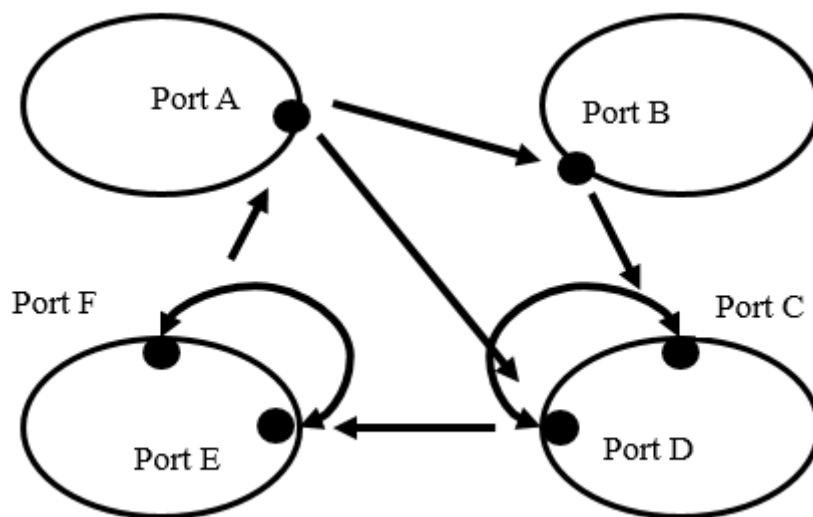


Figure 8 - An illustration of sea routes (Lumsden, 2012).



### 3.3.2 Reliability in the Sea Freight Industry

The sea freight industry has problems with reliability. The on-time performance for containerships during November to January in 2016/2017 were at only 65,3% (Drewry performance Report, Jan 2017). There are several factors impacting the reliability such as bad weather conditions, delays in access to ports, loading and unloading delays, customs and security delays in ports. In 2006, port congestion was the main cause of not being on time. The shippers are aware of this problem and put a lot of focus on solving this issue. Low transit times and high reliability are key factors for shippers and have become important objectives for them (Notteboom, 2006). Even though this issue has been discussed for a long time, it is still an active problem. On April 4th 2017, the European Shippers Council announced during an emergency meeting that port congestions in Europe have led to that exported goods have waited to be loaded to ships for up to 8 weeks. Their concern was that the issues in the maritime sector could have a negative impact on the European economy because of cancelled and lost sales (ESC, 2017). Figure 9 illustrates the schedule reliability for major sea freight lanes from November to January in 2016/2017.

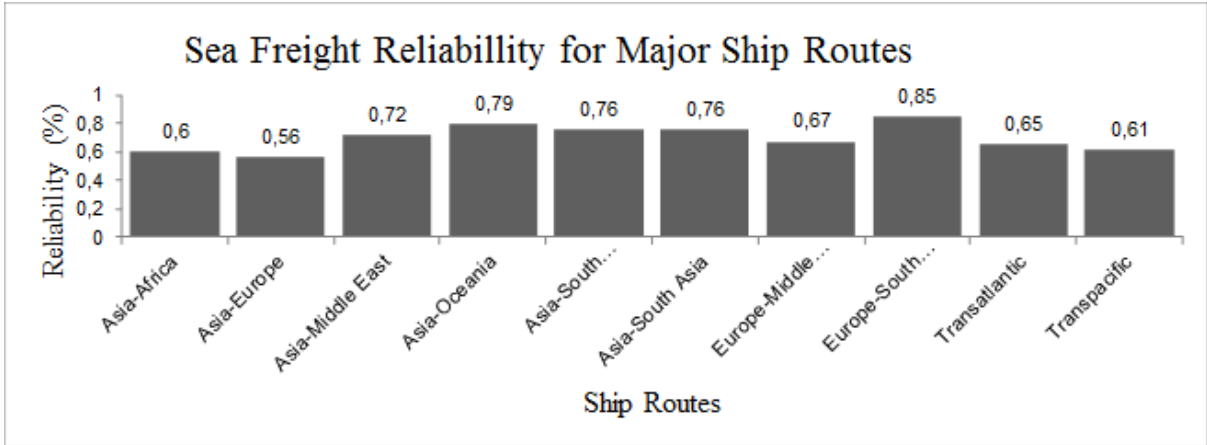


Figure 9 - The sea freight reliability for major ship routes during the period November 2016 to January 2017 (Drewry Performance Report, 2017).

Within each lane, the lead time, reliability and cost varies depending on the carrier. Below is a hypothetical example of what this information can look like within a route.

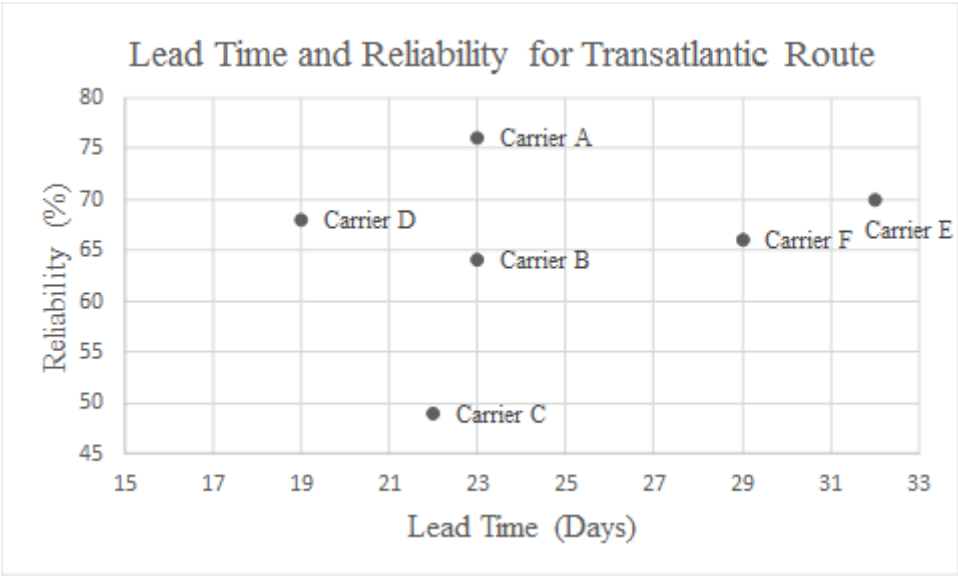


Figure 10 - A hypothetical example of the how different carriers have different historical reliabilities and lead times.

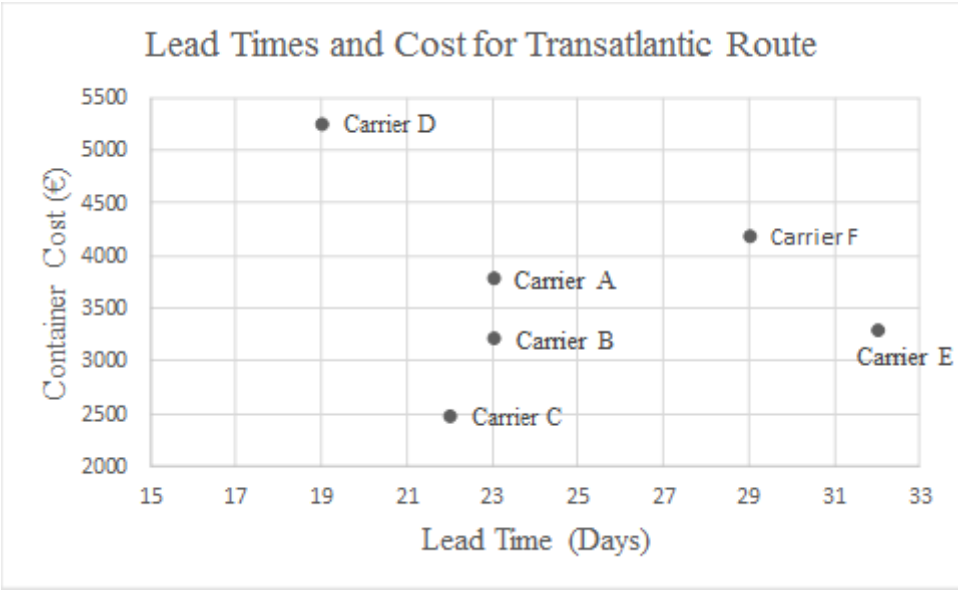


Figure 11 - A hypothetical example of the how carriers have different container cost and lead times.

Seen in figure 10 and 11 the shipper must balance the trade-off between lead time, reliability and cost when choosing the carrier for every route, and the decision should be aligned with the shipper’s freight strategy.

The sea freight industry in which container ports and shipping lines are operating is an ever-changing industry with high competition, high fixed costs and low margins. To increase efficiency, alliances of shipping companies are continuously reforming (Notteboom, 2004). As seen in figure 12, in April 2017 four major alliances will become three which will have a

substantial impact on the sea freight industry. The changes in alliances will have an impact on routes, lead times, costs, reliability, capacity and ports usage. The new alliances will represent nearly 90% of the total container capacity in the world. (Drewry Performance Report, Jan 2017).

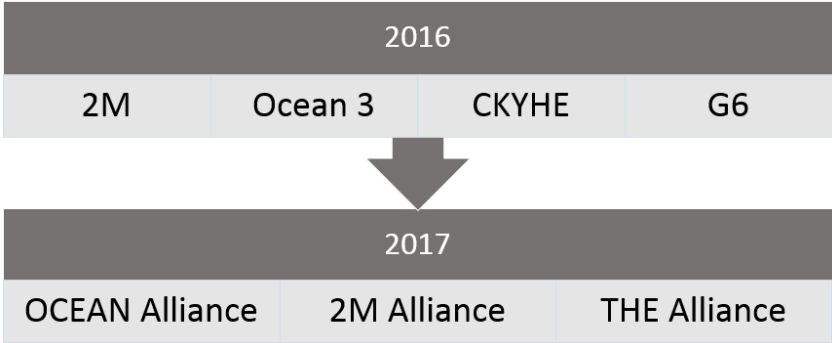


Figure 12 - An illustration of the new formation of sea freight alliances (Drewry Report, 2017).

**3.3.4 Cost Structure for the Sea Freight Industry**

According to Bell, Liu, Rioult and Angeloudis (2013), the liner industry has no universal classification for costs. The authors classify costs into five different categories; operating costs, periodic maintenance capital costs, voyage costs and cargo handling costs. Where operating costs, periodic maintenance and capital costs determine the charter rate, also known as overhead costs. The sum of fuel costs and port costs determine the cost of the voyage. When referring to containers, container handling can be seen as the cargo handling costs (Bell et al., 2013).

In the industry, these are the costs for operating container vessel. For carriers, all these costs are merged together and invoiced to the customer either as a cost per container or cost per shipment. Where a shipment can carry many containers.

The price for a container is dynamic and always changing depending on many factors. One out of many factors is the bunker fuel price. Figure 13 shows the change and correlation between bunker fuel price and the average container price for the transatlantic route from 1993-2008. This is included in the study to illustrate that the price for a container changes over time.

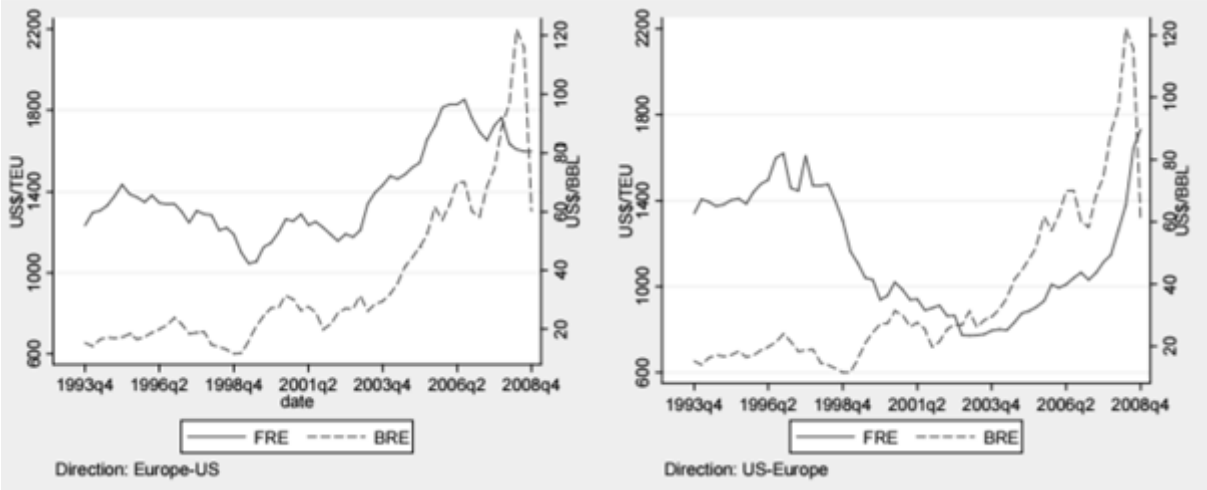


Figure 13 - The change of container cost and bunker fuel prices from 1993-2008 (Beverelli, United Nations, 2010)

### 3.3.5 Load Carrier Unit

A load carrier unit type used within worldwide transportation systems is the container. Its purpose is to enable integrated transports and easy to transport by different transport modes. There are several different types of containers depending on:

- The requirements of the goods shipped,
- The size and weight of the goods
- The ease to handle

A container can reach its maximum loading capacity either by weight or by volume, depending on the characteristics of the loaded goods. When heavy products are loaded into the container, there is a great chance that the payload capacity, i.e. the maximum weight, limit is reached prior to the cubic capacity, i.e. the volume limit.

The load carrier units used in this study is the 40ft container, which is a standard container with a weight capacity of 27800 kg and a cubic loading capacity of 69 m<sup>3</sup> (Lumsden, 2007).

### 3.3.6 Consolidation Advantages

Consolidation is procedure of combining different items, produced and used at different locations and different times into single load carrier units (Hall, 1987). It is an activity that reduces transportation cost by taking advantage of economies of scale. Having larger shipment quantities increases fill rate in the container and reduces shipment frequency, thus lowering transportation cost by increasing vehicle utilization and lowering the amount of shipment dispatches. The effects of consolidation are that it adds complexity to the process and extra time is added for the process. (Capar, 2013).

## 3.4 Total Logistics Cost

Discussed in section 3.2, a large part of the transportation mode selection is based on the cost for the shipment. The total cost is a sum of fixed costs such as freight cost, but the shipper must also decide on how service elements reliability, service levels and responsiveness can be transferred into actual costs.

When the cost for the service elements described above are decided, and some assumptions and notations have been made, the total logistics cost per item  $TLC(x)$  of each transportation mode can be calculated. (Sheffi, Eskandari and Koutsopoulos, 1988)

### 3.4.1 Logistics Costs per Item

In general shipping, there are six factors that contribute to logistics costs;

- Interest charges on goods awaiting.
- Interest charges on goods in transit.
- Interest charges on goods held as safety stock.
- Loss, damage or decay of goods between manufacture and sale.
- Costs of ordering transportation services.
- Cost of transportation.

(Lewis, 1994)

For this study, the cost of transportation and interest charges for goods in transit are the factors considered, since those are the costs directly linked to the actual transportation, which is what this study is about. These costs will be applied per item in the formula with the objective to find the total logistics costs described by Sheffi et al., (1988).

### 3.4.2 Explanation of the Formula

Notations and assumptions:

- Transportation cost per shipment is denoted  $a$  \$/shipment, and is assumed to be fixed per shipment, and thus not dependent on the shipment size.
- Transit time, denoted as  $t$ , is the time on transport in time units, such as days or weeks. The transit times are based on average data and should therefore be fixed for each transport mode and destination.
- Demand rate is denoted as  $s$ , stands for freight units per time unit, and expresses the flow from origin to destination in the selected time unit, and can be expressed either by number of items, weight, volume, containers etc.
- Holding cost expressed as  $V \cdot I / \text{time unit}$ , which is the value of the product ( $V$ ) times the inventory holding rate ( $I$  % per year).
- Capacity of the transportation vehicle (container, trailer, rail), denoted  $u$ .

The main criteria for the logistics cost is the size of the shipment, since that factor creates a trade-off between the freight cost and the in-transit holding cost, meaning that a large shipment size increases the in-transit holding cost but reduces the freight cost, and vice versa.

Hence, if  $x$  denotes the shipment size, following mathematical relationships can be set:

$$\text{Transportation cost per item} = \frac{a}{x}$$

$$\text{Stationary inventory holding cost per item} = V \cdot I \cdot \frac{x}{2 \cdot d}$$

$$\text{In-transit holding cost} = V \cdot I \cdot t$$

(Sheffi, Eskandari and Koutsopoulos, 1988)

The total logistics cost per item  $TLC(x)$  can now be expressed as:

$$TLC(X) = \frac{a}{x} + V \cdot I \cdot \frac{x}{2 \cdot s} + V \cdot I \cdot t$$

How the cost is depending of the shipment size is visualized in figure 14. As seen in the figure, there is a minimum total cost that appears at the optimal shipment size  $x^*$ , a shipment size often referred to as the Economic Order Quantity.

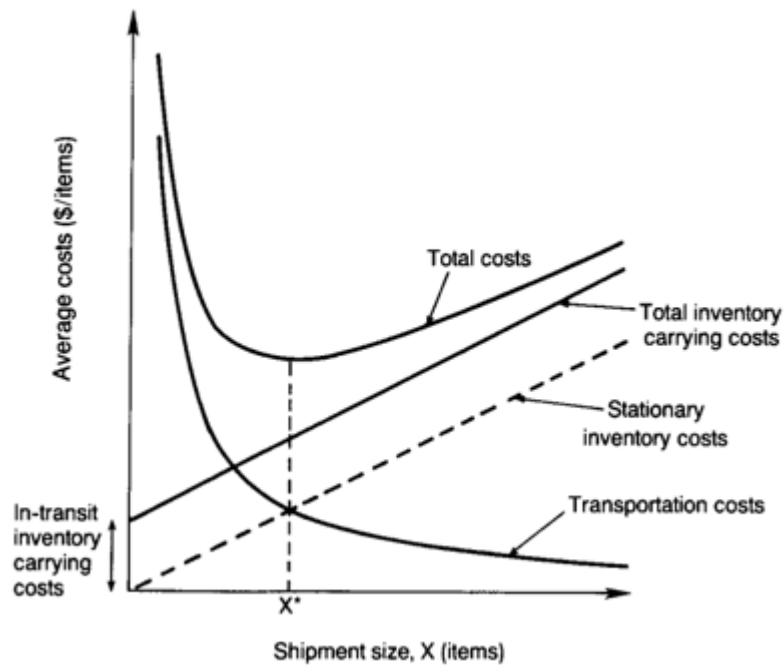


Figure 14 - Inventory transportation and total logistics cost as a function of shipment size (Sheffi, et al., 1988)

### 3.4.4 Product Value Density

In global supply chains, where a wide range of products are distributed to several markets, product segmentation is an important process to ensure that the right products are distributed through the right supply chain design. Lovell, Saw and Stimson, (2005) discuss the importance of supply chain segmentation, and argue that even though several factors influence the supply chain segmentation, the one of the most important factors is the product value density (PVD), which can be seen as a combination of the value and size/weight of a product.

