A cost-perspective on redistribution of aftermarket parts at Sandvik Stationary Crushing and Screening

Master's Thesis

MIOM05 - Division of Production Management

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Master's Thesis in Production Management

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Acknowledgement

This thesis concludes the author's Master of Science at the Faculty of Engineering at Lund University.

I would like to extend my thanks to Sandvik SRP and their division Crushing and Screening for the opportunity to do my master's thesis for you. A special thank you to David Johansson for your commitment and guidance during this project, it would not be possible without you.

I would also like to thank Danja Sonntag, my supervisor during this project, for her expertise and support throughout the course of the project.

Finally, I would like to thank my family and friends who have throughout my studies supported me and been there for me during trying times.

Lund, May 25, 2024

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Abstract

Manufacturing companies face mounting pressure to reduce inventory levels because of high interest rates, while simultaneously meeting an increase in customer demands for shorter lead times and customizable products, increasing strain on supply chains. The logistics department (SMCL) within Sandvik, the investigated company, operates several warehouses around the world. Their supplier network is built up by a central warehouse located in the Netherlands which supplies local distribution centers spread out across the globe. For Sandvik's aftermarket parts, there has been a build-up of overstock in the different distribution centers. Because of this, SMCL is currently investigating how redistribution of the overstocked aftermarket parts back to the central warehouse could alleviate some of the pressure. Based on this, the purpose of this thesis is to analyze and define the major cost bearers associated with the redistribution of aftermarket parts, and to analyze if redistribution from Sandvik's regional warehouses back to the central warehouse would decrease their stock levels throughout their warehouses. Based on the analysis, a framework will be presented that will aid Sandvik in understanding which components are most advantageous from a cost-perspective to redistribute. As a foundation for the framework the following three questions will be answered.

1. Does redistribution back to the central warehouse increase the probability that an item will be sold?
2. What are the major cost-bearers associated with redistribution within SMCL?
3. In what situations is redistribution advantageous from a cost-perspective?

The employed methodology for this thesis was a case-study as it offers an in-depth examination of a specific phenomenon. In conclusion, it could not be found that an arbitrary item in the centrale warehouse had a higher probability of being sold than the same item would have in a distribution center. Furthermore, the major cost-bearers for redistribution were found to be the logistics cost, the fixed order handling cost and the inventory carrying cost. Lastly, two criteria were found for a redistribution to be advantageous from a cost-perspective. Based on these two criteria and the analysis of the redistribution costs, a framework was constructed.

List of used abbreviations

BA	Business area
CW	Central Warehouse
C&S	Crushing and Screening
DC	Distribution center
MOT	Mode(s) of transport
OSMI	Obsolete and slow-moving inventory
PU	Production unit
SA	Sales Area
SMCL	Sandvik Mining and Construction Logistics
SRP	Sandvik Rock Processing Solutions

Table of contents

1 Introduction

The following chapter aims to provide the reader with a background and a brief introduction to the studied company. It will also contextualize the problem and then present the research questions.

1.1 Background

In today's global market, the demand from customers is steadily rising. They expect more personalized choices, faster delivery, and higher product availability. This places significant pressure on companies to optimize their logistical operations to meet these demands and stay competitive. In addition to this, interest rates are currently high which means that there has been an increase in the cost of keeping items in stock. Furthermore, the unpredictable shifts in demand, inconsistent lead times, and global uncertainties introduce further complexity and variability into logistical processes.

To address these challenges, there is a clear imperative to keep inventory levels as low as possible without detrimentally affecting overall business performance. Holding excess inventory drives up costs, while inadequate inventory levels can lead to lost sales or extended customer waiting times, damaging the company's reputation, and potentially reducing revenue. Achieving the optimal balance in inventory levels is therefore essential for maintaining operational efficiency and meeting customer expectations.

1.2 Context

This thesis will be conducted in collaboration with Sandvik AB. Recognized as one of Sweden's largest companies, Sandvik employs around 40,000 people globally. In 2021, the company generated a revenue of 99 billion SEK and a profit of approximately 14.5 billion SEK. Sandvik primarily operates in the manufacturing and construction sectors, focusing on the mining and quarry industries. Additionally, the company is involved in metalworking, additive manufacturing, and material technology.

Sandvik's operations are divided into three business areas (BAs): Sandvik Mining and Rock Solutions (SMR), Sandvik Rock Processing Solutions (SRP), and Sandvik Manufacturing and Machining Solutions (SMM). This thesis will specifically focus on the Sandvik Rock Processing Solutions area, particularly the Stationary Crushing and Screening (C&S) division, in charge of supplying crushers and screeners to their customers.

The aftermarket parts make up a significant percentage of the revenue generated by C&S and will be the sole focus of this thesis. The aftermarket parts, consisting of wear parts and spare parts, are mainly produced by Sandvik themselves in Svedala. They are sometimes extremely time-sensitive for the customers. Not getting these parts in time could lead to their entire mining site being shut down. To tackle this problem, Sandvik has a strategy of having these critical components close to the customer based on forecasts and the criticality level of the items. The more critical they are, the more important it is to store them close to the customer. They achieve this by having three layers of so-called distribution nodes. The first layer is the central warehouse (CW) located in the Netherlands. Almost all products Sandvik produces go through this hub. The next layer is the distribution centers, which are mid-size storage facilities used as a buffer for varying customer demand. This is needed because predicting precisely when and where products are needed is impossible. To counteract this issue, Sandvik has strategically placed out several distribution centers in most continents to store critical components close to the customers. The last layer is the sales areas (SA). Their role is to be in contact with Sandvik's customers and handle all the incoming orders. Most countries that have a Sandvik customer have a SA handling their orders and business relations. While the main objective for the SA is to improve business relations and sell as many products as possible to the customers, they also have a small inventory for critical customer specific products to minimize lead times of these products.

1.3 Problem formulation

Three different owners of the products throughout the supply chain have led to differing opinions regarding optimizing the inventory levels. SMCL wants to minimize their costs as much as possible by minimizing stock levels, while the SAs want to maximize stock close to them so that they can provide better service to the customers and sell more products. In the past, this hasn't been an issue for the company as a compromise was struck between the SA and SMCL on how much should be stored in the CW and how much should be stored close to the customer. However, this compromise has led to build-up of stock in the distribution centers as the SA have requested more items close to them than they have managed to sell. With the recent increase in interest rate, SMCL has prioritized minimizing their stock levels throughout their operations to decrease their operational costs.

Therefore, this thesis aims to identify and investigate the major cost bearers for redistribution within C&S on wear and spare parts. Based on the investigation, a framework will be presented that will aid Sandvik in understanding the cost perspective on redistribution when deciding which components should be moved. The ideal outcome would be that the framework could be used as a reference when the SAs and SMCL create their policy of what items should be redistributed. This will save time as individual components won't have to be discussed between the two parties and will help the company solve their problem with excessive stock within C&S. To create a basis for the framework, this thesis aims to investigate and answer the following three questions.

(1) *Does redistribution back to the central warehouse increase the probability that an item will become moving?* Since the overarching goal is to reduce excessive stock, the entire situation needs to be analyzed from an inventory-management perspective to understand if it is advantageous or not to send back products to the CW.

(2) *What is the major cost-bearers associated with redistribution within SMCL?* The items analyzed are the aftermarket parts which consist of two different item-groups, the wear parts, and the spare parts. These parts have quite different characteristics and will thus be differentiated in the analysis.

(3) *In what situations is redistribution advantageous from a cost-perspective?* By understanding the costs of redistribution, an analysis can be conducted as of when it will be advantageous from a cost-perspective to redistribute. The constructed framework is meant to visualize the different scenarios when this is the case.

1.4 Disposition

The thesis begins with a methodology chapter, discussing the used methodical approach. This is followed by an introduction to the studied company which aims to provide the reader with relevant background information and what parts of their operations this thesis will investigate. A theoretical background comes next, that will act both as a bridge between Sandvik's current inventory management strategy and applicable theories, and introduce concepts relevant for the analysis. Next, an analysis of the gathered data is provided. Based on the results from the analysis, a framework and conclusions will be presented in separate chapters.

2 Methodology

This chapter begins with a discussion of the methodical approach to this project. This is followed by a discussion of the reliability, validity and replicability related to this thesis.

2.1 Chosen strategy

Determining the research approach and strategy is essential for establishing the foundation of a thesis. Projects can serve various purposes, such as being descriptive, explanatory, or problem-solving (Höst et al., 2006). Consequently, this section aims to justify the use of the strategy deemed most appropriate for this specific thesis which is a case study. A case study offers an in-depth examination of a specific phenomenon, with conclusions generally confined to the particular case under study. They are also commonly used by organizations to understand operational practices (Höst et al., 2006). Since the goal of the project is to analyze the cost-perspective of redistribution for Sandvik's overstocked items, it can be seen as an in-depth analysis of their inventory management. The situation is also confined, as it is Sandvik's specific redistribution costs that are investigated. It was hard at the beginning of the project to know what questions to ask, since it was impossible to know what type of data that would be available. Because a case study allows the focus and methods to be adjusted as new insights emerge, it was deemed most appropriate for this thesis. The results from this case-study could be used by Sandvik to conduct an action research of their own, which because of time-constraints is outside the scope of this thesis.

2.2 Chosen data collection methods

For this project, data will primarily be collected through archival studies and analysis due to time constraints, which prevent the collection and summarization of new data. Pre-existing data will be validated before analysis to ensure that the correct phenomena or attributes relevant for this thesis are measured. The archival data mainly consists of reports generated in Power BI, a business analytics tool by Microsoft that enables users to visualize and share insights from their data, by the department to benchmark their operations. Power BI was not fully integrated into the department's operations, which meant that Excel files were used as a complement to the Power BI reports. Limited observations, such as participation in meetings, will supplement the archival data. Additionally, semi-structured interviews with relevant employees or representatives will be conducted to understand the decision-making processes. Semi-structured interviews follow predetermined questions but are mainly used as a guide for the interview and the course of the interview can change as it moves on (Höst et al., 2006). Allowing the interviewed subject to fill in the gaps missed in the questionnaire allows for more information to be gathered, which is why the more open semi-structured interview form was utilized. Both qualitative data from interviews and observations, and quantitative data from archival sources, will be utilized. The qualitative data will mainly be used to understand how the division C&S works and operates and to get an overview of the problem, which will allow the quantitative study to be more aligned with what is intended to be analyzed.