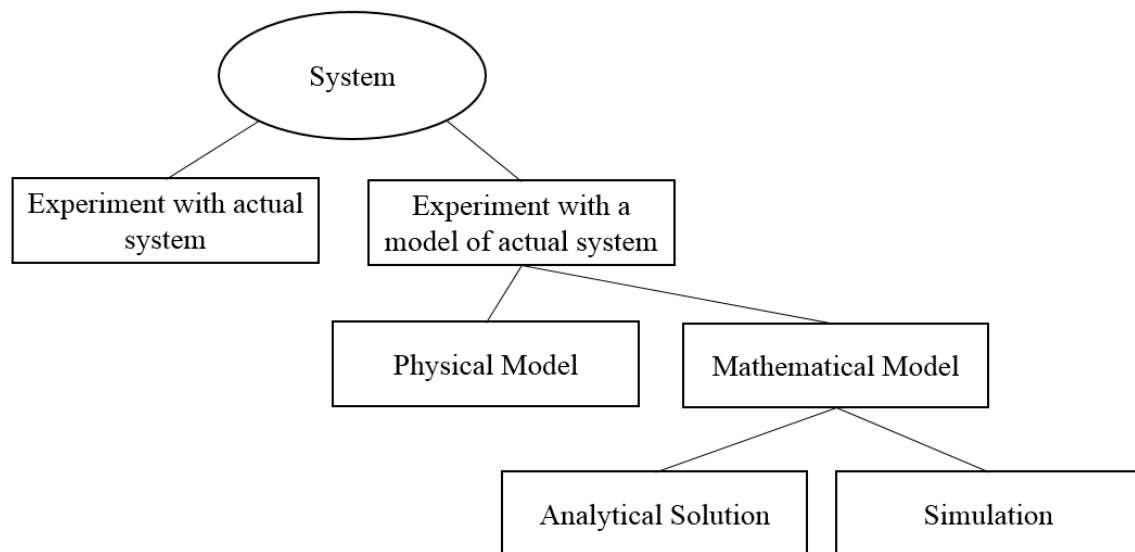
$$\text{Product Value Density (PVD)} = \frac{\text{Product Value}}{\text{Product Weight}}$$

The PVD has a big impact on the transportation mode selection for the distribution network in this study, since as described in section 3.4, the in-transit freight cost per item is based on a formula built on values based on either product weight (transportation cost) and product value (inventory holding cost). This implies that when the PVD is high, the in-transit holding cost in the formula stated by Sheffi et al. (1988) increases, and vice versa.

## 3.5 Simulation and Linear Programming

### 3.5.1 Simulation

According to Law and Kelton (1991), simulation is one of the most widely used techniques within operations research and management science, and it is used to imitate reality in different kinds of scenarios or processes. The process of interest is often called a *system*, where assumptions must be made for the researcher to be able to study the *system* in a *model*, which is where the behavior and performance of the *system* is analyzed. If the model is simple and is based on exact data, analytical solutions can be made to make decisions and study scenarios. However, most real situations are too complex to be studied analytically, and thus needs to be simulated instead. Simulations utilize computers to assess the model numerically, and data are collected to estimate the desired true features of the model. To simulate a model of a system is therefore a way to test and analyze the outcome of potential scenarios and decisions before they are implemented. Law and Kelton (1991)



*Figure 15 - Breakdown of a system (Law and Kelton, 1991).*

Different approaches can be taken when simulating a system, and Law and Kelton (1991) suggest a 10-step approach that can be seen as a guideline of how to structure a simulation study, visualized in figure 16.

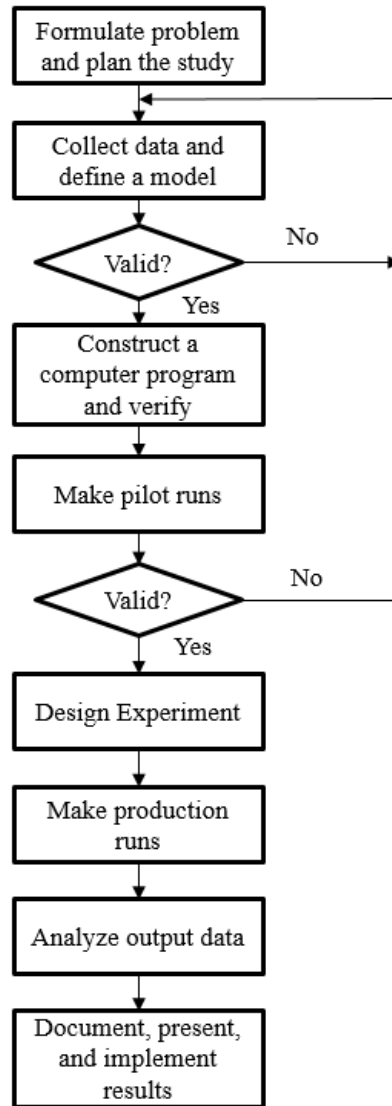


Figure 16 - The 10-step approach to create a simulation study (Law & Kelton, 1991).

To ensure the validity and credibility of the simulation models, Law and Kelton (1991) discuss a three-step approach. First, the model should be developed with high face validity, meaning that the model seems reasonable for people with knowledge about the system. In this step, results can be compared with similar simulation models, theory and validated by experts on the system. The second step is to validate the assumptions made for the model empirically, preferably with a sensitivity analysis. A sensitivity analysis tests the changes of the output of the data if input parameters are slightly changed. If the result changes drastically with small input data changes, the modeling must be done carefully and assumptions must be further analyzed to ensure valid end result. The last step is to compare the output of the model with reality, to see how representative the output data really is. If the baseline of a system is modeled, and the result is similar to reality, the researcher can assume that the model and assumptions are valid and that the end result of the simulations should reflect reality in a reliable way.



### 3.5.2 Linear Programming

Linear programming can be traced back to the 1820s, and has since become one of the world's most recognized and used mathematical tools for optimization, i.e. to achieve the best result with the least possible effort, and it functions as a foundation within operations research, decision science and management science all around the world (Pan, 2014).

When using linear programming, the modeler in a situation when variables whose values are to be decided in the most favorable way. These variables are often called *decision variables*, and denoted as

$$x_j, \quad j = 1, 2, \dots, n$$

The objective with linear programming is to minimize or maximize linear function based on these decision variables, often referred to as the *objective function*

$$\zeta = c_1x_1 + c_2x_2 + \dots + c_n$$

In addition to the decision variables building the objective function, constraints ensuring the model reflects reality and deliver trustworthy results needs to be set and included in the model. According to Vanderbei (2014), the constraints can either consist of an equality or an inequality with the linear combination of the decision variables, denoted as

$$a_1x_1 + a_2x_2 + \dots + a_nx_n \left\{ \begin{array}{l} \leq \\ = \\ \geq \end{array} \right\} b$$

The constraints can easily be converted, meaning that by for example introducing a nonnegative *slack variable*  $w$ , the modeler can transform an inequality into an equality,

$$a_1x_1 + a_2x_2 + \dots + a_nx_n + w = b, \quad w \geq 0$$

And in the same way, an equality constraint can be transformed into an inequality by setting two new equality constraints:

$$\begin{aligned} a_1x_1 + a_2x_2 + \dots + a_nx_n &\leq b \\ a_1x_1 + a_2x_2 + \dots + a_nx_n &\geq b \end{aligned}$$

(Vanderbei, 2014).

A simplified example for when linear programming could be used, is if a manager wants to *maximize* profit by increasing the number of workers, which in this case is denoted as the *decision variables*, and assumed to be *linear* to the profit *objective function*. A *constraint* for the model here could be that the model is not allowed to select more workers than what is available.

Even though linear programming is a simple model based on only decision variables, equalities and inequalities, the size of the model used for modeling real situation can sometimes include thousands of constraints, variables and equations. Therefore, LP almost always require computational aid with advanced software (Pan, 2014).

## 4 BACKGROUND OF SANDVIK SC

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*This chapter presents information needed to understand the situation at Sandvik SC such as its products, distribution network and transportation modes. The chapter is concluded by an analysis of the freight strategy used by Sandvik SC during 2016.*

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### 4.1 Products in Scope

Sandvik SC has two main equipment categories; cone crushers and jaw crushers. These two types of equipment serve three main market segments; *mining, construction and demolition and recycling*. These market segments are supplied from Sandvik SC, with different products serving different customer needs and requirements. Furthermore, with the new decentralized organization, Sandvik SC has gained control of the aftermarket for these equipment categories. This has led to Sandvik SC being responsible for managing the distribution network for aftermarket products.

The products in focus in this study are wear parts and spare parts, at Sandvik SC also referred to as aftermarket products. These products are sold to customers at a regular frequency after equipment has been purchased. Wear parts are often worn out and needs to be exchanged regularly. Spare parts are parts that replace broken parts of the equipment. Because the aftermarket products are crucial for the customers, they are stored as close as possible to the customers in the distribution network to enable high responsiveness. The aftermarket products are thus manufactured without a specific customer order to fill the stock levels in the warehouses, also called make to stock (MTS) products.



Figure 17 - A cone crusher on the left and a jaw crusher on the right.

### **4.1.1 Wear Parts**

Wear parts are parts mounted on the stationary crushers, and their purpose is to be in direct contact with the rocks during the crushing process and thus taking all the pressure and damage from the rocks to protect the equipment. The tough process lead to that these parts need to be changed and replaced periodically, depending on how much the crusher is used.

There are three main parts of wear parts: concaves, mantles and jaw plates. Concaves and mantles are used in cone crushers and jaw plates are used in jawbreakers. All wear parts are made of steel with a percentage of manganese mixed into it. They come in different shapes and sizes depending on the rock type that needs to be crushed and what crusher is used. Due to the different sizes, shapes, manganese levels and purpose of the wear part, the amount of different varieties of wear parts are many, from small parts that weigh only a couple of kilograms to products with very large volumes that weigh several tons. Due to the high weight of the wear parts, the value density of the products is low, even though they have a high unit price. The concaves and the mantle are non-stackable, which adds a lot of complexity to the handling and distribution during transportation.

### **4.1.2 Spare Parts**

Spare parts is a category group, consisting of products such as hoses, nuts, bolts, gaskets and other relatively small type of parts that are needed for the crushes to function. The spare parts are supplied by external suppliers but distributed in Sandvik SC's distribution network.

The characteristics for spare parts as small, stackable and lightweight makes it easier to plan from a distribution point of view. They can more easily be packed in a container and requires less handling. Even though Sandvik SC's spare parts mostly consist of small parts, there are products within the category that are large and heavy. The spare parts have a high value density, meaning that the products are of high value with a relatively low weight.

## **4.2 Sandvik SC Supply Chain Network**

### **4.2.1 Production Facilities**

Sandvik SC's global distribution centers are supplied by three production facilities located in; Svedala, (Sweden), Pune, (India) and Jiading, (China), but most of the production is based in Svedala. Items not produced in-house are supplied from external suppliers around the globe and sourced to European distribution centers.

### **4.2.2 Distribution Centers**

Sandvik SC has two global distribution centers, one located in Svedala (Sweden) and one in Eindhoven (Netherlands). Their purpose is to supply the regional warehouses around the globe, and the difference between the two is that Svedala supplies wear parts while Eindhoven supplies spare parts. The global distribution centers receive stock from the production facilities and external suppliers.

Sandvik SC utilizes five different regional distribution centers (DC) across the globe. The regional DC's are located close to customers with the purpose to supply aftermarket products on a regional level to deliver high responsiveness to customer.

The location of the DCs in the distribution network is illustrated in figure 18 and their internal company codes are shown in table 6.

Table 6 - The geographical location of the regional and global warehouses in the distribution network together with their internal reference code.

Location	Sandvik Internal Reference Code	Type
Svedala, Sweden	7	Global Warehouse
Eindhoven, The Netherlands	C1	Global Warehouse
Chicago, United States	C2	Regional Warehouse
Singapore, Singapore	C3	Regional Warehouse
Johannesburg, South Africa	C4	Regional Warehouse
Brisbane, Australia	63	Regional Warehouse
Perth, Australia	67	Regional Warehouse

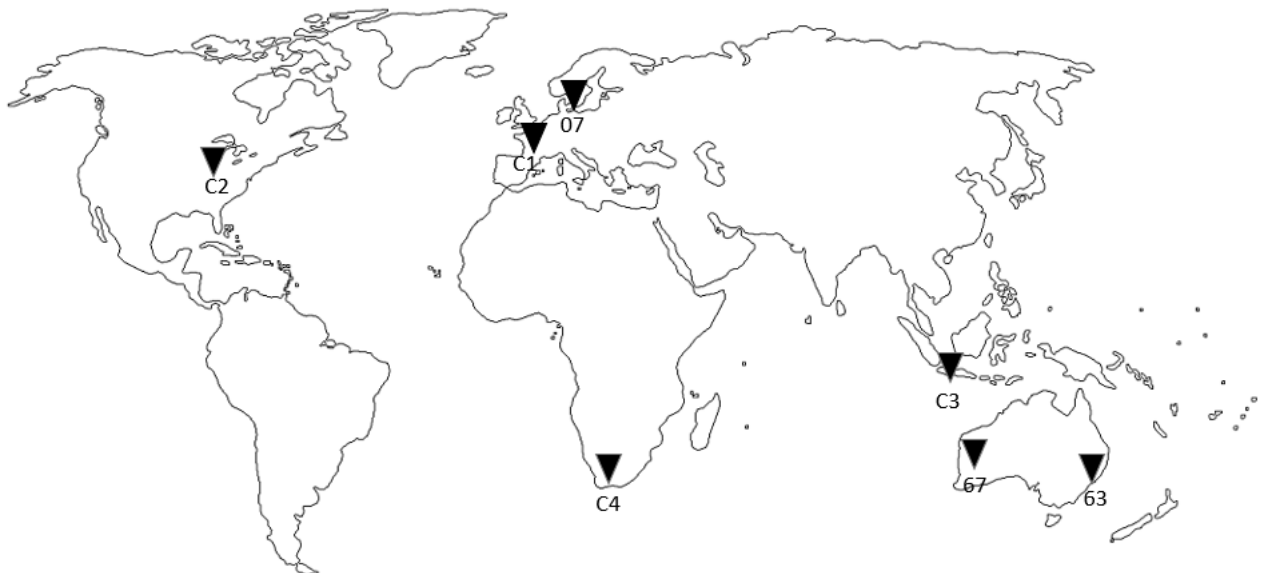


Figure 18- A world map with the warehouses locations in each continent.

### **4.2.3 Sales Areas**

Sandvik CS's customers are spread out across the globe, and to effectively serve the customers, there are several sales areas in each region. The sales areas are the link between customers and Sandvik CS and manage the sales and transactions towards the customers. The sales areas make promises to customers and thus need an available and reliable supply of products to be able to fulfill the promises. Therefore, the purpose of the regional distribution centers is to supply the sales areas by having a high reliability, short lead times, stock on shelves and being geographically close to the sales areas. Even though the sales areas are out of scope for this study, it is important to understand the function of the sales areas.

### 4.2.4 The Distribution Network

Figure 19 and 20 visualizes the distribution network over the flow of products between the functions of Sandvik CS for sea and air freight.

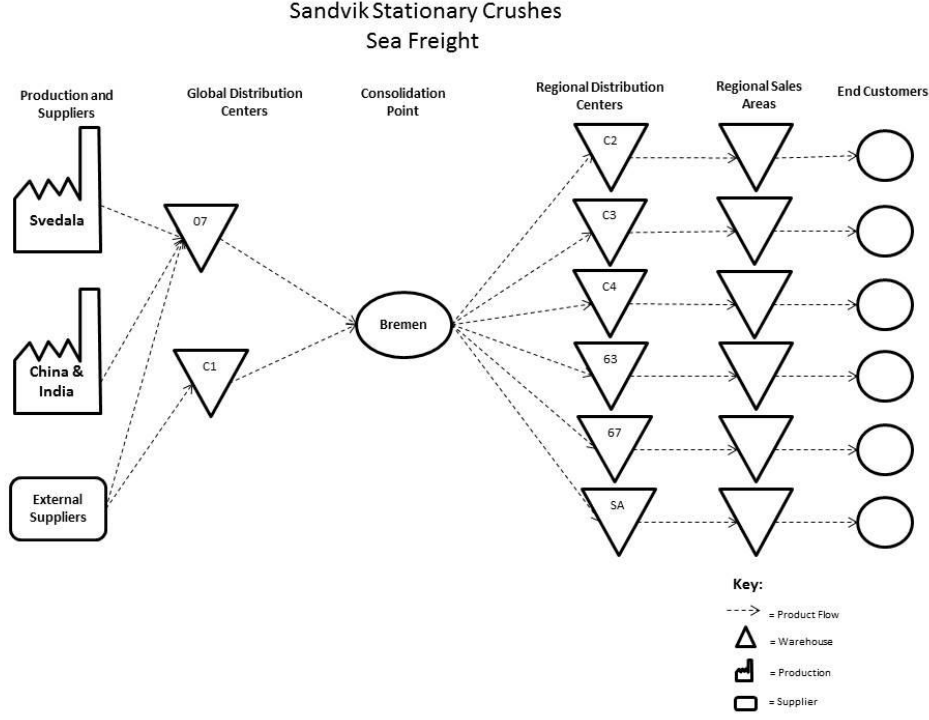


Figure 19 - The distribution network for Sandvik Stationary Crushers for sea freight.