2.3 Project procedure

Having a procedure when doing a project of this magnitude can be seen as advantageous since it contains a sequence that can be followed throughout the project. The procedure followed when doing this thesis was based on the operations research modeling approach which is defined as follows (Hillier & Lieberman, 2010):

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

Operations research models provide a structured framework for analyzing complex decision problems and deriving optimal solutions, thereby enhancing efficiency and effectiveness in various operational contexts (Hillier & Lieberman, 2010). However, because this project is a case-study and is meant to describe observed phenomena and not implement any solutions, modifications were made to this procedure. The procedure adopted for this case is described below:

1. Define the problem of interest and gather relevant data.

2. Analyze the data and formulate the objective function as to when redistributions are advantageous from a cost-perspective.
3. Calculate the redistribution cost and the opportunity cost for redistribution.
4. Construct a framework which shows when redistributions will be advantageous from a cost-perspective.
5. Suggest framework to company officials.
6. Refine and iterate the framework.

In the modified procedure, the first three steps are similar to the operations research approach, except it is more specific to the problem this thesis is investigating. The three last steps are heavily modified as the result of this thesis is a framework to understand when redistribution is advantageous from a cost-perspective, and not a decision model that should be implemented by Sandvik.

This procedure is used as a baseline for the thesis. While the problem was clear from the start of the project, knowing what type of data that was available to analyze the problem was impossible. This meant that the described procedure couldn't be followed in a linear way, and that each step had to be iterated several times to consider aspects that were previously unknown. However, by having a procedure as a baseline, the next step is always defined which facilitates a smoother execution of the project.

2.4 Reliability

Reliability refers to the consistency and stability of the results obtained from a study over time, and if the same results would be reached if the project was done by a different person. High reliability implies that the results are replicable and not significantly influenced by random variations or external factors (Höst et al., 2006). The data used for the analysis of the redistribution cost was extracted from reports that were originally intended for other uses, which in turn reduced the bias of the results. Two strategies were applied to increase reliability. The first was to always validate the assumptions made with company representatives. The second strategy was to always use the most conservative numbers for the analysis of the redistribution cost. If Sandvik were to act and redistribute items based on the results from this thesis, it should never be more disadvantageous than what is presented here.

2.5 Validity

Validity refers to the degree to which what is intended to be measured aligns with what is actually measured (Höst et al., 2006). Measuring the correct things could be hard when making a case-study for a company because the numbers generated from reports that are used in the analysis are hard to validate, since an inside perspective is missing. To validate the results and analysis as much as possible, they were discussed with company representatives throughout the project. Another aspect of validity is that made connections that are expressed should be as trustworthy as possible. An example of this would be stating that transportation costs are higher for wear parts than spare parts because they weigh more in relation to their value. However, in this thesis, these types of statements are always backed up by data and a confirmation from a company representative to minimize the risk of a phenomenon being caused by something else than what is stated.

2.6 Replicability

Replicability is the ability to repeat a study's processes and methods to obtain similar results in different contexts and by different researchers (Höst et al., 2006). Due to the nature of a case study, the results and conclusions may not be replicable in other situations. This is not necessarily because of the phenomenon being studied but due to variations in external and internal organizational factors over time. The cost of transport could drastically change because of external factors, making the presented results inapplicable in the future. As an example, major congestion in Europe's ports could change the transportation costs by sea, significantly altering the transportation costs. Additionally, if the same study was conducted within a different organization, the results might not be applicable due to the unique characteristics of each company's supply chain. While doing a case study at another time or at another organization might yield similar results, assumptions, and conclusions, this is not guaranteed and should be approached with caution.

3 Introduction to Sandvik and C&S

This chapter aims to introduce Sandvik by describing the organization, the supply chain, and the business areas. The provided information is based on their website and discussions with company representatives.

3.1 Background and business areas

Sandvik AB is a manufacturing company, founded in 1862 in Sandviken. Today, Sandvik is one of Sweden's largest companies in terms of revenue, 99 billion Swedish Crowns as of 2021. Their main industry is within the mining and quarry sector, complementing these with also focusing on metalworking and material technology. Based on the industries, Sandvik is divided into three different business areas (BA). They are listed below.

- SRP - Sandvik Rock Processing Solution
- SMR - Sandvik Mining and Rock Solution
- SMM - Sandvik Manufacturing and Machining Solutions

A core concept for Sandvik since 2016, is that each BA acts independently. In practice, this means that the operational choices within each BA are decided by themselves, giving a lot of freedom but also responsibility for their own performance and actions. This was done to emphasize the customer focus Sandvik has by moving the decisions closer to the customer.

The focus on this thesis will be on SRP. Within SRP, there are several divisions. These being Stationary Crushing and Screening (C&S), Mobile Crushing and Screening, Attachment Tools and Shanbao. The scope of this thesis is the division of C&S, which means that all analysis will be conducted on this division. C&S has their office in Svedala, Sweden, where much of the production and many of the support functions are located.

3.2 C&S product and component overview

C&S mainly provides products in two categories, these being Crushers and Screener. Crushers are the main category, involving different types of products that can break down rocks of different sizes into smaller pieces. The outside of a crusher can be seen in Figure 1 below. As a complement, the screeners act as sorters which can sort the crushed rocks of different sizes. The crushers are made of different components, which Sandvik has classified into different categories. These being, major components, key components, wear parts and spare parts.

Figure 1: A cone crusher of model CH420 (Sandvik Group, n.d)

3.2.1 Major Components

The major components are the base components and act as the foundation of the crushers. They are the largest and most expensive parts. If these were to break down, it is often advantageous for the customer to purchase an entirely new crusher instead of trying to repair the old one. Because of this, coupled with the parts being extremely expensive, they are only produced when a customer order is received and are not kept in stock.

3.2.2 Key Components

The key components are on the other hand much smaller but play a crucial role in the functionality of the machine. These rarely break down because they are designed to be more robust. Since they are smaller and less expensive, they are being stored in case there is customer demand. Based on the forecasted amount of the key components, they are divided into two subcategories. These being service items, and extended service items. The service items are key components with a forecasted annual demand above one. If the component has less than an annual demand of one, it will be classified as an extended service item.

3.2.3 Spare parts

The spare parts account for 97% of all stored units from C&S aftermarket section. If a machine breaks down, the spare parts are the parts that are used when the machine is repaired. Spare parts vary in size and price, as they range from nuts and bolts to larger components. C&S has thus divided the spare parts into three subcategories. These being cheap spare parts, mid-range spare parts and expensive items. The cheap spare parts include products such as bolts and nuts. While they do not have a steady demand, they are classified as commercial items because they require low investment and do not take up much warehouse space. The expensive items are spare parts that Sandvik does not currently store, because they either have a small demand for these items from the customers or that they are too costly to store. These parts therefore have a policy of being sourced to order. The mid-range spare parts are, according to Sandvik, everything else that does not match any of the two other subcategories. When storing these items, Sandvik relies heavily on forecasts since having high inventory levels would increase costs considerably.

3.2.4 Wear Parts

Since the crushers operate continuously in a stressful environment, some parts of the machine are susceptible to wear. The wear parts only include a few large parts that have an estimated operational time before they break down based on tests and experiences. While it is hard to exactly determine how often a breakdown occurs for these parts because of external factors, they have a much more stable demand compared to spare parts. This results in a lower risk for Sandvik to store and provide these items to the customer, which is why the margins for wear parts are much lower than for spare parts.

This thesis is done for the aftermarket subdivision of C&S, meaning that the wear and spare parts will be the sole focus of the analysis. Since these component groups are fundamentally different, the resulting framework will differentiate them accordingly.

3.3 C&S's supply network and market

C&S's current supply network is built up by four interdependent layers before reaching the end customers. A simplified visualization of the supply network can be seen in Figure 2 below. The following subchapters will describe each layer in more detail.

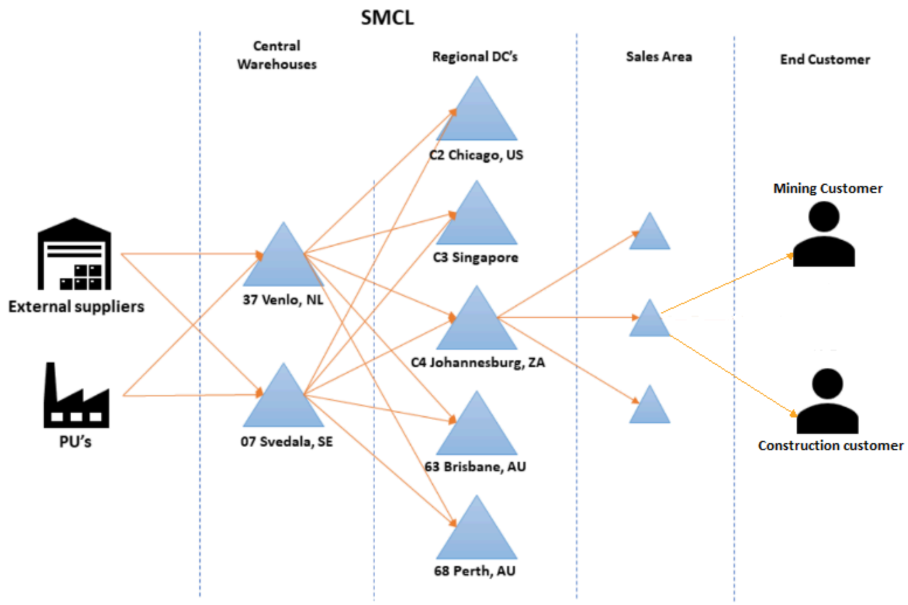

Figure 2: A simplification of C&S's current supplier network

3.3.1 External suppliers and PU

The products C&S is providing to the customers are either produced by Sandvik with their own production units (PU) or are acquired from external suppliers. This is the first layer in C&S's supplier network. Sandvik currently operates three different PUs. One is located in Svedala, Sweden, another is located in Pune, India, and the last is located in Shanghai, China. The three different PUs produce different items. This has resulted in a situation where the PU in Svedala is the only supplier of wear and spare parts for C&S's products and will thus be the only PU that is discussed here. The PU in Svedala has its own foundry, where steel for their products is cast, which has allowed Sandvik to capitalize on many value adding activities such as painting, testing and assembly. Government regulations dictate how much steel a foundry is allowed to produce every year based on size and environmental impact. This means that the foundry in Svedala has a limited total production quantity, which has led to a situation where the demand is higher than the PU's production limit. To cover this deficit in supply, external suppliers are used for some items.

3.3.2 SMCL

Sandvik Mining and Construction Logistics (SMCL) is the responsible division for the distribution and redistributions of the aftermarket parts. To facilitate these distributions and redistributions, they operate warehouses spread across the world. The warehouses they operate include two central warehouses (CW) located in Venlo, Netherlands, and in Svedala, Sweden. When an item is transferred from an external supplier or a PU to a central warehouse, SMCL takes ownership of the product. The CW in Svedala is mainly used for equipment, which means that most aftermarket products go through the CW in Venlo before being shipped out to the regional distribution centers (DC) around the globe. The DCs act as intermediate warehouses, where items are stored before being sent to the SA. Because most aftermarket parts only go through the central warehouse in Venlo, only transfers between this central warehouse and the distribution centers will be considered in this thesis. An overview of the different warehouses operated by SMCL is presented in Table 1 below. The denotations of the warehouses are added to the table because they will be used in the upcoming analysis. The scope of the thesis is to investigate redistribution of aftermarket parts within SMCL, which means that the warehouses seen in Table 1 are all the warehouses that will be analyzed. However, the remaining layers in the supply chain will also be discussed, as it will provide a complete picture of C&S's supply chain.

Warehouse type	Location	Denotation
Central Warehouse	Venlo, Netherlands	DI37
Distribution Center	Chicago, USA	DIC2
Distribution Center	Singapore	C3
Distribution Center	Johannesburg, South Africa	DIC4
Distribution Center	Perth, Australia	DIC5
Distribution Center	Brisbane, Australia	DIC63

Table 1: The different warehouses operated by SMCL and their denotations

3.3.3 Sales Areas

The Sales Areas (SA) are a separate entity within Sandvik that oversee selling and providing items to the customers. When an item is transferred from a DC to a SA, that SA takes over the ownership of the product. In operation, there are currently nine SAs. These being Africa, CIS (Commonwealth of Independent States), China, India Pacific, Latin America, Northern America, Northern Europe, Southern Europe, the Middle East and Oceania. Because of the geopolitical situation following Russia's invasion of Ukraine, no sales currently take place in CIS region and will thus be excluded in the scope of this thesis. The SAs are then further divided into Sales Area entities. An example of a SA entity could be Chile, operating in the Latin America SA. For the purpose of simplification, the SA entities are not included in the supplier network seen in Figure 2. Because the SA entities are in direct contact with several end-customers, they have a better understanding of the short-term needs of these customers.

3.3.4 Customers

C&S has two customer groups, mining and construction. These customer groups are significantly different.

The mining customers rely heavily on crushers, where the crushers fill a core role in their operations and these customers usually operate several crushers at each site. Any downtime of these crushers could have a direct impact on the profitability. Because of this, many of these customers have a small inventory readily available on site, in case of a disruption or breakdown. To minimize downtime, these customers usually schedule maintenance of their crusher by replacing wear parts before their lifetime runs out. This simplifies SMCL's process of knowing when to send certain items, since there is a pre-defined time-window for maintenance.

The construction customers often do projects of a smaller scale, only involving a few crushers. To minimize the upfront investment, they do not have a small inventory of wear and spare parts at the project site. These customers often use their wear parts until they have been completely worn out. Since the crushers are not as imperative for the projects performed by these customers, it is more cost-effective for them to do less maintenance and have some down-time of their crushers. To reduce costs further, they request low lead time on the aftermarket parts provided by SMCL to minimize downtime. This illustrates that there are other reasons to redistribute items, besides reducing costs. By providing a low lead time for these customers, their satisfaction could be increased. This has the potential to generate more revenue in the future. However, the scope of this thesis is to investigate redistribution from a cost-perspective.

3.3.5 Modes of transport

The two modes of transport (MOT) currently in use by SMCL are transportation by air and by sea. Most distributions executed by SMCL are internal transfers between their different warehouses. To reduce the cost of operations, the main MOT is by sea since many of the items SMCL is distributing are heavy. Using air to transport heavy items is extremely expensive. However, as a rule of thumb, air is used for products that have a weight below 50 kg. Since smaller items have a lower transportation cost, the advantages of a lower transportation time are considered more important than reducing the costs for these products. Air is also used when there is an urgent request by the customer. In this case, the customer covers the transportation cost. Since the SA entities are often located close to the customers, the MOT used between the SA entities and end-customers is in most cases by truck. However, the scope of the thesis is to investigate transfers within SMCL, which does not include the transfers between SA entities and end-customers.

4 Theoretical background

This chapter aims to act as a bridge between theory and the inventory management strategy used at Sandvik. This will act as a foundation for the upcoming analysis of the redistribution costs.

The situation this thesis is investigating is fundamentally a supply chain issue. Huddiniah and Pradana (2023) define a supply chain as a logical system of interconnected layers that transforms raw materials into finished products. This logical system can look quite different depending on the number of involved parties, the nature of the goods, the size of the market, and the geographical location. Because of this variability, the length of the supply chain and which parts are involved varies between companies. Sandvik is a large company operating worldwide, which means that their supply chain has a lot of interconnected parts. Because of this, Sandvik's supply chain is seen as quite complex. A big part in managing a supply chain is through optimizing the inventory levels since they make up between 25 and 50 percent of total assets in manufacturing companies (Biswas et al., 2017). This will be the focus of the next subchapter.

4.1 Inventory Management

4.1.1 inventory levels

Inventory levels are important to consider since the capital bound in inventory could be invested elsewhere and return a profit. Thus, minimizing the stock while meeting the company's targets is imperative to increase profitability. If inventory is not managed correctly, costs increase if stock levels are kept too low because there is a cost associated with having a shortage. Generally speaking, the tradeoffs in any inventory system are essentially made up of ordering costs and holding costs versus shortage costs (Edalatpour, Mirzapour Al-e-Hashem, and Fathollahi-Fard, 2024). This means that keeping too little stock would increase shortage costs, while keeping too much stock would increase the holding costs. Managing the inventory levels therefore implies finding a balance where the total cost is minimized.

4.1.2 Multi-echelon inventory management

Because Sandvik is a large international company, with a supply chain made up of several interdependent parts, their approach to inventory management considers various stages of the supply chain. They have done this by incorporating an approach known as multi-echelon inventory management. Multi-echelon inventory management is an advanced approach that considers inventory decisions across multiple levels within a supply chain. This integrated approach aims to synchronize inventory levels, reduce holding costs, improve service levels, and enhance overall supply chain performance across various echelons (Silver, Pyke, & Peterson, 1998). Central to this methodology is the concept of inventory pooling or centralization. By consolidating inventory across multiple echelons, organizations can achieve economies of scale, reduce redundant inventory holdings, and improve overall inventory utilization (Silver, Pyke, & Peterson, 1998). Sandvik's approach to inventory pooling and centralization is done by having a CW that stores and distributes most of the products moving to and from the distribution centers. Products stored at the CW are utilized by the entire company, and can be seen as shared stock that all customers are eligible to purchase.

4.1.3 Demand patterns

A key aspect when utilizing the multi-echelon inventory management approach, is understanding the demand patterns linked to the products a company is providing. Demand patterns are fundamental elements in inventory management, providing insights into the variability and predictability of customer demand over time. Four distinct demand patterns commonly encountered in supply chains are smooth, erratic, lumpy and intermittent (Chopra & Meindl, 2016). Smooth demand patterns involve consistent demand levels over time, allowing organizations to maintain stable inventory levels and production schedules which is commonly observed among everyday products (Chopra & Meindl, 2016). Erratic demand patterns are characterized by random and unpredictable demand fluctuations, making forecasting and inventory management challenging. This pattern is often observed for new or innovative products, seasonal items, or products influenced by external factors (Waller, Johnson, & Davis, 1999). Lumpy demand patterns are characterized by sporadic spikes in demand that occur at irregular intervals, which is commonly observed for seasonal items or event-related products. Intermittent demand patterns refer to demand that occurs infrequently and unpredictably with large gaps of no demand in between. Examples of items experiencing this demand pattern could be custom-made parts and raw materials for large-scale projects. (Chopra & Meindl, 2016).

The two item categories within C&S's aftermarket parts follow different demand-patterns. Because many of Sandvik's wear parts have a predictable life-time, the demand for these items is easy to predict and thus follows a smooth demand pattern. However, the spare parts' demand is harder to predict since spare parts are needed when something breaks down. These breakdowns can happen at any given time, resulting in an erratic demand. While the demand pattern for spare parts fluctuates, no spikes are seen because C&S operates on such a large scale where many customers contribute to the accumulated demand. This means that the spare parts demand pattern does not have the characteristics of a lumpy demand pattern.

4.1.4 Forecasting

Sandvik utilizes the observed demand patterns when constructing their forecast models. Forecasting is a critical component in supply chain management, allowing organizations to plan their inventory, production and distribution to recent demand trends. One commonly used quantitative forecasting method that is particularly relevant in supply chain management is the moving average (Hyndman & Athanasopoulos, 2018). Since the main method of forecasting used by Sandvik is moving averages, it will be the only method described here.

Moving averages is a simple, yet effective forecasting method when there is no seasonality. It involves calculating the average demand of a specified number of most recent data points to create a prediction of future demand values. This method is particularly useful for smoothing out short-term fluctuations and compensating for trends within the demand data (Hyndman & Athanasopoulos, 2018). If there has been a trend of decreased demand in previous periods, the forecasted demand will be lower than in the previous periods. Sandvik's aftermarket parts follow either an erratic or a smooth demand pattern and there is no consistent seasonality for any of the items, which is why Sandvik mainly employs this method. When calculating the moving average, the demand in period t is estimated as the average demand over the most recent N periods. This represents an N-period moving average and is evaluated as follows:

$$F_t = (D_{t-1} + D_{t-2} + \ldots + D_{t-N}) / N \qquad (1)$$

Where F_t is the forecasted demand in period t and D_{t-i} is the observed demand in period $t-i$ where $i = 1, 2, \ldots , N$

Sandvik currently applies a moving average of 12 months, meaning the demand of the last 12 months is used to calculate the following month's expected demand. They apply a rolling horizon procedure, which means that the moving average is reiterated every month. This means that the previous 12 months are always used to forecast the following month's demand. These forecasts are calculated at each specific SA and are inherited up the supply chain. This means that the forecasted demand for the distribution centers is equal to the accumulated forecasted demand from all the sales areas they are supplying. Consequently, the central warehouse will have a forecasted demand equal to the accumulated forecasted demand of all the distribution centers. The total number of items that are produced and ordered from external suppliers is based on the forecast at the central warehouse.

There are several layers between the end-customer and the PU's, which means that something known as the bullwhip effect could take place. The bullwhip effect in a supply chain describes how fluctuations in consumer demand leads to greater variability in orders placed upstream, causing inefficiencies and inflated costs. This phenomenon results from information distortion as it moves along the supply chain, amplifying the perceived demand at each stage (Lee, Padmanabhan and Whang, 2004). However, Sandvik counteracts this by sharing information about changes in customer demand between each layer. This means that every part of the supply chain has full access to the shifts that occur to the customer demand, and can adjust their operations accordingly.