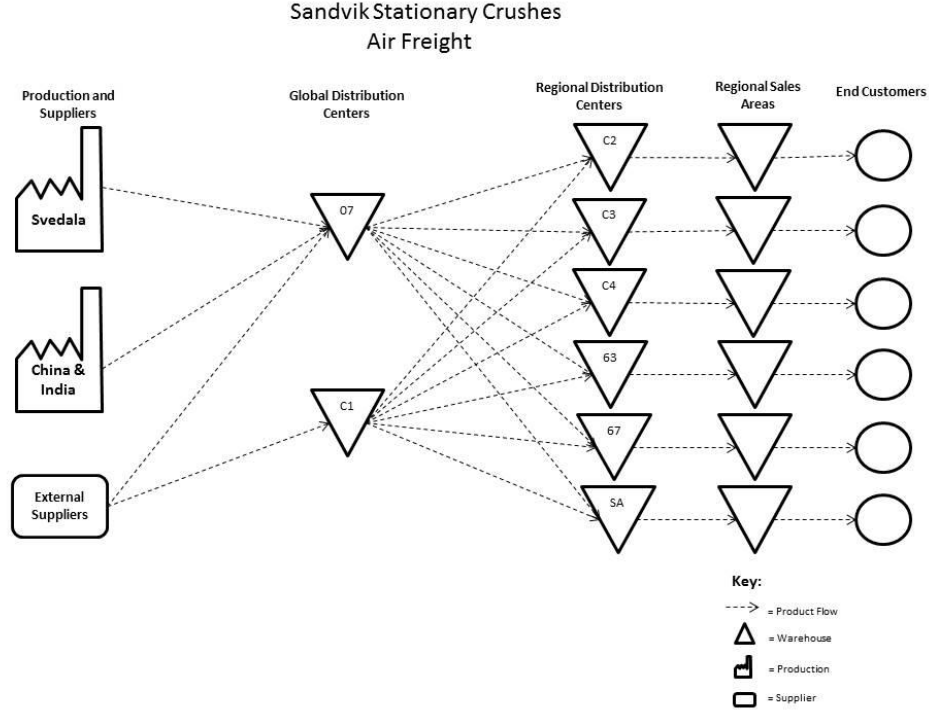


Figure 20 - The distribution network for Sandvik Stationary Crushers for air freight.

## 4.2.5 Transportation

Sandvik SC has outsourced their distribution services to a freight forwarder. The freight forwarder is responsible for the flow of products from global warehouses to regional distribution centers and invoice a cost for each shipment. Sandvik SC has control over the network and can choose what modes and routes to use but the carrier is the company managing all the transportations.

The carrier responsible for the distribution is also responsible for the distribution of products from other Sandvik business units. This is left-over from the previous organization, where the problem with the carrier is that it did not separate items from crushing & screening from other business units within Sandvik AB. With the reorganization occurring there is a process in place to find a new carrier that will only be responsible for Sandvik SC distribution.

### *Transportation Modes*

The modes of transportation used within the distribution network for Europe outbound is air and sea. Land distances to and from ports and airports are covered by truck and is excluded in this study, this excludes lead times, costs and special regulations for truck transportation. the cost for inland transport is assumed to be the same.

Sandvik SC has previously used three types of different air freight alternatives; Economy, Standard and Rush, ranked from slowest and cheapest to fastest and most expensive. Since the focus of this study is sea freight, the three air modes are merged together as one referred to as *air*. The data for all three has been normalized to get the right data for only air.

For sea freight, only one type of shipment and priority alternative is used by Sandvik SC. Sea freight is using container vessels that carry standardized containers. The capacity and size of the vessels are excluded for this study, and it is assumed that all containers always fit on a shipment. The directive from Sandvik is to only focus on 40ft containers for the sea freight.

### *Shipments*

Previously there has been no set frequencies for the shipments between the global and regional warehouses. Sea freight shipment size have been mixed between full containers and not full container, while air freight shipments have been sent daily. The number of containers for each sea shipments and the size of the air shipment have varied, implying that there has been no structure for the planners or receivers to plan the freight or receiving activities beforehand.

## 4.2.6 Freight Cost Structure

The costs for sea freight is divided into two charges set by carrier; a shipment and a container cost. A shipment is denoted as one transport number set up by Sandvik and the cost corresponding to the shipment. In accordance with Bell et al. (2013) the shipment cost can be seen as the overhead cost for the shipment. Example of these cost for Sandvik are: administration cost at origin/destination and the cost in customs.

A container cost is a cost charged per container unit. Container is a standard unit used within the shipping industry and therefore a logical unit to charge. Relating to Bell et al. (2013), container cost is the voyage cost, where each container is charged per voyage. Examples of container costs for Sandvik are: Type of container, container stuffing, terminal

handling cost and bill of lading. Terminal handling is the cost for handling the container in ports and bill of lading is a receipt of ownership over the container. The costs from the carrier are presented in table 7.

Table 7 - The cost per container and shipment from Europe to the regional warehouses.

	C2	C3	C4	63	67
Container Cost €	3713	1616	2888	3432	2275
Shipment Cost €	250	150	400	300	300
<b>Total Cost €</b>	<b>3963</b>	<b>1766</b>	<b>3288</b>	<b>3732</b>	<b>2575</b>

Air freight is charged to customers on shipment level but instead of a charge based on containers, it's based on weight. The invoiced price from the carrier is a single cost for the whole shipment.

For Sandvik SC, all the costs explained above are invoiced as a single cost from the transportation carrier. Therefore, it is assumed that all the costs described are included in the invoiced cost.

**4.2.7 Distribution Strategy**

The two global warehouses have distributed goods to the regional warehouses with both sea and air. The number of dispatched aftermarket products from the two global warehouses with the two transport modes are illustrated in figure 21 and 22. The figures show that almost all products sent from C1 was distributed by air, while for the wear parts from 07, most the items were sent by sea. With an aim to reduce transportation cost, the question was asked why expensive air freight was used for almost all items from C1. The answer was that there was no strategy for choosing transportation mode for replenishment. This was confirmed upon discussion with the supervisors at Sandvik SC.

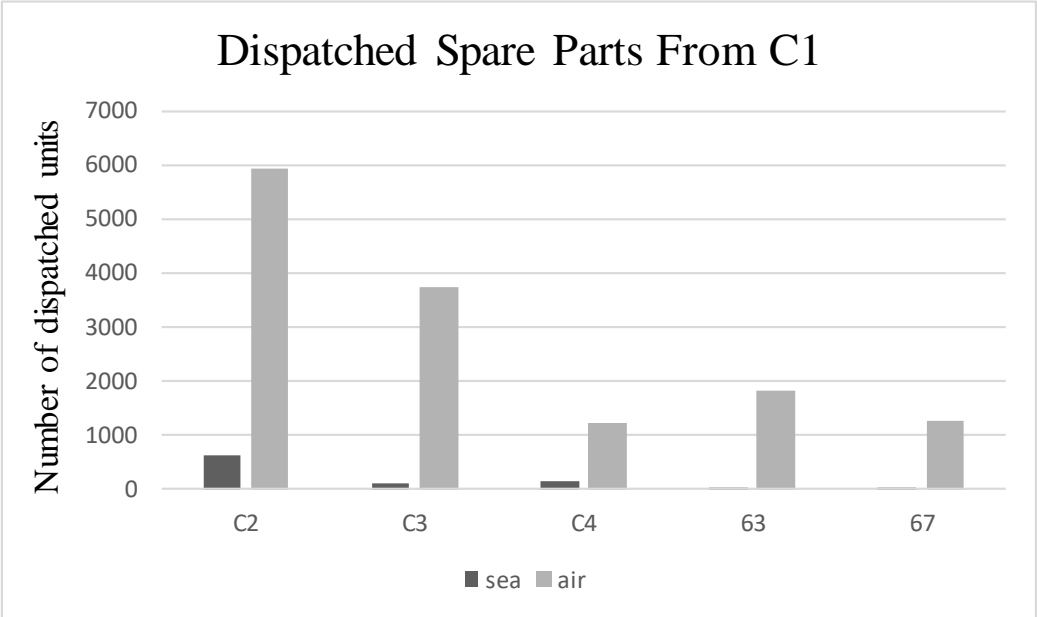


Figure 21 - The dispatched number of items and the transportation mode used from C1 in 2016.



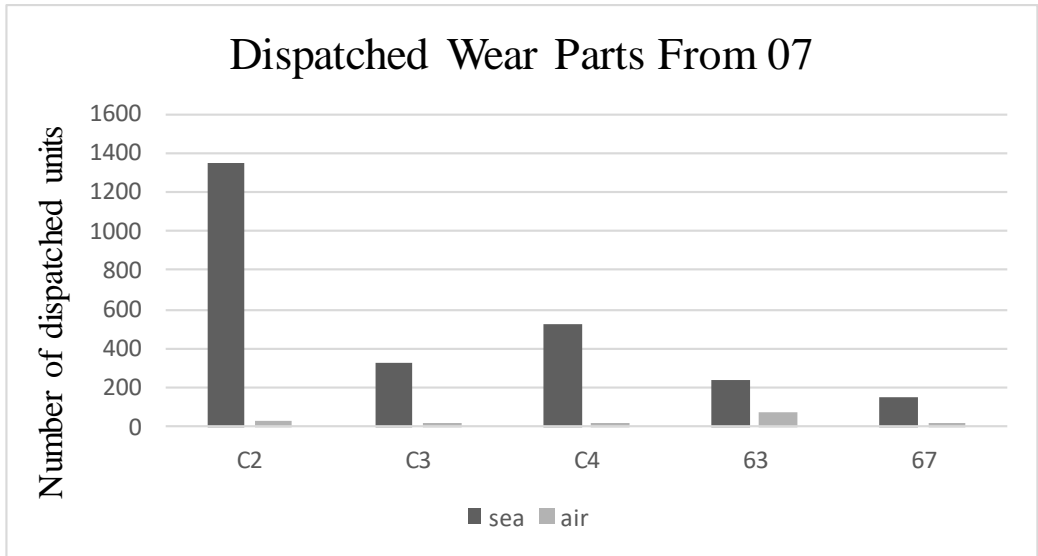


Figure 22 - The dispatched number of items and the transportation mode used from 07 in 2016.

When further analyzing the dispatched items in 2016, the lack of strategy was confirmed. This is illustrated in the scatter plots in figure 23 and 24. On the x-axis is the freight cost per kg and on the y-axis, is the product value density, and each dot in the plot represents an item sent in 2016. The items seen to the right of €1/ kg on the x-axis is distributed by air, and the dots to the left of €1/kg are distributed by sea. When looking at the two scatter plots, two major conclusions can be drawn.

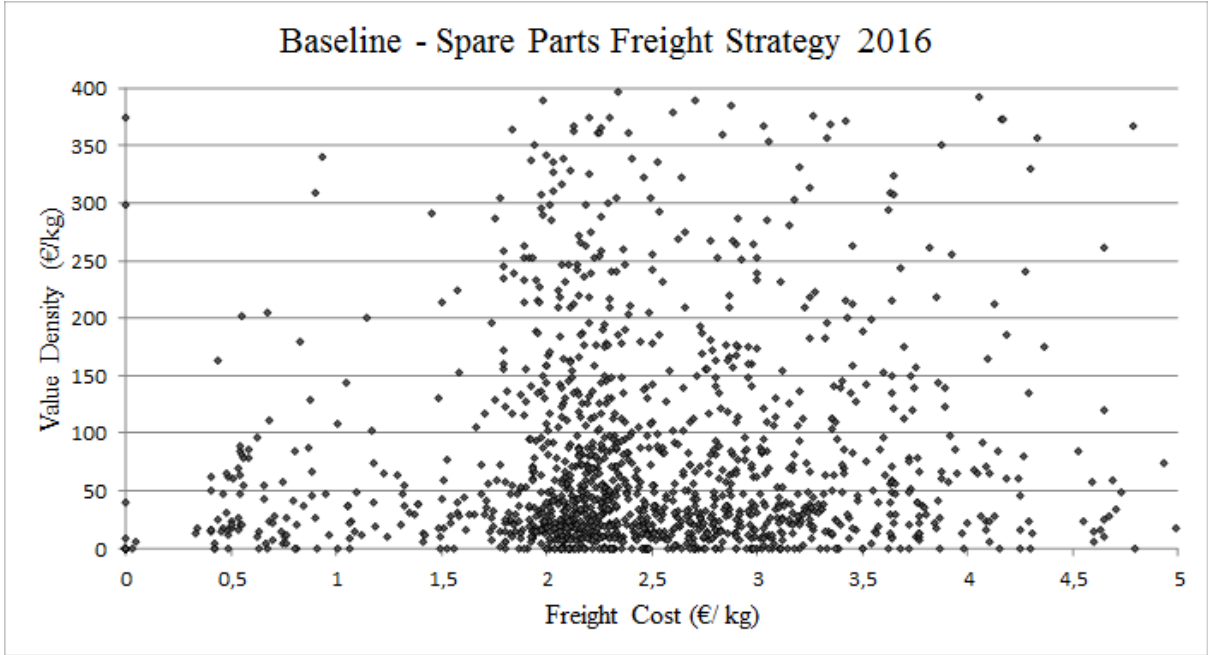


Figure 23 - A scatter plot illustration of how spare parts were shipped in 2016. Each dot is an item code.

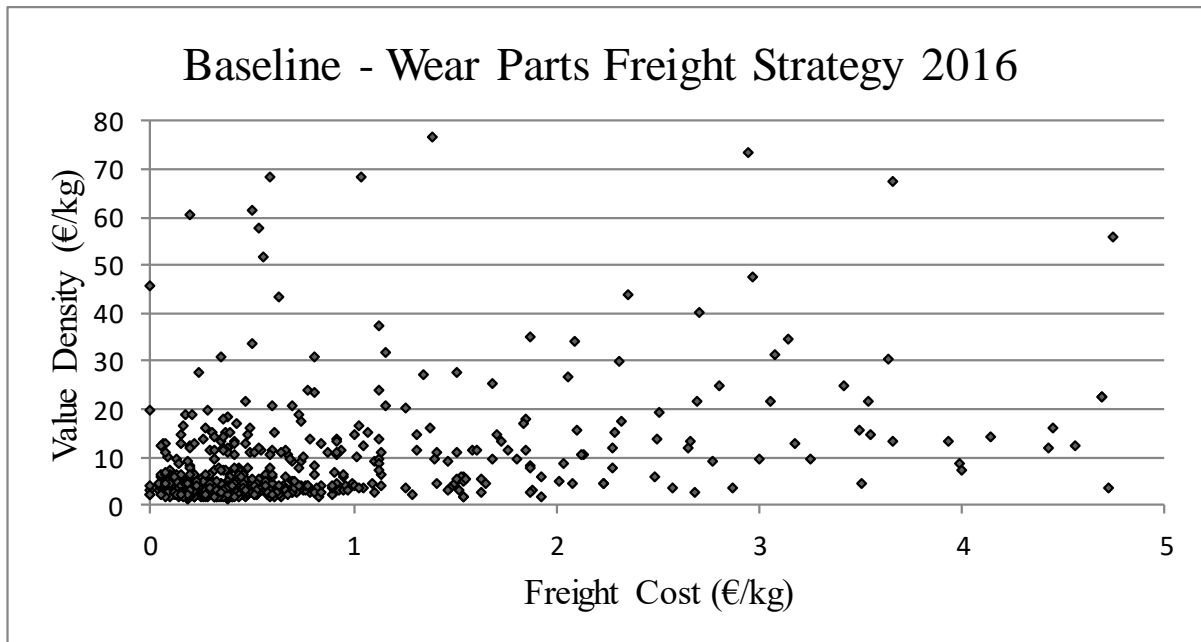


Figure 24 - A scatter plot illustration of how spare parts were shipped in 2016. Each dot is an item code.

First, the lack of transportation strategy previously stated can be confirmed. Especially for the goods sent from C1 where almost all products have been sent by air, which is seen by the dots location on the x-axis in the both plots. If there would have been a strategy, the items would be clustered together at one cost. But since they are spread out in the whole graph, items have been sent with different freight costs. Furthermore, most of the spare parts are of a low product value density, but have been transported at a very high freight cost which not is aligned with theory that states that air freight is suitable for high value products. Secondly, it can be concluded that there has been a relatively stable freight mode decision strategy for the wear parts from 07 the items are clustered together closer to the cost of sea freight. A reason for this is because the wear parts from 07 are heavier and previously have been deemed appropriate for sea freight.

Solving this problem is what the first research question of this study is about; “How can a company determine what transport mode is the best fit for their products with the objective is to minimize freight cost?”

To establish a shipment profile of what items should be sent by which transport mode for each warehouse, a simulation model over the unit transportation cost is to be done.

## 5 DEVELOPING A UNIT COST FREIGHT MODEL

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*This chapter explains the unit cost freight model. It starts with a general description of why the model is created, its approach, the theory behind it and the assumptions made. The second part of the chapter describes the product segmentation process for the two different product categories and the data required for the model. The chapter is concluded with a credibility check to verify that the results from the model are valid.*

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### 5.1 The Unit Cost Freight Model

The objective of the study is to create a shipment profile for Sandvik SC's aftermarket products when distributing the goods from the global to the regional distribution centers and to reduce their transportation cost. The shipment profile includes the recommended transportation mode for each product group.

Meixell and Norbis (2008) describe that there are several approaches of finding the right transportation mode. Since the goal of the study is to reduce freight cost it was concluded to create a model that compares freight cost for different transport modes. The mode with the lowest cost would be the chosen transportation mode.

To establish a shipment profile, the unit cost freight model based on linear programming has been created and simulated to identify transport mode. The model will take transportation cost and in-transit holding cost into consideration and balance those costs to find the optimal solution to minimize the freight cost. The model shows the transportation cost on a unit level. To get the total cost, all unit costs are summed to get a total cost. This makes it possible to see how each item contributes to the total freight cost.

The model uses in-data from 2016 and not predicted demand data for 2017. The output is therefore to be viewed as what the improvement would have been if the optimal transport mode for each product group was used during 2016. The reason for this is because of lack of data of an accurate forecast for dispatched aftermarket products on an item level for 2017.

The result from the model will be used by Sandvik SC when deciding what modes the aftermarket products should be transported with.