4.2 Item Classification

4.2.1 OSMI-classification

The majority of the excessive inventory build-up in C&S's different warehouses consists of obsolete and slow-moving inventory (OSMI). Obsolete inventory refers to items that have lost their value due to changes in market demand, technological advancements, or product lifecycle completion (Hazen, Hall & Hanna, 2012). This type of inventory often accumulates because of overproduction, poor demand forecasting, or shifts in consumer preferences. The presence of obsolete inventory can be detrimental to a company as it occupies valuable warehouse space, incurs storage costs, and ties up capital that could be used more effectively elsewhere. On the other hand, slow-moving inventory consists of items that have a low turnover rate (Chikán, 2008). The inventory turnover rate is the rate at which inventory is sold and replaced over a specific time period. For slow-moving inventory, the inventory turnover rate is low since the frequency these items are sold at is low. The inventory turnover rate will be discussed more in the upcoming subchapter. Slow-moving inventory can result from inaccurate demand forecasting, seasonal fluctuations, or changes in consumer preferences. Slow-moving inventory ties up working capital and increases carrying costs, which include warehousing, insurance, and the risk of obsolescence. The majority of the build-up of excessive stock in SMCL's warehouses is obsolete or slow-moving. This is because the SAs want to maximize the amount of products they can sell to customers. The more items that are available close to the SAs, the more they can sell to the customers. However, some of the items the SAs have requested have not been sold, or have been sold at a lower rate than they expected, and have thus become OSMI-classified and overstocked. The focus of this thesis will be on the OSMI-classified products.

Sandvik has created different classifications for their OSMI-coded products depending on the inventory levels and at which rate they are sold. These are Moving (M), Slow-Moving (S) and Obsolete (O). Products that have a demand that doesn't result in a build-up of stock are classified as M. These can be seen as healthy products where the inventory levels are proportionate to the customer demand. If the item is still moving but there has been a build-up of stock resulting in more inventory than a year's worth of customer demand, it is labeled S. If the product has not been ordered for more than one year, it becomes obsolete and denoted as O.

Numbers are also added behind the item groups O and S to differentiate items within these categories. For obsolete items, the number means how long the item has been obsolete. For example, an item classified as O3 means the item has been obsolete for 3 years. For slow-moving items, the number means how many years of forecasted demand is in stock. For example, an item classified as S3 means that the item is still moving but there is an inventory corresponding to three years of expected demand. These are all the OSMI-codes currently used by SMCL: O1, O2, O3, O4, O5, S1, S2, S3, S4, S5 and M.

Another important factor is that there is a regional and global OSMI-classification system within SMCL. The regional OSMI codes only account for items in a specific warehouse. If an item is regionally classified as obsolete in for example a distribution center, it means that there has not been any demand for that item in that specific distribution center for at least one year. The global OSMI-code instead considers all facilities within SMCL. If any of the warehouses have an order of an obsolete item, the item will lose its global obsolete classification.

Furthermore, if there hasn't been an order of an item within one year across all SMCL's warehouses, the global OSMI-code will be O.

4.2.2 OSMI turnover rate

Relevant to OSMI-coded items is the inventory turnover rate. A high turnover rate indicates efficient inventory management and strong sales, whereas a low rate suggests overstocking or weak sales (Chen, Frank & Wu, 2005). The inventory turnover rate is calculated by dividing the total value of the cost of sold goods (COGS) by the average value of the inventory over a specified period. The COGS refer to all the direct costs linked to the production of the goods sold by a company. Usually this is done over a calendar year. The inventory turnover rate can be calculated by the following formula:

$$Inventory\ turnover\ rate\ =\ \frac{COGS}{Average\ Inventory} \tag{2}$$

Efficient inventory turnover is essential for maintaining optimal inventory levels, minimizing holding costs, and improving cash flow (Koumanakos, 2008). However, depending on the industry, inventory turnover rates are different depending on the type of products that are provided (Kwak, 2019). An example is to compare the clothing industry with the furniture industry. Clothing is a fast-moving consumer good with shorter product life cycles driven by fashion trends and seasonal changes, which requires frequent inventory replenishments. As a result, the clothing industry often has a high inventory turnover rate. On the other hand, the furniture industry often provides high-value, durable goods with longer life cycles and higher prices, leading to a slower sales frequency. Companies within this industry often have a low inventory turnover rate. When comparing a company's inventory turnover rate, it is thus important to do it with companies operating within the same industry. While companies with high turnover rates have a higher risk of not satisfying customer demand because they might be out of stock, they also have a reduced risk of obsolescence. Conversely, a low turnover rate can lead to excessive inventory holding costs, including storage, insurance, and depreciation, and can negatively impact a company's financial performance. Because of this, it is important for a company to find an inventory turnover rate that is suitable for the products they are providing.

For the purpose of this thesis, an alternate definition of the turnover rate is created which will be used when analyzing the obsolete and slow-moving items. This is done to better understand how long items remain within an OSMI-category. The definition is the rate that obsolete items become moving again. This is calculated by dividing the obsolete items that have kept their classification since the previous year, by the number of them that have been obsolete the previous year. The result from this calculation is then subtracted from 1. This is interpreted as the percentages of obsolete items that will lose their obsolete classification during a period of one year.

$$OSMI\ turnover\ rate = 1 - \left(\frac{Number\ of\ the\ same\ items\ that\ are\ classified\ as\ obsolete\ the\ current\ year}{Number\ of\ items\ that\ have\ been\ classified\ as\ obsolete\ the\ previous\ year}\right) \quad (3)$$

For example, if there are 10 obsolete items in the beginning of 2023 and 8 of them are still obsolete in the beginning of 2024, the OSMI turnover rate can then be calculated as follows:

$$OSMI\ turnover\ rate = 1 - \left(\frac{8}{10}\right) = 0.2$$

This means that during 2023, 20% of obsolete items lost their obsolete classification.

4.3 Redistribution costs

SMCL has within their operations experienced a build-up of excessive stock. To reduce their operational costs, they want to reduce their inventory levels without impacting aspects such as lead time and service levels. To provide high service levels and low lead times, some items need to be located close to the customers. If inventory levels are reduced, there is a chance that the items the customers are requesting aren't being stored close to them anymore. This means that it is important to evaluate from different perspectives which items allow a lower inventory level, and which items do not. A way to reduce inventory levels is by redistribution. Within a supply chain context, redistribution involves the transfer of goods from one location to another to better match supply with demand. The process of redistribution mainly consists of five types of costs, these being transportation costs, order handling costs, inventory carrying costs, administrative costs, and potential loss or damage costs. Items regionally classified as obsolete or slow-moving can be seen as overstocked items that accumulate storage costs over time. If the item has a demand elsewhere within SMCL, it is possible to determine if it is advantageous from a cost-perspective to redistribute an item. This is done by comparing the expected accumulated storage cost with the redistribution cost.

Expanding on the redistribution cost, transportation costs are a primary expense in redistribution which includes fuel, vehicle maintenance, driver wages, and transportation infrastructure fees such as tolls. Transportation costs typically account for 30% to 60% of total logistics costs, depending on factors such as the distance between redistribution points, the volume and weight of goods, and the mode of transportation used (Christopher, 2016). Order handling costs are the costs for handling the redistributions orders, which includes wages for workers involved in loading, unloading, sorting, and repackaging items, as well as the use of machinery like forklifts and conveyors. Labor costs in logistics can be significant, particularly in regions with higher wage standards. Automation and efficient workforce management can mitigate some of these expenses, but human labor remains a crucial component of the redistribution process (Rushton, Croucher & Baker, 2014). Inventory carrying costs arise from holding stock at various points in the redistribution process. These costs include warehousing expenses, insurance, taxes, and opportunity costs related to capital tied up in inventory. Goods in transit or in interim storage facilities contribute to these carrying costs. Inventory carrying costs usually vary between 20% to 30% of the total inventory value per year (Lambert, Stock & Ellram, 1998). Administrative costs are associated with managing and coordinating redistribution activities. These costs include planning, scheduling, tracking, and managing documentation for the movement of goods. Loss and damage costs consider the risk of goods being lost or damaged during transit, leading to substantial costs, especially for high-value or sensitive items that are easily damaged. Insurance can mitigate some of these costs, but premiums add to the overall expenses.

While all these cost-bearers are present at Sandvik when doing redistributions, understanding all of them requires an extensive amount of data gathering and manual data-analysis. Today, much of the data Sandvik is collecting in regard to costs are summarized in automatically generated reports. An example of such a report would be the total distribution costs for the aftermarket parts. While these provide a good overview of the total costs, they don't provide any information in regard to what a specific component would cost to redistribute. An approach such as dividing the total cost of distribution with the number of distributed items is insufficient, since there is high variability in regard to weight, size and cost for the aftermarket parts. The following analysis chapter will approximate the cost of redistributing an item based on different parameters, such as cost, weight and mode of transportation.

5 Analysis

This section will begin with a discussion of redistribution based on SMCL's objectives. It is followed by an analysis of redistribution based on Sandvik's OSMI-classification. The chapter will end with an analysis of the different costs and opportunity costs associated with redistribution.

5.1 OSMI movement analysis

The main objective for SMCL is to reduce their bound capital by lowering their inventory levels across their operations. Their planned way of doing this will be to redistribute OSMI-coded products from the DCs back to the CW in Venlo. The idea is that the CW has a higher inventory turnover rate than the DCs. According to Gu, Goetschalckx and McGinnis (2007), central warehouses consolidate the entire inventory into a single location, enabling more efficient inventory management and faster turnover due to streamlined processes and advanced automation. This is further backed by Harrison & van Hoek (2011), who state that regional warehouses are designed to be closer to the market and maintain a broader range of items to meet local demand quickly, which can lead to lower turnover rates as they hold inventory longer to ensure availability. With the CW also being a supplier to the world's entire market, a reasonable assumption would be that there is a higher probability that an item has a higher demand in the CW than further down in the supply chain. If this is the case for C&S's aftermarket products, will be investigated.

By comparing the number of obsolete products in DI37, the CW in Venlo, in the beginning of 2023 with the number of items that are still obsolete in the beginning of 2024, the OSMI turnover rate for 2023 can be calculated based on Formula 3. The results are presented in Table 3.

DI37 OSMI turnover rate 2023	
Number of obsolete in 2023 (O-code)	763
How many of them obsolete in 2024	476
OSMI turnover rate 2023	37.61%

Table 3: The OSMI turnover rate for DI37

Of the 763 products that were classified as obsolete in the beginning 2023 in DI37, 476 of them remained obsolete in the beginning of 2024. This means that during this one-year period 37.61% of the obsolete classified items in DI37 lost their OSMI-code and became moving again. In the beginning of 2024, 2151 items were classified as obsolete in total, independent of their 2023 classification. It implies that the build-up of obsolete items in DI37 is higher than the current OSMI turnover rate. This means that the build-up of excessive stock within SMCL, is currently ongoing. It is apparent that the forecasts used during 2023 have been inaccurate in predicting the actual demand for a significant number of items. In many instances the forecasts are higher than the actual demand, and SMCL needs to take action to reduce the build-up of obsolete products by improving their forecasts. How the forecasts could be improved will not be analyzed in this thesis, as it is beyond the scope. It is however important to highlight that the buildup of excessive stock is ongoing since the purpose of this thesis is to investigate how and when redistribution can be used to lower excessive stock.

This analysis does not consider how long an item has been obsolete. There is reasonably a difference in the OSMI turnover rate for items that have been obsolete for one year compared to items that have been obsolete for four years. To expand the DI37 analysis further, a comparison was made on the OSMI turnover rate, depending on how long obsolete items had been obsolete during 2023. The results are seen in Table 4. The Category O5 was excluded from the analysis, since the small sample size makes the data too unreliable.

DI37 OSMI-Code	DI37 OSMI turnover rate 2023	Number of items within each category 2023
Average	37.61%	763
O1	38.36%	464
O2	41.42%	170
O3	31.91%	97
O4	26.09%	23
O5	---	9

Table 4: Overview of the OSMI turnover rate for the different obsolete categories

From Table 4 it is seen that items that have been obsolete for a longer period also have a lower percentage to start moving, with the exception of the O2 items. As stated earlier, products in stock can become obsolete due to several factors. In this context, if an item has been obsolete for a long period of time, the likelihood of it being outdated or there being a shift in demand is increased. The results from the analysis imply that this correlation is also present for the products Sandvik is supplying. An explanation for the increase in OSMI turnover rate for the O2 items can be explained by the sample sizes used for this analysis. With small sample sizes, such as these, there are margins of errors to consider.

An analysis of the OSMI-turnover rate was done at DIC2, the DC in Chicago, and SA Chile as well. These were the largest warehouses within their respective category, which means that they also provide the largest sample sizes. When analyzing the costs of redistribution, the SA will be excluded since the scope is limited to SMCL's operations. However, since the purpose of this investigation is to find out if an item has a higher probability to start moving higher up in the supply chain, valuable information can be gathered by also considering the SA Chile's OSMI-turnover rate while not being operated by SMCL. The following analysis is looking at the local OSMI-classification at DIC2 and SA Chile. Since they are smaller warehouses than the DI37, the number of analyzed obsolete items is lower than in the previous analysis. This makes the data more unreliable but can still be used to get an overview of the situation. In Tables 5-6, the results from the analysis are presented.

OSMI turnover rate in DIC2 2023	
Number of obsolete beginning of 2023 (O-code)	592
How many of them are obsolete in 2024	207
OSMI turnover rate 2023	65.03%

Table 5: The OSMI turnover rate for DIC2

OSMI turnover rate in SA Chile 2023	
Number of obsolete beginning of 2023 (O-code)	170
How many of them obsolete in 2024	56
OSMI turnover rate 2023	67.05%

Table 6: The OSMI turnover rate for SA Chile

This analysis is not conducted on the same items, meaning that the analyzed obsolete items in DIC2 are not the same as the analyzed obsolete items in SA Chile. This, however, allows the OSMI-turnover rate to be compared for the different warehouses. The numbers presented in Tables 5 and 6 give the impression that an arbitrary obsolete item in DIC2 and SA Chile have a higher probability to become moving than an arbitrary obsolete item in DI37. However, items that get redistributed are classified in Sandvik's data sets as moving or slow-moving. This means that some of the products that lose their O-coding in DIC2, and SA Chile have not been sold, just redistributed. This in turn inflates the numbers, creating the impression that DIC2 and SA Chile have an OSMI-turnover rate. For every outbound delivery in a SA to a customer, there exists a corresponding purchase order. By comparing the obsolete items being ordered by a customer, with the items that were obsolete in SA Chile, the OSMI-turnover rate can be adjusted to not include redistributions. However, it is only possible to adjust the number for SA Chile, since DIC2's outbound deliveries are not linked to purchase orders. The adjusted results from SA Chile are shown in Table 7.

OSMI turnover in SA Chile 2023 (Adjusted for redistribution)	
Number of obsolete beginning of 2023 (O-code)	170
How many of them obsolete in 2024	92
OSMI turnover rate 2023	45.88%

Table 7: The OSMI turnover rate for SA Chile adjusted for redistributions

Adjusting for redistributions, the OSMI-turnover rate is lowered by 21 percentage points for SA Chile. This is because 21 percentage points of the items that lost their obsolete classification were redistributed and not sold. Using the OSMI-turnover rate from Table 7 makes the comparison between the different warehouses more accurate. The results from the analysis of the three different stockrooms are summarized in Table 8 below.

Warehouse	OSMI turnover rate 2023
DI37	37.61%
DIC2	(65.03%)
SA Chile	45.88%

Table 8: The OSMI turnover rates for DI37, DIC2 and SA Chile

As seen, the OSMI turnover rate is lower in DI37 than in SA Chile even though the value at SA Chile is corrected. This means it cannot be conclusively stated that moving an item that is obsolete in both a distribution center (DC) and in the central warehouse (CW), up in the supply chain increases the probability that it becomes moving. Because of the OSMI-turnover rate in SA Chile being higher than the OSMI-turnover rate in DI37, an obsolete item in SA Chile would have a higher probability to start moving than an obsolete item in DI37.

As stated in Chapter 4.3, a way to reduce obsolete stock is to redistribute an item to a location where there is a demand for the item. The previous analysis of obsolete items concluded that redistributing an arbitrary obsolete item wouldn't decrease inventory levels. However, if an item is obsolete in DIC2 but is moving in DI37, a redistribution would decrease inventory levels since the item could be utilized in DI37. Thus, an analysis is performed on how many of the obsolete items in DIC2 are also obsolete in DI37. The results are presented in Table 9. This analysis is conducted on items classified as obsolete at DIC2 in the beginning of 2024.

Obsolete items in both DIC2 and DI37 2024	
Number of obsolete items in DIC2 2024	740
Number of the same items being obsolete in DI37 2024	178
Percentage that are obsolete both at DIC2 and DI37	24.05 %
Percentage where redistribution lowers inventory levels	75.95 %

Table 9: Percentage of obsolete items in DIC2 that are also obsolete in DI37

What can be seen from this analysis is that most items that are obsolete in DIC2 are moving in DI37. This means that a redistribution to DI37 will increase the probability that the item becomes moving for 76 % of the obsolete items in DIC2. The remaining 24 % are obsolete in both DIC2 and DI37. Since the OSMI turnover rate for DIC2 couldn't be adjusted for redistributions, no conclusive answer can be given in regard to where these items will lose their obsolete classification soonest.

5.2 Analyzing the logistics costs

5.2.1 Transportation cost per kg

As stated in Chapter 4.3, one of the main cost-drivers for redistribution is the logistics cost. The goal of this analysis is to approximate the transportation cost for each individual route between the distribution centers and the central warehouse in Venlo. One way to do this would be to look up every single item's transportation cost for every route SMCL is operating. Since this would require an extreme amount of data analysis, the settled method based on discussions with company representatives was to divide the total transportation costs for a route with the amount of kg shipped on the same route. Other approaches were considered, such as dividing the total transportation cost for a route with the number of products sent. However, since the costs for transporting the different aftermarket items vary substantially depending on size and weight, this methodology was disregarded. For some of the DCs, only a few redistributions had been done back to DI37 historically. Only using a few transportations as a basis for calculating the transportation cost would lead to the result being unreliable, thus the analysis is done using distributions to and from the distribution centers. This means that the total cost of transporting items in both directions of a route was divided by the total amount of kg sent in both directions. By doing the analysis in both directions, larger sample sizes were gathered resulting in higher reliability. The routes DIC5 to DI37 and DIC63 to DI37 were combined into one. This was done for two reasons. Firstly, both DIC63 and DIC5 are located in Australia, which means that the transportation distance by sea does not diverge much between the two routes. Secondly, DIC5 is a small warehouse, which means that the number of distributions was low. Thus, combining the two routes into one increased the sample size which in turn increased the reliability.

Another aspect to consider is the MOT used. As described in Chapter 3.3.5, SMCL mainly employs two different MOT when distributing and redistributing their products, these being by air or by sea. To account for this, the transportation cost is calculated by dividing the total transportation cost for a route using one MOT, with how many kg was shipped on the same route using the same MOT. The report that was utilized for this analysis labeled each transportation with the mode of transport used, which enabled the MOT to be differentiated. In Table 10, the cost per kg is presented for the different routes and the different modes of transport.

Route	Air [EUR/kg]	Sea [EUR/kg]
DIC2 - DI37	2.98	0.36
C3 - DI37	2.45	0.27
DIC4 - DI37	3.16	0.30
DIC5 - DI37	6.75	0.39
DIC63 - DI37	6.75	0.39

Table 10: The cost per kg for the different routes using air and sea as MOT

What can be seen from most of the routes is that it is approximately ten times as costly to transport an item by air than by sea. The transportation costs from the two DCs in Australia are significantly higher when using air as MOT. While the distance from DI37 to Australia is longer than from DI37 to any other distribution centers, it cannot be the only explanation as the distance from DI37 to C3 is almost as long. One reason for the increase in cost could be that the airport(s) are located far from the warehouses in Australia, meaning that the items would have to travel long distances on trucks before they can be flown. A second explanation could be that the company operating that specific flight path takes a higher fee for that specific route. What is gained when choosing air over sea is that the lead time will be substantially shorter. Data regarding the average lead time by air for the different routes is not available but will be approximated to be 5 days based on discussions with company representatives. The lead time for the different routes using sea as MOT is gathered from reports generated by SMCL. In Table 11, the lead time of the different MOT for every route is presented.

Route	Lead time by air [days]	Lead time by sea [days]
DIC2 - DI37	5	51
C3 - DI37	5	50
DIC4 - DI37	5	62
DIC5 - DI37	5	90
DIC63 - DI37	5	91

Table 11: The route's different lead times based on MOT

The lead time is substantially shorter by air compared to by sea. Because of this, there are some situations where it is cost effective to redistribute by air. The reason for this is that there is a cost of capital which can be applied to all bound capital. Provided by Sandvik's financial department, the current annual applied cost of capital is 11 %. This means that the capital cost for storing an item for a year is 11 % of its value. By comparing the cost of capital to the extra time it takes to redistribute an item by sea, with the extra transportation cost to redistribute an item by air, a threshold can be reached at which point the value per kg makes it more advantageous to use air as MOT. This analysis assumes that the item has a current demand and will be used immediately after redistribution in DI37. The following formula was used when calculating the thresholds:

$$TH = \frac{\Delta TC}{\Delta LT \times ACC} \tag{4}$$

In this formula, TH is the value per kg threshold at which air is advantageous, ΔTC is the difference in transportation costs between air and sea, ΔLT is the difference in lead time between air and sea expressed in years and ACC is the annual capital cost of 11 percent per year. This calculation was done for every route and the resulting thresholds are presented in Table 12.