#### 5.1.1. Approach

To create an accurate model, the result from the model needs to be like the historical costs for Sandvik SC. This is ensured by following the steps set-up by Law & Kelton (1991) in section 3.5.1. Step one was confirmed by presenting the models for key stakeholders at Sandvik SC who agreed on the model. In step two, a sensitivity analysis was carried out to see how the results were changed if some parameters were changed. When the answer was reasonable, the model was ready to be tested against historical data. The output from the model when the baseline was simulated was compared to the invoiced cost provided from current carrier. When the values from baseline compared to the historical cost had a margin of error of under 10%, the models were confirmed complete. Since there are many costs included in the historical cost and the data was not always 100% either, a 10% margin of error was confirmed to be sufficient for the model to illustrate the situation of Sandvik SC. The margin of error was checked in accordance with Sandvik SC employees. When all three steps were carried out and the model confirmed valid, the model was ready to use.

The model was first applied to the spare parts from C1 and later for the wear parts from 07.

When the baseline for C1 was simulated and the results compared to historical data and deemed correct, the same process was applied for 07. This adds credibility that the model gives accurate results as it was implemented and tested twice.

**5.1.2 Theory**

The model is based on the formula for total logistics cost stated by Sheffi et al. (1988) described in section 3.4. The scope of the study is the unit transportation cost and not the cost of holding inventory. Therefore, the transportation and in-transit inventory cost are included and the inventory holding cost excluded. This means that in the formula for the total logistics cost per item, only the first two values are included in the formula.

$$TLC(X) = \frac{a}{x} + V * I * \frac{x}{2 * s} + V * I * t$$

Hence, the freight cost is denoted as:

$$Freight\ cost = \frac{a}{x} + V * I * t$$

**5.1.3 Creating the Model Using Linear Programming**

The model uses linear programming with the objective to minimize the objective function, which in this model is the freight cost. The decision variables are the transport modes, in where the transport mode with the minimum cost is chosen. Three constraints have been used when creating the model:

- The quantity of items sent needs to match the quantities sent in 2016.
- The same quantity of items within each product segmentation needs to match with the historical data.
- The number of items sent are integers, since all items are whole items and cannot be split up into decimals.

*Table 8 - A summary of which aspects are included in the model.*

<b>Objective function</b>	<b>TLC (x) = a/x + V*I*t</b>
<b>Decision variables</b>	<b>144</b>
<b>Constraints</b>	<b>3</b>

### 5.1.4 Assumptions

The assumptions made for the model are the following:

- Average values - Generalizations of data using averages is necessary to make the data easier to work with. Averages of values were used for costs, lead times, item weights and item values.
- No capacity constraint - All the suggested shipments fit into each shipment and the cost associated with not being sent are excluded.
- On- time - All the shipments are assumed on time and the cost associated with being late are excluded.
- Set transportation costs - The transportation costs for both sea and air freight are fixed in the model.

### 5.1.5 The Data

All the data used in model is historical data obtained from Sandvik sources. Three different data sources were merged into a data file containing the data to be input in the formula. The historical data from 2016 includes the following:

- Dispatched unique items codes
- Dispatched quantity for each item
- Transport mode used for each item
- Freight cost per item
- Destination - Regional warehouse
- Origin - Global distribution center
- Item value
- Item weight
- Date stamps of arrival at destination and departure from origin
- Item Group Major

The data covers all the shipments made in 2016, is over 15 000 order lines long, contains 1800 unique item codes and over 2000 shipments to five destinations. The large amount of data is positive because it enables the model to be as close to reality as possible. To check the validity of the data, the historical values for lead time and costs were compared with both the values in the Service Level Agreement between the carrier and Sandvik. Furthermore, the data was checked with the supervisors at Sandvik.

## 5.2 - Product Group Segmentation

### 5.2.1 Wear Parts - Product Characteristics Segmentation

Due to the large number of items and the use of average values, the items were divided into groups of products with similar characteristics. Sandvik SC had already defined item groups classified as *Item Group Majors*, in which the products were divided into nine groups depending on product characteristics. The Item Group Majors were already familiar for the organization and in place in all internal datafiles, which made it both easy and accurate to use.

The nine different Item Group Majors, with their internal company codes and description of the products can be seen in table 9 below.

Table 9 - The item code for the wear parts and their description.

<i>Item Group Major code</i>	<i>Description</i>
<i>011</i>	<i>Screening Media - Wear Parts</i>
<i>311</i>	<i>Cone Crushers 660 &amp; Smaller-Spare Part</i>
<i>315</i>	<i>Impactor Crushers Spare Parts</i>
<i>317</i>	<i>Jaw Crushers Spare Parts</i>
<i>327</i>	<i>Screens &amp; Feeders Spare Parts</i>
<i>411</i>	<i>Cone Crushers 800 &amp; Large Parts</i>
<i>511</i>	<i>Cone Crusher 660 &amp; Smaller Wear Parts</i>
<i>512</i>	<i>Jaw Crusher - Wear Parts</i>
<i>711</i>	<i>Cone Crushers 800 &amp; Larger Wears</i>
<i>775</i>	<i>Gyrator Crusher - Spare Parts</i>

**5.2.2. Wear Parts - Item Weight Segmentation**

Even though the products in each category are of similar functionality, the weight of the products in each category varies. To further increase the correctness of the model, every item group major was subdivided into weight categories.

The wear part weight categorization was established together with 07’s warehouse manager during a semi structured interview. With several years of experience from numerous facilities within Sandvik CS, the warehouse manager had deep knowledge of the products and their features and characteristics. During the interview, the weight groups were decided and are visualized in table 10.

Table 10 - The chosen product segmentation by weight groups for wear parts.

Weight group	0-10 kg	10-100 kg	100-500 kg	500-1000 kg	1000-1500 kg	1500-2500 kg	+2500 kg
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These weight groups are a good segmentation because within each category, the items have similar physical characteristics. For example: items within 500-1000 kg share the same characteristics while 100-500 kg is significantly different in size and volume. Furthermore, the number of unique items in each weight category are relatively the same

## 5.2.4 Wear Parts - Input

The Item Group Major together with the weight groups divide the wear parts into product groups. For each product group an average value, average weight and the number of dispatched items were added into the model. The values for this data are to be seen in tables 11, 12 and 13.

Table 11 - The average unit value per product group for wear parts inserted in the model.

Average of Unit Value - Wear Parts (€)									
	011	311	315	317	327	411	511	512	711
<b>A0-10</b>	40	71	74	300		1107	95		
<b>B10-100</b>		652	170	607	209	1690	559	236	
<b>C100-500</b>		3868		2540		1825	1586	899	1900
<b>D500-1000</b>		5262		7473		13173	2588	2341	
<b>E1000-1500</b>			19200			23711	4065	3177	4486
<b>F1500-2500</b>		29161					6321	4446	7265
<b>G2500+</b>		70598		144132		186055		7586	10611

Table 12 - The average unit weight per product group for wear parts inserted in the model.

Average of Unit Weight - Wear Parts (kg)									
	011	311	315	317	327	411	511	512	711
<b>A0-10</b>	0,3	5,3	4,2	5,6		2,8	6,0		
<b>B10-100</b>		55,2	20,6	30,8	22,9	91,4	73,0	87,8	
<b>C100-500</b>		219,6		179,9		164,1	362,2	256,4	251,7
<b>D500-1000</b>		557,8		724,9		728,2	714,7	756,8	
<b>E1000-1500</b>			1399,0			1036,5	1204,9	1206,0	1417,0
<b>F1500-2500</b>		1938,6					2008,3	1771,3	1894,6
<b>G2500+</b>		4873,9		14872,3		14496,2		3199,4	3644,5

Table 13 - The amount of dispatched quantities for wear parts in 2016.

Sum of Dispatched Quantities - Wear Parts									
	011	311	315	317	327	411	511	512	711
<b>A0-10</b>	61	33361	1614	40		143	17		
<b>B10-100</b>		2483	253	1479	75	149	1317	27	
<b>C100-500</b>		140		183		582	3604	1399	80
<b>D500-1000</b>		17		28		22	6868	695	
<b>E1000-1500</b>			1			2	3014	663	14
<b>F1500-2500</b>		7					553	812	527
<b>G2500+</b>		124		6		42		563	743

The value of the products within each product group is necessary when calculating the in-transit holding cost for the objective function. The weight is used to calculate the transportation cost. Last, the number of dispatched items is necessary to match the model with the historical values.

## 5.2.5 Spare Parts - Segmenting into Item Group Majors

The spare parts sent from Eindhoven belong to the same Item Group Major as the products from 07. Therefore, the same Item Group Majors were used to segment the spare parts.

## 5.2.6 Spare Parts - Segmenting in weight groups

To further subdivide the spare parts, the Item Group Majors were given weight groups to give additional precision to the model. Described in section 4.2.2, wear parts and spare parts have different physical characteristics where the main difference is the size and weight of the items. Therefore, new weight groups were established for spare parts as provided in table 14.

Table 14 - The chosen product segmentation by weight groups for spare parts.

Weight group	0-0,1 kg	0,1-0,5 kg	2,5-10 kg	10-50 kg	50-2550 kg
--------------	----------	------------	-----------	----------	------------

Compared to the weight groups for the wear parts, the weight groups for the spare parts have a lower span due to the weights of the products. Also, the quantity of items is within the lower weight groups which makes it necessary to make the weight groups in the lower spectrum.

## 5.2.8 Spare Parts - Input

Each Item Group Major and weight group make a product group, in the same way as for the wear parts. The average value per item group, average weight and the number of dispatched quantities within each group can be seen in tables 15, 16 and 17.

Table 15 - The average unit value per product group for spare parts inserted in the model.

Average of Unit Value - Spare Parts (€)										
	011	311	315	317	327	376	411	511	512	775
<b>A0-0,1</b>	3,1	5,7	6,9	11,9	4,9		5,3			
<b>B0,1-0,5</b>	39,8	27,3	51,0	20,6	18,5		22,0			83,7
<b>C0,5-2,5</b>	105,9	184,4	321,1	91,8	377,3		181,2			182,4
<b>D2,5-10</b>	109,7	540,2	375,9	228,4	116,5		759,4			242,1
<b>E10-50</b>	1009,6	1205,3	622,7	1237,6	433,7		4105,3			
<b>F50-2550</b>		6175,6	3934,5	4049,7	2124,4	5063,1	14009,5	1257,0	2176,9	56934,4
<b>G2550+</b>										581981,6



Table 16 - The average unit weight per product group for spare parts inserted in the model.

Average of Unit Weight - Spare Parts (kg)										
	011	311	315	317	327	376	411	511	512	775
<b>A0-0,1</b>	0,0	0,0	0,0	0,1	0,0		0,0			
<b>B0,1-0,5</b>	0,3	0,2	0,3	0,3	0,3		0,2			0,4
<b>C0,5-2,5</b>	1,1	1,4	1,3	1,1	1,4		1,2			1,1
<b>D2,5-10</b>	6,6	4,8	6,4	5,2	6,0		5,1			4,3
<b>E10-50</b>	17,4	21,9	21,2	26,4	22,2		27,4			
<b>F50-2550</b>		172,7	485,5	192,4	145,8	110,0	284,6	498,0	173,9	595,4
<b>G2550+</b>										7631,0

Table 17 - The amount of dispatched quantities for spare parts in 2016.

Sum of Dispatched Quantities - Spare Parts										
	011	311	315	317	327	376	411	511	512	775
<b>A0-0,1</b>	640	26618	717	1363	172		2473			
<b>B0,1-0,5</b>	2004	28603	687	3168	303		6213			3
<b>C0,5-2,5</b>	177	18541	255,8	2706	156		2805,4			118
<b>D2,5-10</b>	398	4017	2573	1878	322		2530			16
<b>E10-50</b>	430	3243	1095	529	62		380			
<b>F50-2550</b>		1233	181	263	32	5	621	1	10	5
<b>G2550+</b>										1

## 5.3 Input Data for the Model

### 5.3.1 The Number of Items in a Container

Described in the theory and in section 3.3.4, the invoiced cost for sea freight pricing is based on number of containers and/or shipments. The objective of the model is to describe the costs per item. Since pricing is based on cost per container, it is important to understand the number of items that can fit in one container to get the freight cost per item. However, the data provided by Sandvik SC and the carrier had no data regarding dimensions or volumes of wear parts. That missing piece of information was provided by the warehouse manager's product knowledge which gave valuable insights in determining the number of items in each product category that can fit into a container.

Together with the warehouse manager, the number of items that can fit into one container was determined. For stackable items, it is possible to pack them into a container until the payload capacity is reached, where the assumption that when stackable wear parts are loaded into the container, the maximum payload capacity is reached before the cubic capacity. This assumption is in line with reality due to the heavy weight of the wear parts, where relatively small items in terms of volume can weigh several tons.

For non-stackable products, the characteristics and dimensions of the product sets the limitation of how many of that item that can fit into one container. To clarify this, the items in Item Major Group 511 and weight group 1500-2500 kg can only fit four items per container

until the container has reached its cubic capacity, even though the payload is less than half its maximum loading capacity.

The number of items per group that can fit into one container given by warehouse manager for 07 is showed in table 18, where the cells with number shows the maximum items that can fit into one container before the maximum cubic capacity is reached. For the categories that do not have a fixed loading restrictions in table 18, these can be loaded until the container reaches its maximum payload capacity.

Table 18 - The number of items that can fit into a container for non- stackable wear parts.

Maximum Units Per Container for non-stackable Wear Parts									
	011	311	315	317	327	411	511	512	711
<b>A0-10</b>									
<b>B10-100</b>		60							
<b>C100-500</b>		150					24		
<b>D500-1000</b>		20		24			14		
<b>E1000-1500</b>							6		6
<b>F1500-2500</b>		8					4		6
<b>G2500+</b>		6		2					4

### 5.3.2 The Transportation Cost

To get a cost for each transport mode per item, a fixed cost for each transport mode was set. The cost came from the averages of the invoiced cost from the carrier. For air shipments, the total cost was divided by the total weight sent by air which gave a cost per kg.

For sea shipments, there could be two costs, depending on if a container reached its maximum payload or cubic capacity. For products where the payload was the restraint, the freight cost was divided by the weight capacity of a 40-ft. container, which gave a cost per kg. For the non-stackable wear parts seen in table 18 the number of products that can fit in a container, was divided by the freight cost for a container. The quota was the transportation cost per item.

The cost for air per kg and sea per kg is presented in table 19.

Table 19 - The cost per kg for air and sea freight to each regional warehouse.

	C2	C3	C4	63	67
Air Cost (€/kg)	2,64	2,68	4,21	5,32	5,82
Sea Cost (€/kg)	0,6	0,72	0,74	0,84	0,79

**5.3.3 In-transit Holding Cost**

The holding cost rate at Sandvik SC is based on an annual basis, and if divided with the number of days per year, the firm get the cost of keeping an item in inventory per day. This daily cost plays a big part in the item freight distribution model, where the daily inventory holding cost multiplied by the value of the item and the lead time in days for the specific route is referred to as the in-transit holding cost

Currently, the holding cost rate at Sandvik SC is 8% per year.

**5.3.4 Lead Times**

For this study, the port-to-port (PTP) lead time is used. Described in section 3.3.1, the lead times are calculated from when a truck enters the origin port to when it leaves the port of discharge. For both Eindhoven and Svedala, sea freight shipments are trucked to the port of Rotterdam which is the port of discharge for both warehouses. The PTP lead time is therefore the same. For air shipments, the lead times are the same even though they use different airports. The time and costs to and from ports and airports are assumed to be the fixed and the same for both transportation modes.

Lead time is an important factor to consider for both the model and the analysis. For the model, the lead time affects the in-transit holding cost which affects the total cost. For the analysis, lead times is needed to consider shipment size. The lead times, in calendar days, are presented in table 20.

*Table 20 - The lead times to each regional warehouse for each transportation mode. The lead time for sea is the same because the same port is used.*

	<b>C2</b>	<b>C3</b>	<b>C4</b>	<b>67</b>	<b>63</b>
<b>Sea</b>	28	36	38	58	50
<b>Air (07)</b>	3	3	6	3	3
<b>Air (C1)</b>	4	4	3	4	4

**5.4 Credibility of the Model**

To validate the model, historical data in terms of transportation mode and total dispatched quantity for each product group at each global warehouse was inserted in the model. If the costs for the models’ baseline were in line with what Sandvik SC had paid last year, the model was confirmed to be correct. The historical cost for each destination from both global warehouses together with the model’s baseline costs and its margin of error is showed in figure 25 and 26.

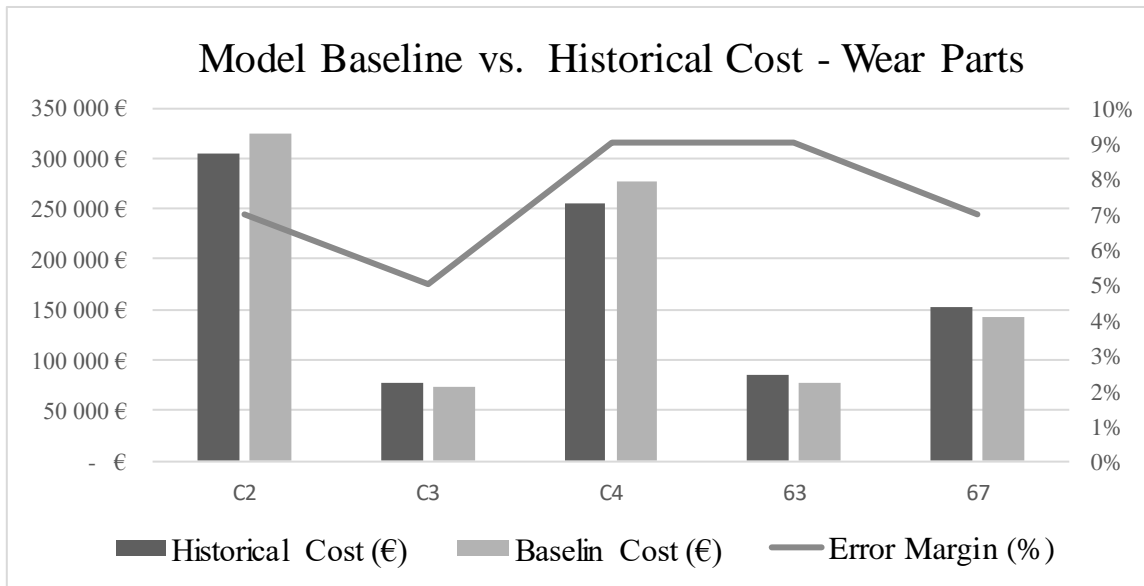


Figure 25- A comparison of the historical cost and the suggested cost from the model for wear parts. The error margin between the results is presented as a percentage.