Route	ΔTC [EUR/kg]	ΔLT [Years]	Annual capital cost [% per year]	TH [EUR/kg]
DIC2 - DI37	2.62	0.126	11	188
C3 - DI37	2.18	0.123	11	160
DIC4 - DI37	2.86	0.156	11	167
DIC5 - DI37	6.36	0.233	11	248
DIC63 - DI37	6.36	0.235	11	246

Table 12: The threshold where air is the most cost-effective MOT for the different routes

Take route C3 - DI37 for example. If an item has an immediate demand in DI37 and has a value of more than 160 EUR per kg, it is advantageous to transport it by air. For all items below this threshold, transporting by sea is most cost-effective. For most items it will not be advantageous to ship by air, but for some products where the value per kg is extremely high, it is worth considering air as MOT for SMCL. This means that the policy of using air as MOT for items below 50 kg, as stated in chapter 3.3.5, is not always cost effective. However, other benefits that come with shorter lead times are gained by choosing air which could make it more advantageous, but is beyond the scope of this thesis.

5.2.2 Cost based on value

As mentioned earlier in Chapter 3.2.4, the aftermarket parts are made up of both wear parts and spare parts. The previous analysis didn't consider the differences between the two item groups. The wear parts are generally much larger than the spare parts, and have lower profit margins. Because of the differences, valuable information can be gathered by differentiating the wear parts and spare parts, making the previous analysis more nuanced. One way of differentiating them is by calculating the transportation costs as a percentage of the value of the products. Within SMCL, the product value is equal to the production cost of the same item because they only handle internal transfers of items. This means that the terms production cost and product value will be used interchangeably throughout the rest of this thesis. In the data used for this analysis, there was no division of the transportation costs on a route specific level. This means that calculating the transportation cost based on the value of the item cannot be done for every route.

Instead, the result will be an average cost based on value to send an arbitrary item on any of the routes SMCL is operating. Calculating the transportation cost based on value is done by dividing the total transportation costs between SMCL's warehouses with the total value of the transported products for both item groups respectively. To further expand the analysis, the two different MOT are differentiated. This was done by dividing the costs of transportation using one MOT, with the value transported with the same MOT. The capital cost of 11 percent is included in transportations by sea because there is a large difference in the lead time between the two MOT. It was done by applying the capital cost of 11 percent on the average extra time it takes to transport an item by sea for the different routes, seen in Table 12. It was calculated to be 1.92 % of the item's value. This means that the transportation cost based on value using sea as MOT for both item groups is around 2 percentage points (p.p.) higher because of the capital cost. The results of the analysis are shown in Table 13.

MOT	Wear parts [% of value]	Spare parts [% of value]
Sea	13 % (of which 2 p.p. is capital cost)	4 % (of which 2 p.p. is capital cost)
Air	61 %	18 %

Table 13: Cost as percentage of value for wear parts and spare parts including the capital cost

What is seen from the analysis is that there is a significant difference between wear parts and spare parts regarding transportation cost as a percentage of the value. On average, redistributing a wear part worth 100 EUR by sea would cost 13 EUR, while the same cost for a spare part worth 100 EUR would be 4 EUR. From the previous analysis in section 5.2.1, the transportation costs per kg for the different routes were found to be quite similar. The cost based on value presented here does not differentiate the different routes. However, because the transportation cost per kg for the different routes were similar, the numbers in Table 13 are a good approximation of the cost based on value for all the different routes. Since the main objective is to understand the differences between wear parts and spare parts, the results still provide valuable insights.

With spare parts having a high profit-margin, redistributing these by sea won't affect the profitability much based on the percentages shown above. For example, if a spare part with a profit margin of 50 percent was redistributed by sea, only 4 percentage points of the profit margin would be lost. If there is an immediate demand somewhere else, it could even be beneficial to redistribute the item by air since the cost is still relatively low compared to the profit margins. For the wear parts, the situation is quite different. Lower profit margins coupled with higher transportation cost based on value means that these products are less advantageous from a cost-perspective to redistribute. However, an important aspect to consider is that it is still advantageous to redistribute wear parts instead of producing an entirely new product by solely looking at the transportation costs. While a redistribution would cost 13 or 61 percent of the wear parts value, depending on MOT used, it would cost 100% of the value to produce an entirely new product.

5.2.3 Analysis of tolls and packaging costs

The wear parts are large and expensive components. This means that they are transported on pallets. Since the cost of using a pallet is negligible compared to the cost of the item, it will be disregarded in this analysis. The spare parts are smaller and less expensive, and are usually sent by crates or boxes. For these items, the packaging costs are more significant. Based on information gathered from company representatives, the transportation cost is increased by 5 % if packaging material is considered for the spare parts. While this increases the transportation cost by air by 1 percentage point, it does not noticeably change the other transportation costs and it is still more advantageous from a cost-perspective to redistribute spare parts compared to wear parts.

As stated in Chapter 3.3.1, most of the aftermarket products that SMCL is distributing are manufactured in the PU in Svedala or by external suppliers located mainly in Europe. Within the European Union (EU), every item that is exported outside of the EU gets classification-coded based on its purpose. If the route between DI37 in the Netherlands DIC4 in Africa is looked at for example, the toll that is applied is dependent on what EU-classification the item gets, which means that standardized tolls cannot be applied to that route. Since Sandvik's master data does not have item classifications, each product Sandvik is supplying would have to be manually compared to the EU's register containing these classifications which is not feasible for the scope of this project. However, one standardized toll could be applied to products produced in China that are being transported to the US. Because of the geopolitical situation between the US and China, tariffs of 25 % of the value of manufactured goods have been introduced. The transportation cost based on value with the addition of a 25 % tariff is presented in Table 14. While most of the aftermarket parts are produced in Europe, it is important for Sandvik to consider this as it significantly increases the cost for redistributing items where this is applicable.

	Wear parts [% of value]	Spare parts [% of value]
Sea	38 %	29 %
Air	86 %	43 %

Table 14: Total redistribution cost as percentage of value for wear parts and spare parts, if produced in China and sent to the US

5.3 Analysis of the fixed ordering handling cost

As described in Chapter 4.3, distributing and redistributing an item comes with an order handling cost. The majority of these costs come from the manual workers who are in charge of picking, packing, and handling orders. Since the number of employed manual workers won't be affected by a single redistribution request, a presumption for this analysis is that the labor cost is fixed. Furthermore, an assumption is made that the time to pick an item is constant for all items. The fixed order handling cost will be based on the number of order lines processed, which according to Sandvik representatives would be the most accurate and conservative approximation. An order contains one or more order lines, which are the number of unique items within an order. This means that the fixed order handling cost is independent of the number of items of the same type. No differentiation will be made to the size or the weight of the product when conducting this analysis. The data received from Sandvik does not differentiate the labor cost for inbound and outbound handling. A way to counteract this is by spreading out the entire labor cost, both the inbound and outbound labor cost, on the total amount of outbound order lines for each warehouse. The result from this is a fixed order handling cost that contains both an inbound and outbound component, and can be seen as the average cost of both sending and receiving an item in that specific warehouse. Since all redistributions are handled when they are sent and when they are received, this method was deemed appropriate. In Table 15 the order handling costs are shown for the different warehouses.

Warehouse	Fixed order handling cost [EUR/order line]
DI37	45.74
DIC2	28.31
C3	8.32
DIC4	---
DIC5	18.33
DIC63	29.15
Weighted average	38.49

Table 15: Fixed order handling cost for the different warehouse

There was no data available regarding labor costs for DIC4 in the report used to create this analysis. A reasonable assumption would be that the fixed order handling cost for DI37 would be lower than for the other warehouses, because of its size. Larger warehouses are generally more cost-effective because they benefit from economies of scale, reducing costs through more efficient use of labor. However, from Table 15, it can be seen that the fixed order handling cost is highest for DI37. One explanation as to why the costs are higher in DI37 may be because it takes more time to handle an order because of longer distances to travel within the warehouse. Another explanation would be that more stocktakings are made in DI37 compared to other warehouses to ensure inventory levels are correct. This would mean that parts of the labor cost used to calculate the fixed order handling cost comes from laborers in charge of stocktaking.

The route specific order handling cost can be calculated by taking the average fixed order handling cost at the two considered warehouses. As an example, an item being redistributed from DIC2 to Venlo, the route specific fixed order handling cost would be $\frac{45.74 + 28.31}{2} = 37.02\, EUR$. These results are solely based on the labor cost in the warehouses. However, an outbound planner from within the logistics department is involved when a redistribution is done, as someone needs to validate and confirm that the correct items are sent. When interviewing company officials who are involved in this process, they stated that it would take them approximately 10 minutes on average per order line to validate and confirm the redistribution. By applying the fee of 32 EUR per hour that Sandvik pays their consultants, an approximation of the additional order handling cost can be calculated. The additional cost is 5.33 EUR. In Table 16 the total fixed order handling costs per route are presented when considering the outbound planners.

Route	Fixed order handling cost [EUR/order line]
DIC2 - DI37	42.35
C3 - DI37	32.36
DIC4 - DI37	---
DIC5 - DI37	37.36
DIC63 - DI37	42.77

Table 16: Fixed order handling cost for the different routes where administration is considered

The initial cost to execute a redistribution is at least 32.36 EUR per order line. There will be a difference in the order handling cost between a small bolt or nut compared to a large wear part. However, by assuming that the fixed order handling cost is only proportional to the number of order lines processed, the result will overestimate the handling costs for the low-value items, and underestimate it for the high-value items. By overestimating the handling cost for low-value items, a conservative approach is used when calculating the scenarios a low-value item should be redistributed. For the large items, a lower handling cost would not affect the scenarios of when redistribution is advantageous, because they have a value significantly above the order handling costs. This means that while the calculated fixed order handling costs are not precise, they create a good foundation to conservatively analyze when items of different sizes and values should be redistributed. As stated earlier, the spare parts and wear parts are quite different in characteristics. Most wear parts have a high value where a cost of 32 EUR won't affect whether or not the item should be redistributed. Among the spare parts there are a lot of products that have a considerably lower value, such as screws and nuts. This means that the fixed order handling cost in some cases would be substantial compared to the profit margins or even the product's value, which is something SMCL should consider when considering a redistribution of a spare part.

5.4 Cost of storing goods analysis

The alternative to redistributing components in the scope of this thesis is to let the component be stored in the same facility until it is purchased by a customer. However, storing goods in a warehouse does have an associated cost. The costs of storing goods, also called the inventory carrying cost, in a warehouse encompass not only the space rental but also operational expenses such as labor, utilities, and inventory management systems. Additionally, companies must consider costs related to insurance, security, and potential inventory shrinkage, which can significantly affect overall storage expenditures (Rushton, Croucher, & Baker 2017). SMCL has divided their inventory carry cost into two components. The operational inventory carrying costs and the previously discussed capital cost. The operational inventory carrying costs consist of the expenses directly linked to keeping an item in stock, such as utility costs, insurance costs, and rental costs. The capital cost is the indirect cost for storing an item, as the value of the product being stored could be invested elsewhere and generate a profit. These two together make up the inventory carrying costs and are seen as the opportunity cost of a redistribution. Thus, the operational inventory carrying cost and the capital cost are weighed against the costs of redistributing when deciding from a cost perspective if it is advantageous to redistribute or not.