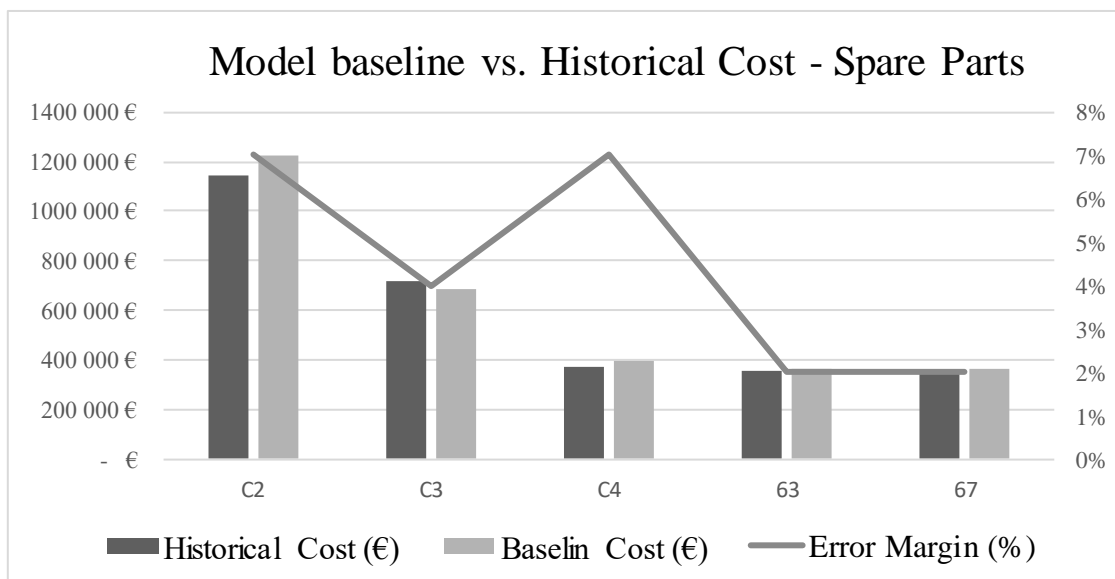


Figure 26- A comparison of the historical cost and the suggested cost from the model for spare parts. The error margin between the results is presented as a percentage

Seen in figure 25 and 26, the difference between the baseline and historical cost has a margin of error around 7% for the wear parts from 07, and around 5% for the spare parts from C1. The margin of error is the consequence of several factors; variation in historical cost, consolidation between different business units and the use of averages in product segmentation.

Solutions to these factors were found and when the assumptions made for each destination were done and approved by Sandvik SC and the data was put in the model which gave an error margin of less than 10 percent, the model was confirmed to be correct and the simulation and optimization could start and results could be seen. The way of solving the error factors and the credibility of the results from the model will be further discussed in section 7.1.

## 6 RESULTS

*In this section results from the model is presented in three parts. The first part presents the new shipment profile suggested by the model, which is followed by the freight cost savings the new shipment profile would have implied during 2016. The final part presents the first actual result seen at Sandvik SC after applying the changes made suggested from this study.*

### 6.1 New Shipment Profile

The result of the model is the new shipment profile, which is a matrix that tells the user which transportation mode every product group should be transported with.

The new shipment profile for the spare parts is shown in table 21. For spare parts from C1, the only product group that should be sent by air is Item Group Major 315 weight group 0-0,1 kg.

*Table 21- The new shipment profile for item groups and weight groups of spare parts, based on the results from the model.*

New Shipment Profile - Spare Parts										
	Item Group Major									
Weight Group	011	311	315	317	327	376	411	511	512	775
A0-0,1	sea	sea	air	sea	sea		sea			
B0,1-0,5	sea	sea	sea	sea	sea		sea			sea
C0,5-2,5	sea	sea	sea	sea	sea		sea			sea
D2,5-10	sea	sea	sea	sea	sea		sea			sea
E10-50	sea	sea	sea	sea	sea		sea			
F50-2550		sea	sea	sea	sea	sea	sea	sea	sea	sea
G2550+										sea

The shipment profile for the wear parts is seen in table 22 below. The only product group that should be sent by air from 07 is item group major 411 and weight group 0-10 kg.

*Table 22- The new shipment profile for item groups and weight groups of wear parts, based on the results from the model.*

New Shipment Profile - Wear Parts									
	Item Group Major								
Weight Group	011	311	315	317	327	411	511	512	711
A0-10	sea	sea	sea	sea		air	sea		
B10-100		sea	sea	sea	sea	sea	sea	sea	
C100-500		sea		sea		sea	sea	sea	sea
D500-1000		sea		sea		sea	sea	sea	
E1000-1500			sea			sea	sea	sea	sea
F1500-2500		sea					sea	sea	sea
G2500+		sea		sea		sea		sea	sea

With this new shipment profile, where only items from one product group from 07 and one product groups from C1 should be distributed by air, a severe reduction of air freight compared to the baseline is suggested.

## 6.2 Result of Simulated Freight Cost

To answer the first research question “How can a company determine what transport mode to use in the distribution network with the objective to minimize freight cost?” a unit cost freight model was built. The model, which is based on the formula for the total logistics cost, proved to be a good tool for comparing transport modes. The freight cost savings from the model is illustrated in figure 27 and table 23. The figures illustrate the cost savings using the new shipment profile if it would have been used last year by Sandvik SC for shipment from C1.

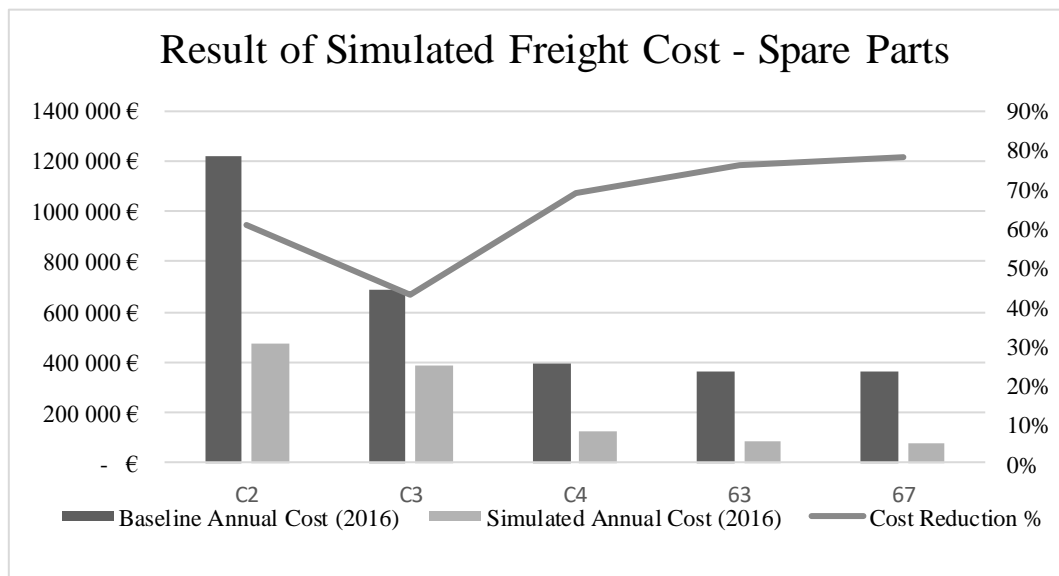


Figure 27- The result of the simulated optimal solution from the model together with a comparison from the baseline for spare parts.

Table 23 - Table format of the exact numbers from the model.

Result of Simulated Freight Cost - Spare Parts					
	C2	C3	C4	63	67
<b>Historical cost</b>	1 146 173 €	715 793 €	369 623 €	357 448 €	357 697 €
<b>Baseline model cost</b>	1 222 184 €	688 264 €	394 563 €	362 957 €	366 573 €
<b>Error margin %</b>	7%	4%	7%	2%	2%
<b>Solver optimal cost</b>	477 945 €	391 206 €	123 465 €	88 613 €	80 461 €
<b>Saving %</b>	61%	43%	69%	76%	78%
<b>Saving (€)</b>	744 239 €	297 058 €	271 098 €	274 344 €	286 112 €
<b>Total saving</b>	<b>1 872 852 €</b>				

The results show that the cost will be reduced for all destinations and that the cost savings are large. For some destinations, the savings are greater than others, where the average cost saving for the five destinations is 65%. The results are based from the baseline model and the optimal cost. The historical cost and error margin is presented to give an indication of how close the simulated cost is to reality.

For 07 the results from the model and cost savings for 2016 is presented in figure 28 and table 24.

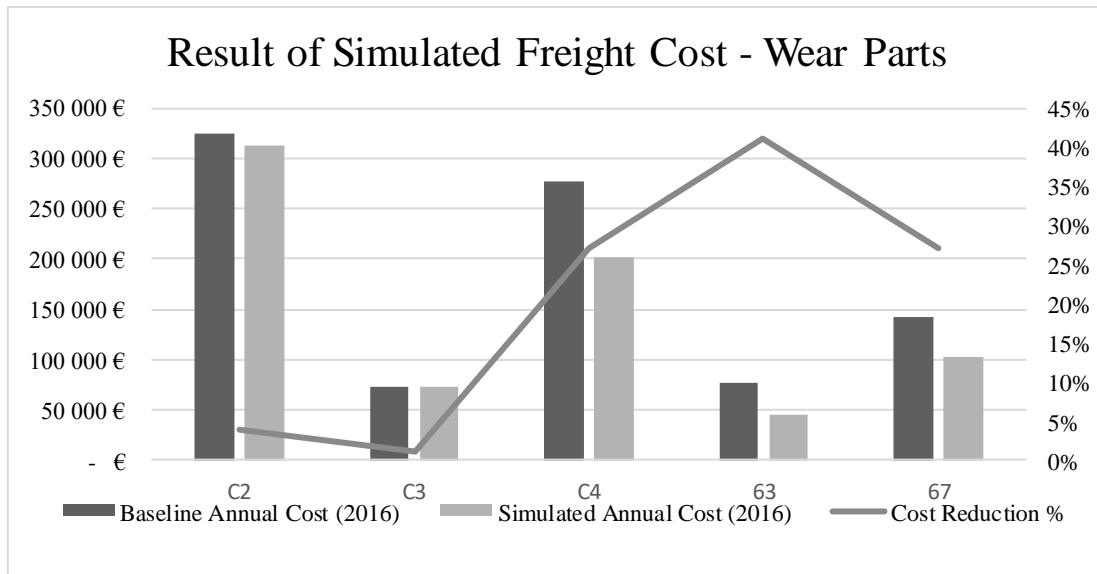


Figure 28- The result of the simulated optimal solution from the model together with a comparison from the baseline for wear parts.

Table 24- Table format of the exact numbers from the model

Result of Simulated Freight Cost - Wear Parts					
	C2	C3	C4	63	67
<b>Historical cost</b>	305 030 €	77 471 €	255 333 €	85 913 €	151 998 €
<b>Baseline Model</b>	325 550 €	73 368 €	277 932 €	77 869 €	141 646 €
<b>Error margin</b>	7%	5%	9%	9%	7%
<b>Solver optimal Cost</b>	313 270 €	72 728 €	202 396 €	45 893 €	102 698 €
<b>Saving %</b>	4%	1%	27%	41%	27%
<b>Saving €</b>	12 280 €	640 €	75 536 €	31 976 €	38 948 €
<b>Tot savings</b>	<b>159 379 €</b>				

As seen in table 24, the savings add sum up to €159 379, with an average cost reduction of 20%.

Seen in the tables 23 and 24, the new distribution strategy for the wear and spare parts will result in great savings in the freight costs. The savings will be larger for the spare parts from C1 compared to wear parts from 07 due to the previous freight strategy with more sea freight from 07. For example, from C1 to 67 the cost savings is simulated to be up to 78% per year, while for wear parts transported from 07 to C3 the optimal freight cost from the simulation only implies a cost reduction of 1%. How the freight savings vary from regional warehouse is due to the amount of air shipments that took place during 2016. For example, a large amount of the spare parts was transported from C1 to 67 by air, while almost no wear parts from 07 to C3 was sent by air. Therefore, the cost savings for C1 is larger than for 07, which is in line with the expectations and the results from the previous freight strategies visualized in the scatter plots in figures 23 and 24 in section 4.2.7.

In total, the new shipment profile suggests cost savings from C1 to all the regional warehouses of around € 1,9 Million per year, which will entail a 61% reduction of the total

freight spend. For the wear parts from 07, the yearly savings are simulated to be around €160 000, which will reduce the total freight spend with almost 18%.

How the freight cost structure has changed with the new shipment profile is visualized in figure 29. The reduction of the freight costs for the two aftermarket products is seen together with the sectioning of the transportation cost and in-transit holding cost. Previously discussed, the biggest changes are seen for spare parts from C1, where previous air freight strategy implied high transport costs but tied up little value during the short lead times.

Further, the higher value of the spare parts ties up more capital than the wear parts during the longer lead times at sea, which is seen when comparing the cost structures of the 07 - New Shipment Profile and C1 - New Shipment Profile.

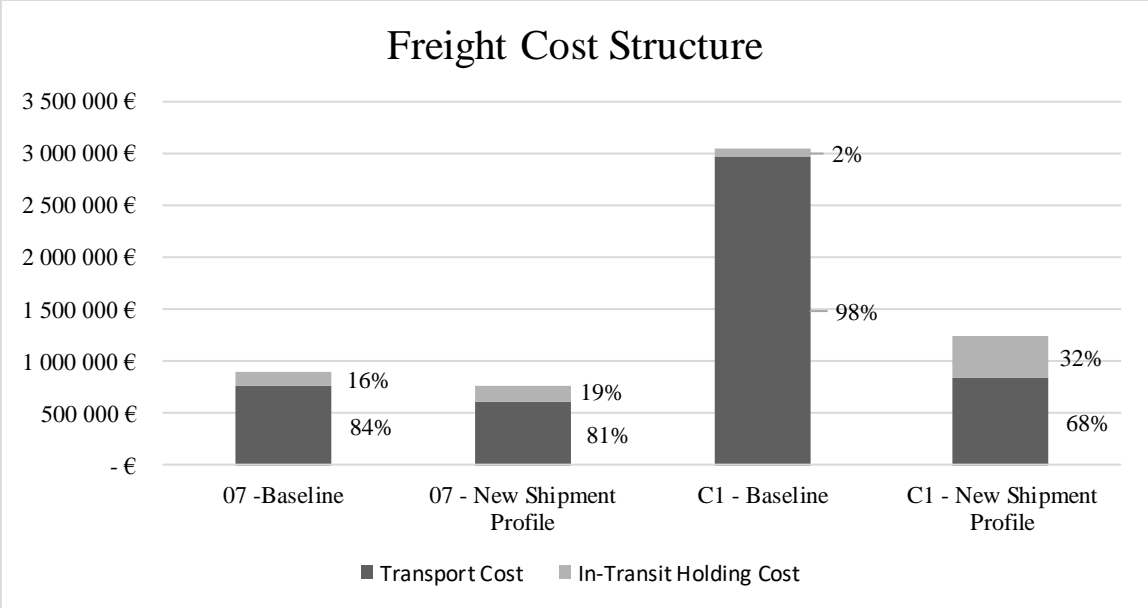


Figure 29 - The transport and in-transit holding cost share of the total cost for each warehouse compared to the baseline.

To conclude the freight savings, the model has simulated the total savings for Sandvik SC for the European outbound distribution of aftermarket products to € 2,032,231 if the new shipment profile would have been used last year, which implies a reduction of the total freight spend of 52% per year.



### 6.3 Results at Sandvik SC

During the period of this study, close collaboration has taken place with the logistics team at Sandvik SC, led by external logistics manager staff at Sandvik SC have put trust in the author’s competence and the result from this study. Shortly after having presented the first results and findings from our model, the proposed new shipment profile was implemented. This implied that numerous aftermarket products changed transportation mode from air to sea in the middle of march 2017.

#### 6.3.1 Freight Cost Reduction

Because of the previous lack of freight strategy for the spare parts sent from C1, where most of the products were sent on daily rush air orders, that is where the most savings could be done and where the first implementation started.

To easy illustrate the difference between sea and air after the implementation, the transported weights for each mode and the monthly freight cost is presented in figure 30 and 31. Illustrated in the figures, the weights and costs after the implementation in 2017 is compared with the same numbers from 2016. The first results from the changes can be seen starting from April 2017.

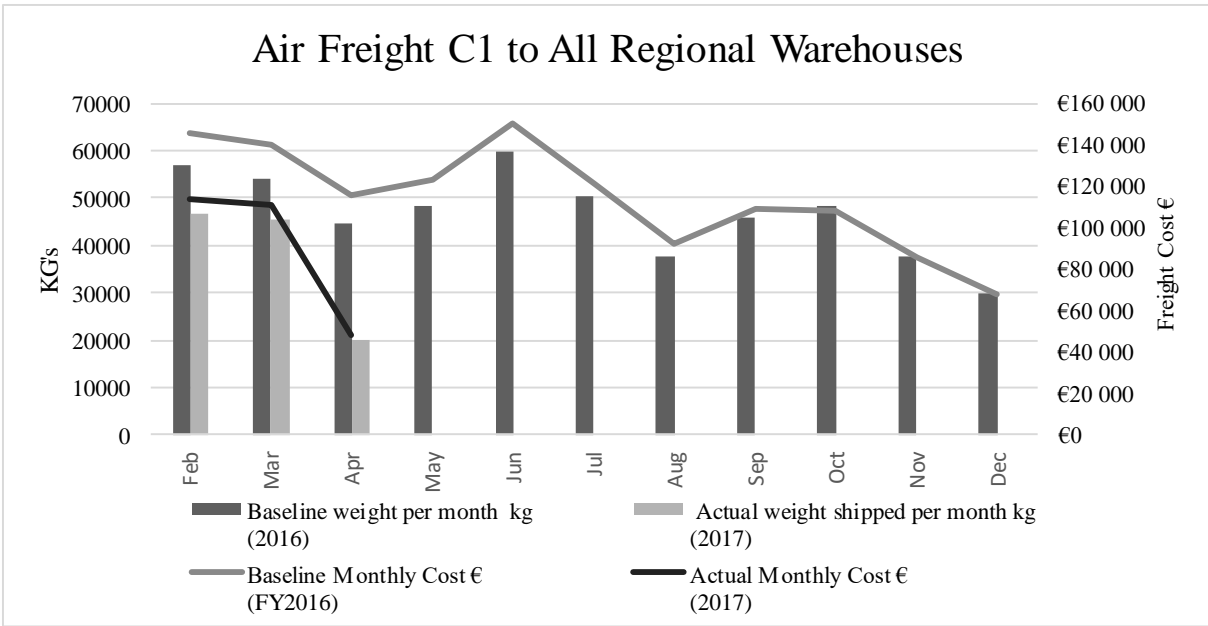


Figure 30 - The actual cost reductions and shipped weight for air freight from C1 after implementing the suggested changes.

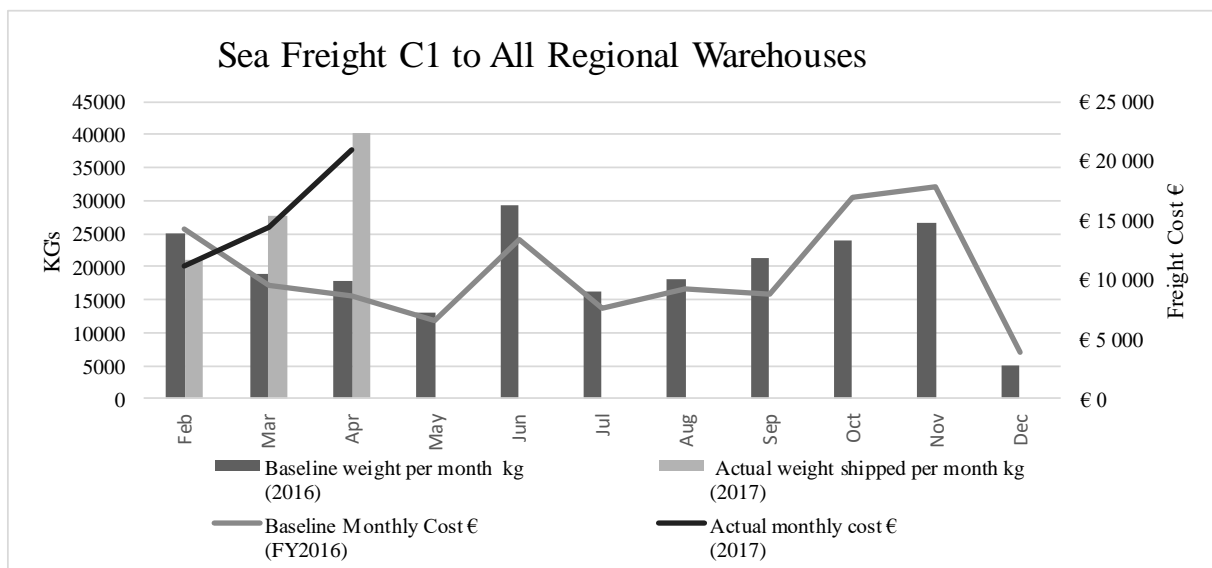


Figure 31- The actual cost reductions and shipped weight for sea freight from C1 after implementing the suggested changes.

When analyzing the graphs, it is seen that the total weight transported by air in the month of April reduced from around 45 ton to 20 ton, a weight that now instead is sent by sea freight in accordance to the new shipment profile. Further, it is seen in figure 30 and that the costs for Air freight from C1 decreased while the costs for sea increased which is a consequence of the changed distributed weights for each mode.

Changing mode of transportation is a complex decision that needs to be implemented under incrementally during a long period of time to avoid stock outs and disruptions in the distribution network. Therefore, Sandvik SC started the transportation mode change for the spare parts in the product groups with the highest weight groups. In the month of April, where the first changes can be seen, the freight costs were reduced from €130 000 to €60 000, which implies cost savings of around €70 000 or 54%.

### 6.3.2 - Internal Changes from New Distribution Strategy

To answer the second research question for the study: “What factors are important to consider when changing transportation mode from air to sea freight?” monitoring the changes made was meaningful. It is easy to see the effects of reducing cost. However, the business environment is more complicated than that. Changing from air to sea demands more factors to consider.

During the implementation, the other factors Sandvik SC experienced was:

- New transit times.
- Planning of shipments.
- Reliability changes of the transport mode.
- Supply chain synchronization with external suppliers.
- Strategic planning of the operational changes

### **6.3.3 - Finding a Lead Logistics Partner**

In addition to establishing a new shipment profile for the wear- and spare parts, a part of the work during the period for this study was to aid Sandvik SC with finding and evaluating several different lead logistics companies who all competed in becoming the new partner for Sandvik SC to help manage the distribution within the distribution network. Together with the external logistics manager at Sandvik SC and the researchers from the air freight project, a thorough partner evaluation process has been carried out.

For various reasons, this part of the project is not included in this thesis, but a lead logistics partner has successfully been found and awarded the full responsibility for managing both the inbound and outbound freight of goods within the entire distribution network for Sandvik SC.

## 7 ANALYSIS

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*The analysis is divided into four different sections that analyzes the results from different perspectives. The first part investigates the new shipment profile suggested by the unit freight cost model. The second part analyzes the stability of the model, i.e. how the results from it vary with changes in the variable parameters holding cost rate and sea freight container cost. The third section discusses the credibility of the model, and the chapter ends with an analysis of the internal effects a company faces when changing transportation mode from air to sea freight.*

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### 7.1 The New Shipment Profile

When applying linear programming, and simulating the different freight scenarios for the freight unit cost model based on the theory described by Sheffi et al. (1988), result indicated that sea freight is the most suitable alternative as a transport mode for most of the product groups. For the product groups where sea freight is suggested as transportation mode, the cost for the transportation is greater than the in-transit inventory holding cost seen in figure 29. This means that the tied-up capital caused by the value of the product is less than the transportation cost. Sea can therefore be concluded to be a better transportation mode for Sandvik SC's products from a cost perspective. The reasons behind the results are because of the cost structure for the different transportation modes and the type of products transported in the distribution network.

#### 7.1.1 The Transport Modes Cost Structure Makes Sea More Beneficial

The cost structure for the two transportation modes are different. For air freight, the transportation cost per kg was based on historical data and validated with the agreed cost from the carrier. That is also how air freight is charged in the industry, which made result from the costs of air valid compared to the invoiced data.

For sea freight, the cost per kg is based on the cost of a container and the capacity of a container. The exact cost for a container can therefore vary. The historical cost of a container depends on the destination which is set by the carrier, described in chapter 3.3.2. The historical cost per item depends on the number of items in a container. A more filled container decreases the cost per item since there are more items to share the container cost. In the model, averages of data were used to identify the number of items in a container. The average container price was then divided by the number of items in a container. With that in consideration, the model proved that sea is cheaper compared to air based on weight per item. Like the data and theory states, sea is a transport mode with lower freight costs compared to air. Therefore, having high weight items with a relatively low product value density, sea is a better transport mode than air from a cost perspective.

If, however, different averages or another type of segmentation were used to determine the number of items in a container, a different cost per container would be the result. This could either increase or decrease the cost per item and give a different end result. Therefore, when doing a unit transportation model based on item weight, it is necessary to emphasize the importance of calculating container cost with reasonable assumptions based on the number of items in a container.

The data shows that most items from Svedala was shipped by sea in 2016. Yet, many item groups had still been sent by both sea and air last year. There are several reasons for using two

types of transport modes even though they are going to the same destination. However, the model proved that from a cost perspective only one transport mode should be used. For future shipment planning, the unit freight cost model can be referred to verify that from only a transport cost perspective sea is mostly the better alternative.

### **7.1.2 How Product Characteristics Impacts the Mode Choice**

The product characteristics of wear parts shipped from Svedala make them a good fit for sea freight. Relating to table 5 in section 3.2.1, sea freight has a large loading capacity, travels long distances, has a low transport cost and can take any type of products. Wear parts with large-volume, heavy weight and bulky dimensions are ideal for sea shipments since sea freight has a large loading capacity and carry almost any type of cargo. For Sandvik SC, this means that all the heavy and big goods with a low product value density can be filled in standardized containers which are easy to handle and can hold large quantities at a low cost. Compared to air, there is no standardization. Each item is packed and sent individually. This increases costs since each item is charged per kg. Also, not all items can be sent by air due to capacity constraints, whereas for sea, the capacity constraints are less. The many shapes and sizes of wear parts described in 4.2.1 and the weight groups used in the model confirm that the variation of wear parts is high. For this type of variation, sea is a more flexible option since the capacity constraints are less for sea than air. Described in section 3.2, air is limited to the volume in plane which makes it more difficult to fill it with large, heavy bulky items.

The spare parts are smaller, stackable and have higher product value density than the wear parts, and when comparing transport modes in table 5 in section 3.2.1 the transportation mode choice is not obvious. Both air and sea are suitable options, but air seems to be a better choice because it's suitable for small and lightweight items with a high value. However, when analyzing the simulation results from the model, the results show that it is more cost effective to send the products by sea instead of by air. This is because the in-transit cost is lower than the transportation cost.

The value of the products is an important aspect, which affects the in-transit holding cost. In accordance to Sheffi et al. (1988) and Lovell et al. (2005) high product value density implies that the in-transit holding cost increases when the lead time increases, which is a reason for why Lumsden (2012) suggest that high value products should be sent by air freight to reduce that cost. A high value increases the in-transit cost where a shorter lead time can reduce the that cost. For low value products, the cost will be low, a longer lead time is therefore acceptable. In the baseline, item groups have been sent by both sea and air. For the new profile, only one item group needs to be sent by air and the rest by sea. The item group sent by air, has a higher value compared to other item groups. This confirms the theory that items with higher value should be shipped with faster transport mode and low value items shipped by a mode with a longer lead time to have a low total logistics costs.

Even though the products characteristics for Eindhoven products are different from Svedala, the model still wants to send most items by sea. The reason for this is because sea has the cheaper transportation cost per item and that the product value density for Sandvik SC product is not high enough to justify air freight. For the average product to be shipped by air, some factors need to change. Either the transportation or the in-transit cost needs to change. An increased cost for sea or a decreased cost for air could change and impact the transport mode choice. For the in-transit, the change of product value density is unlikely but the holding rate set by Sandvik SC could change. The analysis for this is presented in section 7.2.

## 7.2 Model Stability

The distribution model is based on the parameters described by Sheffi et al. (1988); some that are fixed, and some that might change in the future. Before implementing any of the suggested changes, it is therefore of highest interest to see the robustness of the model, i.e. how big of an impact the potential changes in the variable parameters will have on the result from the model.

Table 25- The fixed and changeable parameters used in the stability analysis for the model.

Fixed Parameters	Changeable Parameters
Item Weight	In-transit holding rate
Item Value	Transportation costs

The parameters item weight and item value are assumed to be fixed. There is no information regarding product development which is why these parameters fixed. If new items are introduced in the product assortment, these would either be input in product groups where they belong, either an already existing product group or a new, depending on the product characteristics. Nonetheless, the model handles new items in the same way as already existing items.

The parameters that can vary, and thus can have an impact on the shipping profile, are the In-transit holding rate and the transportation costs.

### 7.2.1 In-transit Holding Cost

The in-transit holding rate for Sandvik CS is currently 8% per year. Described by Chopra and Meindl (2013), this cost refers to the costs appearing if items kept as inventory are to be unsold. This number is set by the top management team, and as the firm increases profitability and requires a higher return on equity, the cost for keeping items as inventory increases. Therefore, it is of interest to see the robustness of the unit cost freight model if the in-transit holding rate increases, i.e. to analyze if the model would suggest different modes of transportation for the aftermarket products if the in-transit holding rate was higher.

The factor the model bases the transportation mode on is cost. The goal is to minimize the logistics cost per item, which is the sum of the transportation cost and the in-transit holding cost. When the inventory holding rate changes, the transportation cost remains the same, which means that it is only the in-transit holding cost that will be affected by the changed inventory holding rate.

To illustrate the changes of transport mode depending on holding cost rate, an analysis of different holding costs is done, beginning with comparing to the baseline. The shipment profile for the aftermarket products when the inventory holding cost is 8% annually, is seen in table 26 and 27.

Table 26 - The baseline shipment profile for spare parts with an 8% annual holding cost rate.

<b>Shipment Profile - Spare Parts</b>										
<b>8% Holding Cost Rate</b>	<b>Item Group Major</b>									
<b>Weight Group</b>	<b>011</b>	<b>311</b>	<b>315</b>	<b>317</b>	<b>327</b>	<b>376</b>	<b>411</b>	<b>511</b>	<b>512</b>	<b>775</b>
<b>A0-0,1</b>	sea	sea	air	sea	sea		sea			
<b>B0,1-0,5</b>	sea	sea	sea	sea	sea		sea			sea
<b>C0,5-2,5</b>	sea	sea	sea	sea	sea		sea			sea
<b>D2,5-10</b>	sea	sea	sea	sea	sea		sea			sea
<b>E10-50</b>	sea	sea	sea	sea	sea		sea			
<b>F50-2550</b>		sea	sea	sea	sea	sea	sea	sea	sea	sea
<b>G2550+</b>										sea

Table 27 - The baseline shipment profile for wear parts with an 8% annual holding cost rate.

<b>Shipment Profile - Wear Parts</b>									
<b>8% Holding cost Rate</b>	<b>Item Group Major</b>								
<b>Weight Group</b>	<b>011</b>	<b>311</b>	<b>315</b>	<b>317</b>	<b>327</b>	<b>411</b>	<b>511</b>	<b>512</b>	<b>711</b>
<b>A0-10</b>	sea	sea	sea	sea		air	sea		
<b>B10-100</b>		sea	sea	sea	sea	sea	sea	sea	
<b>C100-500</b>		sea		sea		sea	sea	sea	sea
<b>D500-1000</b>		sea		sea		sea	sea	sea	
<b>E1000-1500</b>			sea			sea	sea	sea	sea
<b>F1500-2500</b>		sea					sea	sea	sea
<b>G2500+</b>		sea		sea		sea		sea	sea

As previously discussed in section 6.1, only one item group of the spare parts and one item group of wear parts should be distributed by air in the baseline when the holding cost rate is 8% annually.

When increasing the holding cost from 8% to 15% annually, changes in the shipment profile are visualized in tables 28 and 29.

Table 28 - The shipment profile for spare parts with an increase from 8% to 15% annual holding cost rate.

<b>Shipment Profile - Spare Parts</b>										
<b>15% Holding Cost Rate</b>	<b>Item Group Major</b>									
<b>Weight Group</b>	<b>011</b>	<b>311</b>	<b>315</b>	<b>317</b>	<b>327</b>	<b>376</b>	<b>411</b>	<b>511</b>	<b>512</b>	<b>775</b>
<b>A0-0,1</b>	sea	sea	air	air	sea		sea			
<b>B0,1-0,5</b>	air	sea	air	sea	sea		sea			air
<b>C0,5-2,5</b>	sea	sea	air	sea	air		air			air
<b>D2,5-10</b>	sea	sea	sea	sea	sea		air			sea
<b>E10-50</b>	sea	sea	sea	sea	sea		air			
<b>F50-2550</b>		sea	sea	sea	sea	sea	sea	sea	sea	sea
<b>G2550+</b>										sea

Table 29 - The shipment profile for wear parts with an increase from 8% to 15% annual holding cost rate.

<b>Shipment Profile - Wear Parts</b>									
<b>15% Holding Cost Rate</b>	<b>Item Group Major</b>								
<b>Weight Group</b>	<b>011</b>	<b>311</b>	<b>315</b>	<b>317</b>	<b>327</b>	<b>411</b>	<b>511</b>	<b>512</b>	<b>711</b>
<b>A0-10</b>	air	sea	sea	sea		air	sea		
<b>B10-100</b>		sea	sea	sea	sea	sea	sea	sea	
<b>C100-500</b>		sea		sea		sea	sea	sea	sea
<b>D500-1000</b>		sea		sea		sea	sea	sea	
<b>E1000-1500</b>			sea			sea	sea	sea	sea
<b>F1500-2500</b>		sea					sea	sea	sea
<b>G2500+</b>		sea		sea		sea		sea	sea

The results from the increase in holding rate makes the model suggests that 11 of the group categories of the spare parts and two of the wear parts should be transported by air when the holding rate is at 15%.

Additional changes in the shipment profiles can be seen in tables 30 and 31, when the holding rate is increased to 25%.

Table 30- The shipment profile for spare parts with an increase from 15% to 25% annual holding cost rate

<b>Shipment Profile - Spare Parts</b>										
<b>25% Holding Cost Rate</b>	<b>Item Group Major</b>									
<b>Weight Group</b>	<b>011</b>	<b>311</b>	<b>315</b>	<b>317</b>	<b>327</b>	<b>376</b>	<b>411</b>	<b>511</b>	<b>512</b>	<b>775</b>
<b>A0-0,1</b>	air	air	air	air	air		air			
<b>B0,1-0,5</b>	air	air	air	sea	sea		air			air
<b>C0,5-2,5</b>	air	air	air	sea	air		air			air
<b>D2,5-10</b>	sea	air	sea	sea	sea		air			sea
<b>E10-50</b>	sea	sea	sea	sea	sea		air			
<b>F50-2550</b>		sea	sea	sea	sea	sea	sea	sea	sea	air
<b>G2550+</b>										sea



Table 31- The shipment profile for wear parts with an increase from 15% to 25% annual holding cost rate.

<b>Shipment Profile - Wear Parts</b>									
<b>25% Holding Cost Rate</b>	<b>Item Group Major</b>								
<b>Weight Group</b>	<b>011</b>	<b>311</b>	<b>315</b>	<b>317</b>	<b>327</b>	<b>411</b>	<b>511</b>	<b>512</b>	<b>711</b>
<b>A0-10</b>	air	sea	sea	sea		air	sea		
<b>B10-100</b>		sea	sea	sea	sea	sea	sea	sea	
<b>C100-500</b>		sea		sea		sea	sea	sea	sea
<b>D500-1000</b>		sea		sea		sea	sea	sea	
<b>E1000-1500</b>			sea			sea	sea	sea	sea
<b>F1500-2500</b>		sea					sea	sea	sea
<b>G2500+</b>		sea		sea		sea		sea	sea

When the Inventory holding cost rate is 25% annually, 21 of the product groups for spare parts and still only two of the wear parts should be transported by air to reach the lowest total logistics cost.