Sandvik calculates both the operational inventory carrying cost and the capital cost as an annual percentage that is applied to the value of the product. The capital cost, as mentioned in section 5.2.1, is currently at 11 percent. Based on discussions with company representatives within the warehousing department, the current operational inventory carrying cost that is applied by SMCL throughout their operations is 12 percent. The costs are summarized in table 17.

Cost of storing goods	
Operational inventory carrying cost	12 %
Capital cost	11 %
Total opportunity cost	23 %

Table 17: The annual opportunity cost as a percentage of value for redistribution

This implies that the cost for storing a product for one year in any of SMCL's warehouses would cost them around 23 % of the product's value. Meaning that an item that has been stored for slightly more than four years has an accumulated cost of its entire value.

5.5 Summary

This subchapter aims to summarize the investigations that have been conducted in this chapter as well as the key-finding from the analysis. In Tables 18-19, the costs associated with redistributing aftermarket items, that will be used in the upcoming discussion, are presented.

In Chapter 5.1, a first analysis was conducted on OSMI-turnover rate for the different warehouses operated by SMCL. It could not be concluded that an arbitrary obsolete item in DI37 had a higher probability of being sold than an arbitrary obsolete item in DIC2. However, 76 % of the items that were obsolete in DIC2 were moving in DI37. This suggests that the majority of obsolete items in a DC can be used elsewhere within SMCL.

The second analysis, in Subchapter 5.2.1, investigated the transportation cost per kg for the different routes operated by SMCL. In this analysis, no differentiations were made between the spare parts and the wear parts. By applying the capital cost of 11 % to the difference in the lead time for the two different MOT for all routes, a threshold was calculated where air would be beneficial to use for redistribution from a cost-perspective. These thresholds were the EUR per kg the items should be worth to be advantageous to send by air. They were however quite significant, 160 EUR for the least expensive route, which means that it will only be beneficial from a cost-perspective to use air for a few extremely valuable items.

To differentiate the two items-groups within SMCL's aftermarket parts, the wear parts and spare parts, a second cost analysis was conducted in Subchapter 5.2.2. The redistribution costs were calculated as a percentage of the item's value, and was done for both wear parts and spare parts using both MOT. By also considering packaging material, no significant differences were found as it only added 5 % to the redistribution costs for the spare parts. Also, no general tolls could be applied, beside the 25% tariff for items produced in China that are sent to the US. Since only a fraction of the aftermarket parts are produced in China, it will not be applicable to many of the items distributed by SMCL.

The fixed order handling cost for the different routes was analyzed in Chapter 4.3. This analysis considered the costs for the laborers working within the warehouses and the administrative costs for planners within SMCL executing the redistribution.

A final analysis was then done on the inventory carrying cost in Chapter 4.4, which can be used to calculate the opportunity cost of a redistribution. This consists of both the operational inventory carrying cost of 12% and the capital cost of 11%, totaling to an annual cost of 23% of an item's value.

<table>
<tr><th>Route</th><th>Cost per kg by air [EUR/kg]</th><th>Cost per kg by sea [EUR/kg]</th><th>Fixed order handling cost [EUR]</th><th>Cost based on value by sea [% of value]</th><th>Cost based on value by air [% of value]</th><th>Inventory carrying cost [% of value]</th></tr>
<tr><td>DIC2 - DI37</td><td>2.98</td><td>0.36</td><td>42.35</td><td rowspan="5">13 %</td><td rowspan="5">61 %</td><td rowspan="5">23 %</td></tr>
<tr><td>C3 - DI37</td><td>2.45</td><td>0.27</td><td>32.36</td></tr>
<tr><td>DIC4 - DI37</td><td>3.16</td><td>0.30</td><td>---</td></tr>
<tr><td>DIC5 - DI37</td><td rowspan="2">6.75</td><td rowspan="2">0.39</td><td>37.36</td></tr>
<tr><td>DIC63 - DI37</td><td>42.77</td></tr>
</table>

Table 18: Summary of the costs associated with redistributing a wear part

<table>
<tr><th>Route</th><th>Cost per kg by air [EUR/kg]</th><th>Cost per kg by sea [EUR/kg]</th><th>Fixed order handling cost [EUR]</th><th>Cost based on value by sea [% of value]</th><th>Cost based on value by air [% of value]</th><th>Inventory carrying cost [% of value]</th></tr>
<tr><td>DIC2 - DI37</td><td>2.98</td><td>0.36</td><td>42.35</td><td rowspan="5">4 %</td><td rowspan="5">18 %</td><td rowspan="5">23 %</td></tr>
<tr><td>C3 - DI37</td><td>2.45</td><td>0.27</td><td>32.36</td></tr>
<tr><td>DIC4 - DI37</td><td>3.16</td><td>0.30</td><td>---</td></tr>
<tr><td>DIC5 - DI37</td><td rowspan="2">6.75</td><td rowspan="2">0.39</td><td>37.36</td></tr>
<tr><td>DIC63 - DI37</td><td>42.77</td></tr>
</table>

Table 19: Summary of the costs associated with redistributing a spare part

6 A cost-perspective on redistribution

This chapter will compare the cost of redistribution with the opportunity cost for different time-horizons and discuss when it will be advantageous to redistribute from a cost-perspective. Wear parts and spare parts, along with the two different MOT will be differentiated.

6.1 Overview

This section aims to compare the opportunity cost with the cost of redistribution. Because the aftermarket parts include both the wear and the spare parts, these will be differentiated in the analysis. There are also significant differences in the cost of redistribution for the two MOT, air and sea. Therefore, they will also be differentiated. For this entire chapter, the route DIC63-DI37 will be used to create the most conservative model as it is the most expensive route in terms of the fixed order handling cost. No route specific comparison was made, as it was not possible to determine the cost based on value for the different routes. Furthermore, the cost per kg calculated in Subchapter 5.2.1 did not differentiate between the wear parts and spare parts. Using the cost per kg for the following discussion would have meant that valuable insights would be missed as to how the differences between the item groups affect when certain items should be redistributed. Because of the significant fixed order handling cost associated with redistributing an item within SMCL, the value of the product is important when comparing the opportunity cost with the redistribution cost. This aspect will be considered by analyzing items of different values.

6.2 Spare parts

Within the spare part item group, the products' value ranges from a few EUR to several thousands of EUR. If for example a spare part worth 5 EUR were redistributed, the fixed order handling cost of 42.77 EUR would be significantly higher than the value of the entire product. Since no valuable information would be gained by comparing the redistribution cost with the opportunity cost for a spare part with such a low value, the following analysis is conducted on spare parts above the value of 50 EUR. The discussion in this section will be conducted on three examples of spare parts worth 50 EUR, 500 EUR and 5000 EUR as this is also the interval that spare parts typically fall within. The redistribution cost of these spare parts will be compared to the opportunity cost for storing the same items. The resulting graph will show for how many years an item must be stored for the opportunity cost to be equal to the redistribution cost using both MOT. In the figure, the x-axis is the number of years the item is stored, and the y-axis is the value of the item. The line shows when the opportunity cost and the redistribution cost are equal, where the upper line is for air as MOT and the lower line is for sea as MOT, and the initial value is for a spare part worth 50 EUR. The two red lines are meant to highlight the spare parts worth 500 and 5000 EUR. The results can be seen in Figure 3.

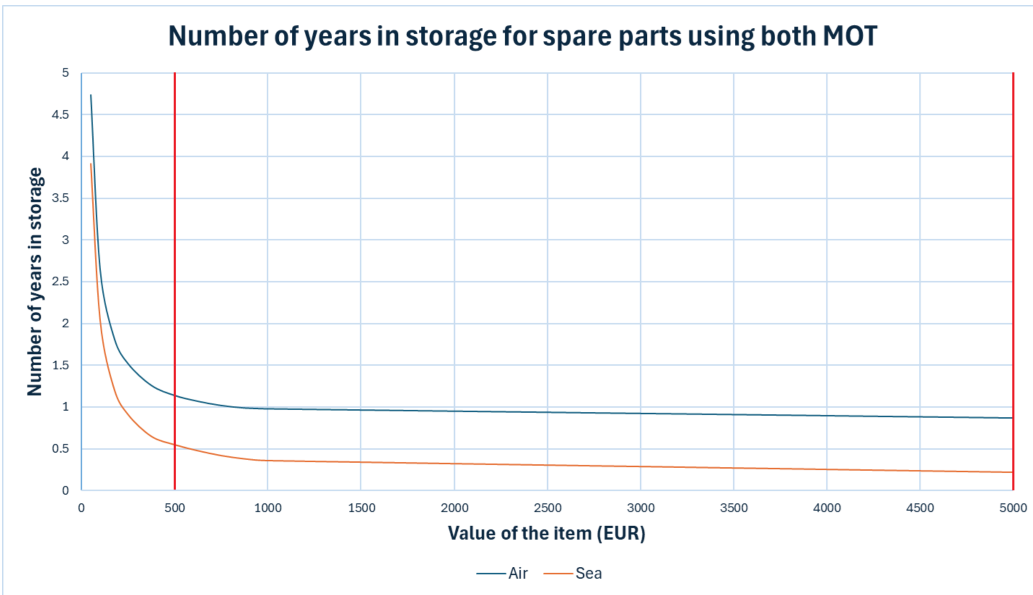

Figure 3: Number of years a spare part must be in storage for the opportunity cost to be equal to the redistribution cost for both MOT

By first analyzing the sea as MOT, it is seen that for a spare part worth 50 EUR, the opportunity cost is equal to the redistribution cost at around four years. This means that for an item in this category, it is more advantageous from a cost-perspective to leave it in any of the distribution centers for four years than to redistribute it to the CW, even if there is an immediate demand. However, it is also seen that the cost of storing an item for four years or redistributing the item would mean a cost of around 90 % of the product's value. This would mean that it might be more beneficial to scrap the product if there is no expected demand within 4 years and to produce a new unit when the item is needed again. For spare parts worth 500 EUR and 5000 EUR, the situation is quite different. The cost of storing these for one year is significantly higher than redistributing them. This would mean that it is only beneficial to leave these in the distribution center if there is a predicted demand locally within less than one year. Every S category means that the item is overstocked of at least one year worth of forecasted demand, which means that neither classification suggests that the item will be used within one year. Because of this, if these items are classified obsolete or slow-moving in a distribution center and moving in the central warehouse it will always be beneficial to redistribute them, since the opportunity cost for storing them for one year is higher than the redistribution cost. A trend that is also seen is that the more expensive the part is, the more beneficial it is from a cost-perspective to redistribute the item. This is due to the fixed order handling cost being lower relative to the value of the item.