Summarizing, the inventory holding rate was increased from 8% to 15% and 25% making more product groups change from sea to air. The conclusion can be stated the holding rate has a larger impact on the transportation mode for spare parts compared to wear parts. For spare parts, the model suggestion went from 2 to 21 product groups transported by air with the increase in holding rate.

The reason for the difference between the wear and spare parts is the product's value density, which is higher for the spare parts; both visualized in table 32 and 33.

Table 32- The product group value density for spare parts.

<b>SPAREPARTS Value Density, € / kg</b>										
<b>Item Group Major</b>										
<b>Weight Group</b>	<b>011</b>	<b>311</b>	<b>315</b>	<b>317</b>	<b>327</b>	<b>376</b>	<b>411</b>	<b>511</b>	<b>512</b>	<b>775</b>
<b>A0-0,1</b>	114,5	140,0	296,8	147,6	108,8		142,7			
<b>B0,1-0,5</b>	149,9	126,8	192,4	76,6	64,0		91,3			209,4
<b>C0,5-2,5</b>	98,2	134,9	248,8	86,2	277,0		150,5			165,8
<b>D2,5-10</b>	16,5	113,0	58,5	43,9	19,4		148,3			55,8
<b>E10-50</b>	58,0	55,1	29,4	47,0	19,6		149,8			
<b>F50-2550</b>		35,8	8,1	21,0	14,6	46,0	49,2	2,5	12,5	95,6
<b>G2500+</b>										76,3

Table 33 - The product group value density for wear parts.

<b>Wear Parts Value Density, € / kg</b>									
<b>Item Group major</b>									
<b>Weight Group</b>	<b>011</b>	<b>311</b>	<b>315</b>	<b>317</b>	<b>327</b>	<b>411</b>	<b>511</b>	<b>512</b>	<b>711</b>
<b>A0-10</b>	158,2	13,5	17,7	53,8		397,1	15,9		
<b>B10-100</b>		11,8	8,3	19,7	9,1	18,5	7,7	2,7	
<b>C100-500</b>		17,6		14,1		11,1	4,4	3,5	7,6
<b>D500-1000</b>		9,4		10,3		18,1	3,6	3,1	
<b>E1000-1500</b>			13,7			22,9	3,4	2,6	3,2
<b>F1500-2500</b>		15,0					3,1	2,5	3,8
<b>G2500+</b>		14,5		9,7		12,8		2,4	2,9

The reason for why the value density impacts the modal choice is because a high weight it implies a greater freight cost because freight cost is based on weight. The same principle can be applied for the product value. When the value of an item is high, the in-transit holding cost is high. This provides a large difference between the transportation modes. Air freight distribution implies a high transportation cost, but a low inventory holding cost due to short lead times, while sea freight provides low transportation costs for a long lead time. This balance between freight cost based on weight and in-transit holding cost based on value is the balance our unit transportation model is built on. If the in-transit holding cost reaches a certain point where that value becomes higher than the transportation cost, due to long transit times for sea, air is suggested as the cheapest transportation mode.

Analyzing the impact of the product value density and how the annual holding cost rate affects the model's transport mode decision provides insights into costs. Figures 32, 33 and 34 provide further explanation of how the transportation cost for both air and sea freight vary with the value density of the products. The results are in line with what Lovell et al. (2005) discuss in terms of how different product segments should be distributed with different supply chain designs and strategies.

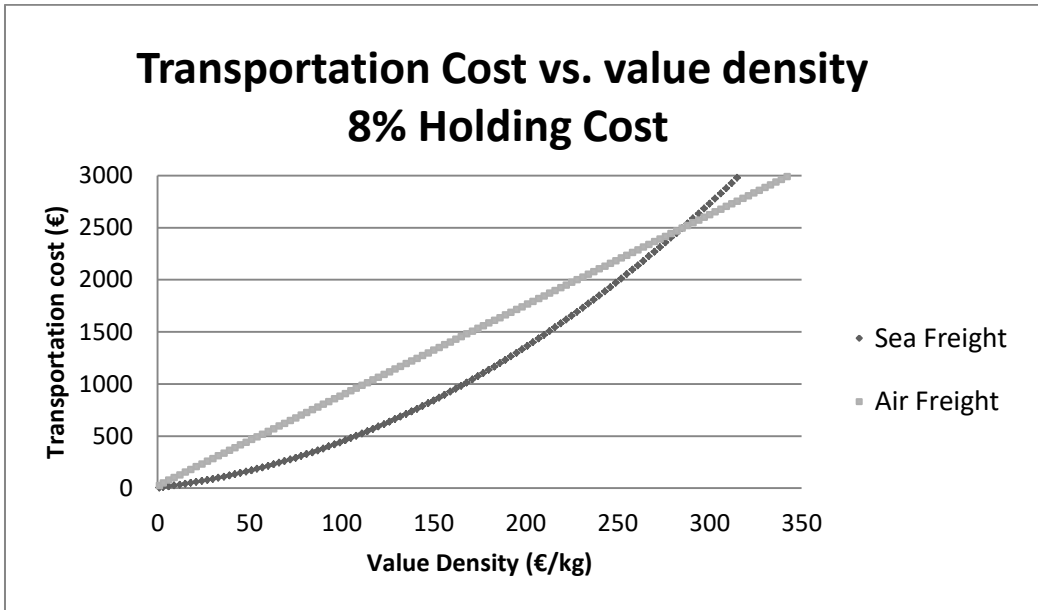


Figure 32- The transportation cost and product value density for air and sea freight with an annual holding cost rate at 8%. The intersection of the transport modes is the breakpoint of which cost is the lowest

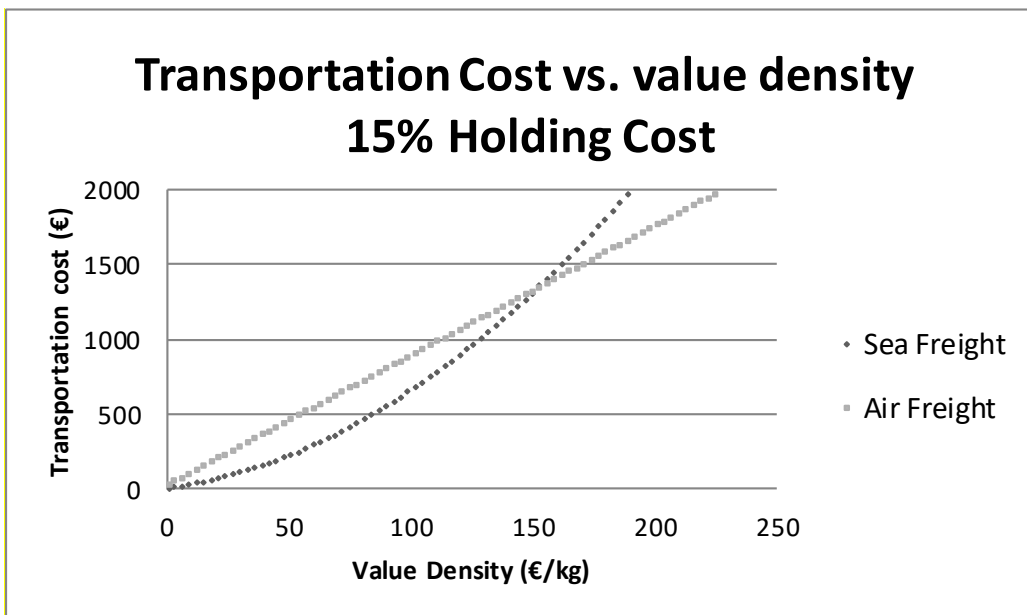


Figure 33 - The transportation cost and product value density for air and sea freight with an annual holding cost rate at 15%. The intersection of the transport modes is the breakpoint of which cost is the lowest

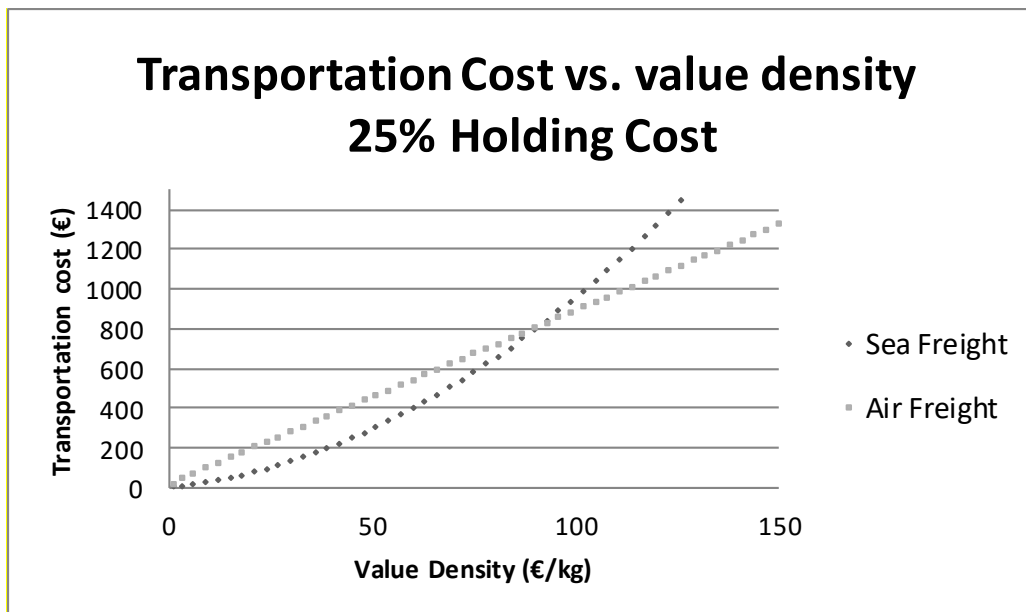


Figure 34 - The transportation cost and product value density for air and sea freight with an annual holding cost rate at 25%. The intersection of the transport modes is the breakpoint of which cost is the lowest

Shown in figures 32, 33 and 34, sea freight is the cheaper transportation mode to for products with a low value density, which is in line with the theory suggested by Lumsden (2012), who argues that sea freight should be used for low value products. The value density breakpoint, i.e. where the costs for sea freight and air freight intersect in the graphs, change as the holding rate increases. That is the reason for why the shipment profile varies with increased holding rates. With an inventory holding rate of 8% per year, the product value density breakpoint is 288 €/kg, with 15% the breakpoint is 144 €/kg and 87 €/kg when the holding rate is 25%. This implies that the higher annual holding rate, the more products will be above the product value density breakpoint. Therefore, those product groups should be sent by air to minimize costs due to the higher in-transit holding costs during sea shipments.

## 7.2.2 Transportation Cost

Analyzing the second variable parameter, transportation cost, it is of interest to see how the mode choice differs with changes in transportation costs. Stated in the theory, the cost for a container is dynamic and changes over the years. The container price changes due to many reasons. Two factors that influences are the new alliances created and the cost for fuel which will have an impact for Sandvik SC's long term decisions. Since choosing transport mode is a strategic choice that will last for many years, it is of interest to see what the results from the model would be with increased container cost. The analysis is done and presented in the same way as for the in-transit holding cost.

The baseline model suggests that most products should be distributed by sea when historical freight costs are used and inventory holding rate is 8%. When increasing the cost per container with 20%, 50% and 100%, the product value density breakpoints decreased from 288€/kg to 270€/kg, to 243€/kg and 201€/kg, in the same way it did when the inventory holding rate increased. This means that when the cost for sea freight increases, the model indicates that more product categories should go with air.

When the cost for the containers increase with 20% one additional product group, Item Group Major 327 weight group 0,5-2,5 kg, should be distributed by air instead of by sea. If the cost per container instead increased with 50%, one additional product group, Item Group Major 315 weight group 0,5-2,5 kg, should now also be distributed by air. If instead the cost per container would double in the future, only one additional product group should change transport mode from sea to air, Item Group Major 775, weight group 0,1-0,5 kg.

When comparing how the changes in inventory holding cost and cost for sea freight affect the model and its suggestion for transport mode, it is seen that the biggest impact comes from changes in the internal holding rate. This can be seen when comparing the changes in product value density breakpoints when changing the two variable parameters, seen in table 34 and 35.

Table 34- The decrease of the breakpoint between air and sea with an increase of holding cost rate.

Annual Holding Cost Rate Changes	8%	15%	25%
Value Density Breakpoint (€/kg)	288	153	93

Table 35 - The decrease of the breakpoint between air and sea with an increase in container cost.

Container Cost Changes	100%	120%	150%	200%
Value Density Breakpoint(€/kg)	288	270	243	201

As seen in tables 34 and 35, changes in the annual holding cost rate have a bigger impact on the product value density breakpoint than changes in the container cost. Even if the cost per container were to increase by 200% i.e. the cost would double, the impact on the model's suggestion on transportation mode is less than if the annual holding cost rate would increase to 15%.

This analysis concludes that the model is stable to changes in the variable parameters annual holding cost rate and the cost per container. However, when comparing the two parameters, it is seen that changes in the annual holding cost rate have a larger impact on the model than changes in sea freight container cost.

### 7.3 Model Credibility

When basing the results of a study on a model, it is necessary to evaluate the credibility of the data which the result is built upon, something that Law and Kelton (1991) stress with their three-step approach to ensure validity and credibility of a simulation model.

In this study, multiple data were required to build the model. Data that was collected either from datafiles, both internal and external, or from qualitative interviews or observations. Multiple data files were received and a large amount of time was spent on trying to find and understand all the received data. A reason for why the data was difficult to understand was because some of the files contained the same information but with different numbers. For instance, when analyzing the freight costs, the historical costs, i.e. the actual invoiced costs from current carriers to Sandvik SC differed to the internal shipment files from Sandvik SC's transport management system that include the freight costs.

After numerous discussions, the reason was found to be the consolidation among different business units within Sandvik AB, which previously has been described in chapter 4.2.5. There is no data of many of the shipments that was consolidated or how big part of the freight cost for those consolidated shipments that Sandvik SC paid for. The reason for the lack of consolidation data is because of the previous centralized organization, where the carrier did not have to distinguish what items belonged to what shipment or business unit, but instead charges the different business units based on historical weight averages. Several explanatory conversations with supervisors and current carriers had to take place before the data files could be understood and confirmed.

Additionally, the qualitative data collected through interviews and observations supported the data from the data files when needed, and the qualitative collected data is solely based on averages which raised question regarding its correctness. The products segmentation based on Item Group Major and weight groups have not been used before, and developing them based on average will make up for uncertain error margins. One example where the averages could create problem is when calculating the freight cost per item. Previously, all items have been charged based on their weight, but during observations at the production facility in Svedala, it was clearly noticed that even though the non-stackable wear parts had a chargeable weight higher than the unit weight, the containers leaving the warehouse with wear parts were full, but looked less than half empty. The lack of data over the dimensions of the items in the data forced us to solve the problem by interviewing the warehouse manager whose product knowledge and loading experience could help us set the number of units for each product category that could fit into a 40ft container. The lack of dimensions on the items has been discussed with managers at Sandvik SC during this thesis, and such project is in the pipeline to be carried out. The assumptions and problem solving methodology was confirmed and validated by supervisors at Sandvik and by the warehouse manager, which is in line with step one in three step model validation approach suggested by Law and Kelton (1991).

When the assumptions to solve the consolidation factors were, a sensitivity analysis of the assumptions were made. The baseline situation for the freight was entered in the model and compared to the actual historical costs, and output gave error margins below 10%. These error margins for the different routes were discussed with supervisors at Sandvik SC and confirmed to be low enough to ensure the credibility of the model's results. The sensitivity analysis

together with the comparison of the models results and the reality is in line with Law and Kelton (1991) second and third step to ensure validity and credibility of a simulation.

The baseline cost and the results with potential savings that the model showed were then compared to the results that came from the master thesis with focus on air freight. Even though their project only focused on items distributed from C1 and had taken a different approach when segmenting the spare parts and also included the three previous air freight alternatives, the results were notably alike. Their freight model gave close to the same shipment profile and indicated potential total savings of around 1,57 M Euro, which is not very far from our model who indicated savings up to 1,87 M Euro. Since the result from C1 thereby is confirmed with the Air project, the credibility of the results from 07 increases and are concluded to be legitimate. The confirmation of the result from this study with the results from the Air project is a triangulation, both methodological and data triangulations as described by Denscombe (2009). To use triangulation for the outcome does not only confirm the result and increases the quality of the project, but also tells that the right data has been used and that the made assumptions only have had a small impact on the final outcome.

## 7.4 Internal Effects When Changing From Air to Sea

For large organizations considering changing transport mode to reduce overall supply chain costs (Fisher et al., 2015), transport cost is an important factor. What other aspects need to be considered before taking action? What are the impacts of a low reliability? How does longer lead times for impacts stock levels and stock availability? These are two questions that were discussed after the result of the unit transportation model.

Changing transportation mode for most of the aftermarket products from air to sea freight implies other factors to consider than just unit transportation costs. Two important factors to consider are the longer lead times and the reduced reliability. Both factors can affect the suggested cost savings from the model, which makes them important to analyze when changing transportation mode.

### 7.4.1 Increasing Lead Times

For this study, the lead times for sea freight depend on the lane taken by the carrier and how the lead times are measured. The measurement for lead times was port-to-port since that is the most accurate measurement of only transit time (Harrison & Fichtinger, 2003). If door-to-door would have been used, the lead times would increase as they include all movements from customer to supplier. For Sandvik SC however, the DTD lead times is a more realistic interesting measurement as it includes the total transportation transit time. The model built for this study includes therefore only a part of the lead time, and prior to changing the transportation mode, the DTD and PTP lead times need to be compared for each transport mode to find any significant differences between the modes that might give other results than for PTP.

The chosen shipment route is also important when considering sea freight since it has an impact on the lead times. In contrast to air freight which uses direct shipments, sea freight shipments go by routes (Mulder & Dekker, 2013). Each route lane is set up by the carrier to increase efficiency by having more loading and unloading at several ports on the way between origin and destination. Relating to theory, this decreases cost but impacts the lead time. During phase 1 of the research execution, several alternatives of lanes were presented from different carriers. Each lane had the same origin and destination but different stops on the lane, thereby affecting the total PTP lead time. Several alternatives were considered but the carrier with the lowest lead times was chosen to be compared to the historical values for the model. This was also the route with the shortest number of stops. If another route from another carrier would be used, this would have impacted the results, since a longer lead time means that items are in-transit for a longer time which in the model has an impact on the in-transit holding cost, especially for high value items.

When changing transport modes, thus increasing the lead times, it is important to do the changes correctly and have a transition period where the usage of both modes is available when needed. When changing from a fast transport mode as air to sea freight with longer lead times, the change will have an impact the safety stock levels in the regional warehouses. If stock is replenished and reorder points are based on air freight lead times, replenishments are quick and frequent. Sea however, is generally less frequent and slower but can carry more goods. During the transition period from air to sea, the safety stock levels need to be increased



and reorder points adjusted to the longer lead times. The risk of not adapting inventory levels can lead to a decrease of stock availability, loss of sales and low customer satisfaction.

If changing transport mode to a cheaper alternative, leads to a lower reliability and missed sales. The missed sales can be far more critical than a low freight cost, as a missed sale is not just missed revenue but also an unsatisfied customer. To counter this reliability issue, it is important to investigate the issues and effects of what a low reliability could have on the business and distribution network. What are the risks of not arriving as planned? If reliability is an important issue, it might be more suitable to choose a more reliable transport mode even though it's more expensive.

Changing from air to sea leads to other uncertainties, depending on industry characteristics for sea freight. Due to the changes in the sea freight industry, where new shipping alliances will be formed during 2017, big uncertainties regarding the new routes and lead times have arrived and the effects from the new industry formation are still unknown. But what's sure is that a new set of alliances will change sea routes and ports, thereby impacting lead times and service levels. With already high congestions in ports (ESC, 2017) it is important to monitor and stay updated on the changes in the industry and to take necessary actions when needed. Example of actions could be to send rush air shipment if a container shipment is delayed. The changes in the sea freight industry will have an impact on the reliability for shipments.

#### **7.4.2 How Reliability Impacts the Modal Choice**

The strategic decision by Sandvik SC is to have a stable flow of replenishment with a low-cost transportation mode. The freight strategy is aligned with the distribution network design by moving low value products with a slower transport mode, which further is in line with the theory discussed by Lovell and Stinson (2005). For this issue, reliability is an important aspect to consider and not just to reduce transportation costs.

The low reliability of shipments, illustrated in figure 9 in section 3.3.2, is a factor that might result in less savings than expected when changing transport mode from air to sea. The transatlantic route between the US and Europe had a reliability of 65% on time (Drewry, 2017). As mentioned in section 3.3.2, congestions in the seaports can cause big problems with up to several weeks of delays.

The reasons for the low reliability and delays in ports are many (Notteboom, 2006; ESC 2017), but what's important for Sandvik SC to realize is how they will impact the freight strategy for the distribution network.

Delays in the ports are hard to forecast, which means that to successfully handle the situation when such potential problems appear, Sandvik SC needs to be updated of the current situation around the world to be able to adjust the distribution when required. Solutions to solve a problem with delays in a specific port can be to ship products from another port or to send products by air during this time.

To solve the problems with delays is critical since this eventually will lead to low or no stock availability in the regional warehouses. Not having enough stock will imply unfilled sales orders which can lead to cancelled orders or missed future sales, which on the bottom line will impact the profitability for Sandvik SC.

The poor schedule reliability in the sea freight industry will always be the case, but it is however something that Sandvik SC can have a say in since there is a choice to select carriers with a higher schedule reliability for each lane.

This could be an important decision for Sandvik SC since poor schedule reliability makes it hard for the people working at the regional warehouses to plan the receiving operations and for the sales people to know when the products will be available.

### **7.4.3 Consolidation Opportunities**

A synergy effect with the result from the model, that most items should be sent by sea freight, is the consolidation possibilities of items sent from Svedala and Eindhoven. Consolidation of items has the possibility to reduce transportation cost discussed by Capar (2013). One of the main reasons for doing a case study at Sandvik SC was to reduce transportation cost for replenishment orders. With the results, that the model suggested to ship more items with sea freight, the savings potential can be further increased with consolidation of sea shipments.

The warehouses in Svedala and Eindhoven are located in different countries but both use the Port of Rotterdam as the port of discharge for outbound shipments. If the door-to-port distance is synchronized to arrive at the same time from both warehouses, consolidation of the aftermarket products is possible. With a synchronized departure schedule from Svedala and Eindhoven, wear and spare parts can be consolidated into the same shipments leaving Europe for the different regional warehouses. Since wear parts have a large volume and are bulky while spare parts are small in comparison, they can all be consolidated into a 40ft. container. Items previously sent by air can be stuffed in the container going with sea freight. Since the freight cost per container is fixed, increasing the utilization and fill rate of a container will lower the total freight costs. The negative effects that this has on the distribution network is that it adds a level of complexity of merging shipments together at the consolidation point. In the end, however, this synergy effect can lead to further savings.

## 8 DISCUSSION AND RECOMMENDATION

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*This chapter is divided into two parts, where each part discusses the answers to the two research questions, and give recommendations for the success of the transition from air to sea freight.*

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### 8.1 Comparison Between the Model and the Actual Results

The first research question this study set out to answer was “*How can a company determine what transport mode to use in the distribution network with the objective to minimize freight cost?*”

To answer the first research question, a unit cost freight model was built and various freight scenarios were simulated until the freight cost for all aftermarket products to all regional warehouses were minimized. The output from the simulations was the foundation of the new shipment profile, which for each product group indicated what mode the group should be transported with to minimize the freight cost by balancing transportation and in-transit holding cost.

The model suggested that the transportation mode for both the wear parts and spare parts should be sea with only a few exceptions with air freight for product groups with a high product value density. The model suggested freight cost reductions for the spare parts of 65% and 20% for the wear parts, and the difference in freight reduction for the different types of aftermarket products is because of the previous freight strategy seen in the scatter plots in figure 23 and 24 in section 4.2.7.

Right away, the model and its results seemed reliable and was in line with early stated expectations set by the supervisors at Sandvik SC. Being able to triangulate and thus confirm the result from the model with the air project gave early indications that the simulations were reliable which increased its trustworthiness. After having presented the first results from the new shipment profile and the potential freight savings for Sandvik SC, the logistics department started to change transportation mode from air to sea. The change started with the spare parts, specifically the spare parts in Item Group Majors with higher weight groups product groups because that is where the biggest savings could be found. The transition period from air to sea freight was short and the first results could be seen in April 2017 which implied freight cost reductions of 54%. When comparing the freight cost savings that Sandvik SC experienced during the month of April 2017 to the suggested savings from the unit cost freight model of 65% for the spare parts, the results are concluded to be correct. The difference in the savings are based on the spare parts with a lower weight category that still have not transferred from air to sea freight, which entails that if all product categories would have been sent according to the suggested shipment profile, the savings would have been even closer to the simulated 65%.

The decision to not include the stationary inventory holding cost was taken early in the project because Sandvik SC wanted the model to only be about the in-transit distribution of the aftermarket products and thus get the shipment profile only based on the freight. Aligned with this thought is the results from the transport mode change coming from Sandvik SC who only has measured the reduction of transportation cost and thus not included the increased tied up capital the model change will imply. Because Sandvik SC only measured the savings on the freight in the same way as the unit cost freight model did, the savings are based on the same parameters and therefore gave similar results.

Because of the directives given by Sandvik SC, no deeper analysis has been carried out in this study in regards to how the saving would have been affected if the stationary inventory holding cost from the regional warehouses would have been included in the model. However, because of the longer lead times and lower reliability for sea freight, the inventory levels and safety stocks at the warehouses would have to be increased to enable to meet customer service levels and thus imply a higher cost of tied up capital through the distribution network. This means that if the holding cost in the warehouses would have been included in the model, the total savings for the new shipment profile would have been lower than what the model indicates. Even though the change from air to sea freight has already been carried out for most aftermarket products, the next step for Sandvik SC should be to include the stationary holding cost when measuring the savings from the change to get the total result.

With this in mind, the answer to the research question is found in the creation of the unit cost freight model based on the total logistics cost suggested by Sheffi et al. (1988). Hence, using linear programming and simulation of the freight costs is a valid solution for companies to determine the transportation mode for the products in the distribution network when the goal is to minimize freight costs.

The recommendation for Sandvik SC is to follow the new shipment profile and continue the transition from air to sea freight for the remaining spare parts and the small amount of wear parts that are yet distributed by air freight. Additionally, Sandvik SC is recommended to start measure the increasing costs for tying up extra capital in the warehouses due to the higher stock levels of aftermarket products to hedge for the lower reliability of sea freight. To include the stationary holding costs would enable Sandvik SC to get a better overview of how the activities in the distribution network impact the organization.

## 8.2 Factors to Consider When Changing Transportation Mode

The second research question defined in the study is: *What factors are important to consider when changing transportation mode from air to sea freight?*

Identifying these factors was done using different methods. The unit freight cost model was a method to determine how the cost factor influences modal choice. Other factors were recognized while observing, interviewing and participating in the change from air to sea during the case study at Sandvik SC. Three factors recognized were

- Reliability
- Transit Times
- Supply Chain Synchronization

Reliability was an issue since sea freight has a lower reliability than air. The transition phase is a crucial phase with many new administrative changes due to the new freight strategy. During the transition phase, it is important to be flexible and to adapt quickly to changes. Changing from air to sea is changing from a transport mode with high reliability and low lead times to mode with long lead times and low reliability. Adding flexibility can counter the effects that low reliability can cause, an issue that has been addressed at Sandvik SC. The organization assigned a person with the authority to change shipment mode and plan shipments without asking for permission to managers for every decision. Since the new directives are to distribute the aftermarket products by sea, changing to air for certain items requires confirmation. Some customers have not been accepted the new longer lead times because it is more difficult for them to plan against. They want their shipments like before. This is where the flexibility comes in. The person with the authority can then change to air for those specific customers or that product group. This keeps customers satisfied during the transition phase

Another advantage with a responsible person to add flexibility, is to avoid further reliability issues. Issues that can be caused by arriving too early or too late against the planned arrival time caused by delays in ports, customs, weather conditions etc. If something happens, the person responsible can send rush air shipments to deliver the goods so customer do not have to wait for the sea shipments to arrive late.

To further adapt to the reliability issues, transport mode change cannot be done overnight but needs to be a process. Explained in the theory, three primary factors are reliability, transit times and cost. These can all be changed depending on the chosen carrier. A part of the study, which was excluded from the scope after the results from the model, was to find a lead logistics partner to manage the freight and thus select appropriate carriers for the sea freight distribution. Since reliability is a critical success factor for Sandvik SC, carriers with higher reliability is decided to be prioritized even if the cost is higher. If the reliability can be kept high but at a higher cost, then gradually the cost can be reduced over time when the changes of transport mode have had an effect. Eventually, the goal is to change most items to sea, but it takes time. Until then a flexibility of using both transport modes is necessary.

The decision to change transport mode needs to be synchronized with the supply chain and align with the industry characteristics (Ke, Windle, Han & Britto, 2015). Changing from air to sea freight leads to larger batch sizes and higher stock levels to compensate for the longer lead times and poor schedule reliability. Increasing batch sizes and stock levels needs to be matched with other parts of the supply chain, not just the own distribution network. For Sandvik SC, with many external suppliers for the aftermarket products, their actions impact supplier's reactions. If Sandvik SC starts with a new ordering pattern by increasing stock and batch sizes to fill containers instead of small air shipments, it needs to be communicated to the

suppliers. If the suppliers don't have the capacity to make the necessary changes to adapt, they will not change. Their shipment levels might not change or not be in line with what Sandvik SC wants. In the end, the decision to change mode might not be as successful as intended.

To counter this issue, communication between supply chain stakeholders is important. Before changing transportation mode based on solely costs, a discussion with suppliers is needed to understand if they have capacity for a different ordering pattern. The result from that discussion should be the time horizon of when to implement the transport mode changes.

The recommendation to Sandvik SC is to have a transition period of implementing the change from air to sea. During the transition period, the selected carrier should focus on reliability over cost for sea shipments. Meaning that carriers with a higher cost but more reliable should be prioritized. This is done to still meet customer needs while changing from a high to a low reliable transport mode. Over time, when the new freight strategy is fully implemented, further cost reduction programs can be performed. Furthermore, air shipments should be kept during the transition period. It is important to be ready to send rush shipments to counter the effects of bad reliability and long lead times.

Also, after the transition period, consolidation opportunities should be considered to reach further cost savings. This is applicable since the new strategy should use sea shipments for both C1 and 07, thereby, increasing the fill rate in the standardized containers.

### **8.3 Next Steps**

After the distribution network has been stabilized and regained trust, there are actions that Sandvik SC can take to further improve the distribution network and reduce freight costs. First, the consolidation opportunities of wear and spare parts discussed in section 7.4.3 should be further evaluated. Such consolidation could solve the problem with low fill rate due to non-stackable wear parts and thus have a great freight cost saving potential. Secondly, opportunities to source items from external supplier locally should be evaluated. Instead of sourcing everything to C1 and then distribute the goods within Sandvik SC's distribution network, each regional warehouse could source locally within its region if the supplier is located there. This would reduce number of shipped items and thus logistics costs. Finally, inventory levels need to meet demand and accurate forecasts need to be in place. This will make it easier to plan and synchronize the distribution network.

### **8.4 Contribution to Research**

This study confirms the statements made by Lovell and Stimson (2005) and Ke et al., (2015), who argue that transportation mode is not only a tactical decision to ship goods, but also a strategic decision that have the possibility to reduce cost and gain competitive advantage.

Meixell and Norbis (2008) argue that there exist various models and approaches to simulate transportation cost, all with different factors and approaches. This study confirms that the combination of the simulation method from Law and Kelton (1991), linear programming and the formula for total logistics cost suggested by Sheffi et al. (1988) can serve as a decision model for choosing transport mode.

Furthermore, during the case study, both short and long term factors were identified that coexist with transportation mode choice, like reliability and supply chain synchronization. Factors that are known from earlier but still important. These factors need to be taken into consideration and further evaluated to make the transportation mode choice easier for companies that have never done it before.

### **8.5 Further Research**

For future research, the study could be improved by including the inventory levels in the model, shipping frequency and the environmental effects of each mode. Including inventory levels would imply that the all the total logistics costs formula would be included and make it more broad and applicable to other cases. For this study, the shipping frequency was fixed and cost was the only factor considered. To make it more applicable to other situations, adding a frequency variable could be included the choice of transport mode. The frequency could be matched with inventory levels and demand so that the right shipment, is sent with the right mode and arrive at the right time, with the lowest cost.

The environmental aspect of the transport modes is an interesting area for future research and could be included in future models. Each transport mode has different emission levels and if the value of the emission levels could be incorporated in the model it would give an extra dimension. For the case at Sandvik, there was no information if Sandvik or their customers valued lowered emissions. However, this is sure to be area of interest for them in the near future if not now already.

## 9 CONCLUSION

To reach competitive advantage through high customer service with low costs, the supply chain needs to be aligned with the firm's products and overall strategy. (Lovell & Stimson, 2005). For global companies, the logistics cost is a large part of the total supply chain cost (Zeng & Rossetti, 2003), and a way of reducing the logistics cost is to manage the freight cost, which stands for most the total logistics cost (Ke et al., 2015). Not only is transportation a major cost for companies, but it is also important since it is directly linked with customer satisfaction and efficiency, thus the competitive advantage (Lovell & Stimson, 2005). To choose the right mode for transportation is therefore a great strategic decision based on factors such as costs, service levels, reliability and transit lead times (Meixell & Norbis, 2008).

An organization that experienced high logistics costs is Sandvik SC, a business unit part of the industrial organization Sandvik AB. For Sandvik SC, there existed no freight strategy for the aftermarket products spare and wear parts, which implied high freight spendings and poor efficiency in the distribution network.

This study set out to create a unit cost freight model to aid in the decision regarding what transport mode to use for the products in the distribution network to reduce freight cost. The model is based on the formula described by Sheffi et al. (1988) by using on linear programming and simulations, and the input is product value, product weight, transportation cost and in-transit holding rate. The output from the model is the shipment profile, which is a matrix that gives the user an easy indication of what mode of transportation the product category should be distributed with to minimize the freight cost. Additionally, the model suggested the potential cost savings if the new shipment profile would have been used.

The model indicated that for Sandvik SC, almost all products should be transported by sea freight, which would imply freight cost reductions of 65% for the spare parts and 20% for the wear parts. When comparing the savings indicated by the model and the real savings measured by Sandvik SC after implementing the new shipment profile for most of the spare parts, the savings was calculated to 57% freight cost reduction. The outcome from the new shipment profile is well in line with theory suggested for products with similar characteristics (Lumsden, 2012) and the cost savings suggested by the model is close to the real savings experienced by the case company Sandvik SC.

Additionally, the study discusses the effects that appear when changing transport mode from air to sea freight, and argues that the most important actions a firm needs to take when changing transport mode is to do so during a longer transition period to ensure product availability throughout the implementation. During the transition period, sea freight carrier with high reliability should be prioritized over cost to ensure a successful mode change. Furthermore, the importance of still having air freight as an alternative to sea freight is stressed, where air freight should be used in case of long delays or poor schedule reliability for sea freight to ensure high customer service.



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## APPENDIX A

Below is a list with the people who have contributed to the study through meetings, interviews, conversations and workshops. The names are anonymous due to confidentiality reasons and only their titles are presented. The four 4PL companies that have been included in the study and contributed with valuable insights, but are also kept anonymous. They are named A, B, C and D for confidentiality reasons.

<b>Company</b>	<b>Title</b>
Sandvik Crushing & Screening	Logistics Director
Sandvik Crushing & Screening	External Logistics Manager
Sandvik Crushing & Screening	Logistics Developer
Sandvik Crushing & Screening	Global Inventory Specialist
Sandvik Crushing & Screening	Warehouse Manager
4PL Company A	Vice President, Global Account
4PL Company A	Key Account Manager Sandvik Group of Companies
4PL Company A	Director Ocean Freight
4PL Company B	Global Sales Executive
4PL Company B	Regional Manager Network Solutions
4PL Company B	District Sales Manager
4PL Company B	Logistics Engineer
4PL Company C	Key Account Manager
4PL Company C	Procurement Manager Sweden
4PL Company D	Business Support Director
4PL Company D	Strategic Account Manager