By instead looking at air as the MOT, the upper line in Figure 3, some variations are found compared to sea. One difference is that it now takes nearly five years before the opportunity cost for the spare part worth 50 EUR to be higher than the redistribution costs. Also, the redistribution cost is above 100 percent of the value of the product. Both redistribution using air as MOT and storing the item for five years would cost significantly more than producing an entirely new item. It is in this scenario, from a cost-perspective, more advantageous to scrap the product and once there is a customer-demand to produce it again. The redistribution cost for a spare part worth 500 EUR is now higher than the inventory carrying cost after around 14 months of storing. The regional item-classification S1 means that there is an overstock equal to one year of forecasted demand. Thus, the expected time an item classified as S1 will be stored is one year. Because of this, a spare part worth 500 EUR would be disadvantageous from a cost-perspective to redistribute if it is classified as S1 in the distribution center and M in the central warehouse, as it is expected to move within one year. For the 5000 EUR spare part, it will always be more advantageous to redistribute the item if it is moving in the central warehouse and obsolete or slow-moving in a distribution center, since the opportunity cost is equal to the redistribution cost at around 11 months.

6.3 Wear parts

The wear parts mainly consist of mantles for the different crushers. These are large components varying from around 1000 EUR to several thousands of EUR. Because the wear parts are worth less per kg, the cost based on value to redistribute will always be higher for the wear parts than spare parts if they are redistributed with the same MOT and have the same value, as concluded in Subchapter 5.2.2. For this analysis to be as useful as possible, the analysis will be done on two wear parts with a value of 1000 and 10000 EUR which is the interval the wear parts typically fall within. The same analysis as in section 6.2, where the opportunity cost is compared to the redistribution cost, is conducted on these two wear parts where the two MOT are also differentiated. The resulting graph highlights how many years a wear part must be stored for the redistribution cost to be as high as the opportunity cost. The line shows when the opportunity cost and the redistribution cost are equal, where the upper line is for air as MOT and the lower line is for sea as MOT. The two red lines are meant to highlight the wear parts worth 1000 and 10000 EUR. The results are presented in Figure 4.

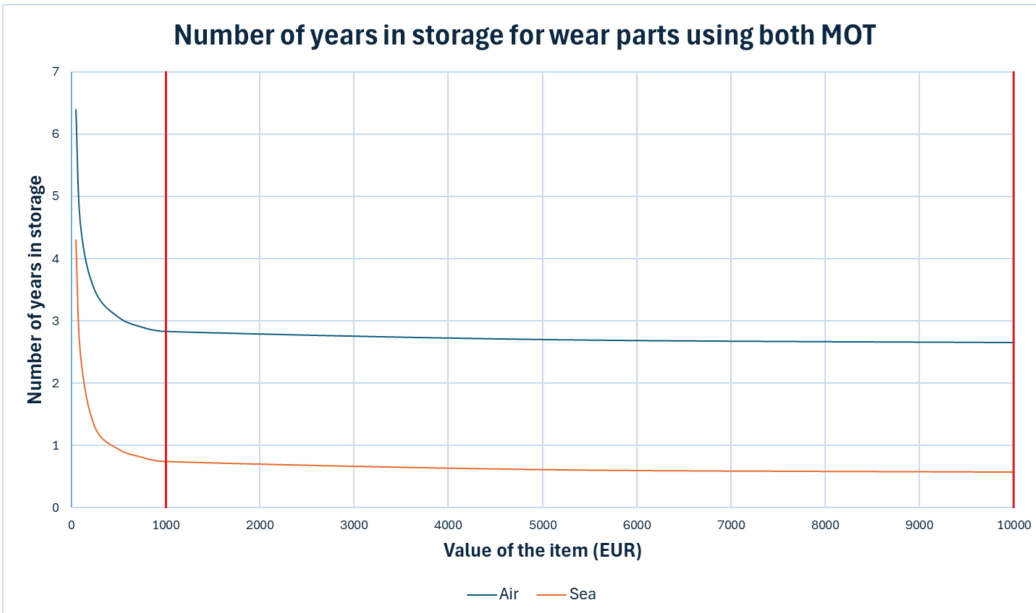

Figure 4: Number of years a wear part must be in storage for the opportunity cost to be equal to the redistribution cost for both MOT

Because the fixed order handling cost is more apparent for low value items, most of the redistribution cost consists of the transportation costs for the two analyzed wear parts. By first looking at sea as MOT, it is seen from the figure that the wear parts worth 1000 EUR have an opportunity cost as high as the redistribution cost after around 9 months. The same number for the wear parts worth 10000 EUR is 7 months. As a result, if these two types of items are moving in the central warehouse and are obsolete or slow-moving in a distribution center, it is always from a cost-perspective advantageous to redistribute them. This is because the opportunity cost for storing these items for one year is higher than the redistribution cost.

Considering that the redistribution cost based on value for the wear parts is 61 % using air as MOT, the opportunity cost should be lower than the redistribution cost for a significant amount of years. This can be seen by looking at the upper line in Figure 4. There is no significant difference between the wear parts worth 1000 EUR and 10000 EUR being redistributed by air. In both instances, the opportunity cost is as high as the redistribution cost at around three years. This means that redistribution by air would only be advantageous for these items if the expected time they will be stored was more than three years. Thus, if the item was classified as S4 or S5 in a distribution center and classified as M in the central warehouse, it would be cost-effective to redistribute them. As stated earlier, the profit margins are quite low for wear parts. From a cost-perspective, this means that air should never be considered if both MOT are available.

7 Redistribution framework

This chapter will begin with presenting two criteria for a redistribution to be advantageous from a cost-perspective and a discussion of these. Based on the criteria, a decision matrix will be constructed for the different item-groups and the different MOT.

The main objective with this thesis is to provide Sandvik with a framework that will help them understand which items from a cost-perspective should be redistributed to reduce their excessive stock in their distribution centers. Their goal is to free up capital with as little cost as possible. This framework will present what conditions need to be fulfilled for the redistribution to be cost-effective, as well as how wear parts and spare parts should be treated differently.

7.1 Criteria for advantageous redistribution

There are two criteria for a redistribution to be cost-effective and each will be discussed separately.

1. Redistribution costs should be lower than the cost of producing a new item, the cost of distributing the item from the PU to the CW, and the scrapping cost.

At the most fundamental level, for a redistribution to be advantageous from a cost-perspective, the cost of redistribution must be lower than the cost of producing a new item, distributing it to the CW and scrapping the old product. For example, take an obsolete item located in DIC2 that is moving in DI37. If this item had a redistribution cost above 100% of its value, it would cost less to scrap it and produce a new item and send it to the DI37 than it would be to redistribute it. This principle is true for all items, regardless of their classification. This thesis did not investigate the mechanisms and costs SMCL has for scrapping, as the scope would have become too big. For this reason, the scrapping cost is assumed to be 0. The distribution costs between the PU in Svedala and the CW were negligible compared to the value of the items, and was therefore also assumed to be 0. It means that this analysis will compare the production costs with the redistribution costs. If the redistribution cost is below the value of the product, the second criteria should be looked upon, and it is as follows:

2. The cost for redistribution should be lower than the opportunity cost for the extra time an item is expected to be stored.

For example, if an item in DIC2 is expected to be sold within a week, the opportunity cost of storing the item for one week would never be as high as redistributing it back to the central warehouse. By utilizing the OSMI-classification of Sandvik's products, it is possible to approximate the time for an item to be sold. Looking at S3, this means that there is an excessive stock equal to 3 years' worth of forecasted customer demand. Redistributing such an item to a place where it will be immediately sold would reduce the time the item is expected to be spent in storage by three years. In this scenario it is possible to compare the opportunity cost of storing the item for three years with the redistribution cost to see if it is advantageous to redistribute. If the item was categorized as S2 in the central warehouse but S3 in the distribution center, the cost of storing the item for one year could be compared to the redistribution cost, since the codes indicate that the item will be stored for one year longer in the distribution center as explained in Subchapter 4.2.1. By instead looking at an obsolete classified item in the distribution center, it is impossible to say how long such an item is expected to remain in storage. This is because no conclusive answer was found for the OSMI-turnover rate in distribution centers, as discussed in Section 5.1. It is therefore impossible to compare the redistribution cost with the opportunity cost for the obsolete classified items. For these items there is a risk that SMCL will pay the cost of redistribution, without achieving their goal of reducing the amount of excessive stock, since it is not known when obsolete items are expected to be sold. When Sandvik decides which items should be redistributed, other criteria that are not associated with cost could be used. Examples of this would be to fulfill certain service levels or to have strategically placed stock. This is beyond the scope of this thesis and will thus not be included in the framework.

7.2 Criteria 1 as foundation for redistribution

The first criterion is that redistribution costs should be lower than the cost of producing a new item. Depending on what item group an item belongs to and what MOT is used for the redistribution, the threshold when redistribution costs are less than what item is worth is different. For deciding when wear parts and spare parts using both MOT are worth more than the redistribution cost, the following decision variables are introduced:

A = Product value

HC = fixed order handling cost

TC = transportation cost

If the production cost is higher than the redistribution costs, i.e.

$$A > HC + TC \quad (5)$$

the items should be considered for redistribution. If it is less expensive to produce a new item than it is to redistribute, i.e.

$$A < HC + TC \quad (6)$$

the item should not be considered for redistribution. Since a newly produced item and a newly redistributed item in the CW must be transported the same way to reach the same customer, only the above costs have to be compared. When doing these calculations, the numbers for the transportation cost based on value presented in Chapter 5.2.2 will be used. The highest fixed order handling cost, 42.77 EUR, will be used to create the most conservative model. Using Formula 5 & 6, the threshold as to when criteria 1 is fulfilled is calculated for the wear parts and spare parts using the two MOT. The result is presented in Table 20 below.

Thresholds for criteria 1		
MOT	Wear parts	Spare parts
Sea	49 EUR	45 EUR
Air	110 EUR	53 EUR

Table 20: Threshold for different types of items using different MOT to fulfill criteria 1

All wear parts have a value of more than the calculated thresholds for air and sea. This means that they always fulfill criteria 1. For the spare parts, a substantial number of items have a value of less than 50 EUR. This means that a lot of spare parts can be completely disregarded when considering redistribution, as it will be less expensive to produce a new item.

7.3 Criteria 2 as foundation for redistribution

The second criterion is that the cost for redistribution should be lower than the opportunity cost for the extra time an item is expected to be stored. As stated earlier, it is possible to compare the costs of redistribution with the opportunity cost of the extra time an item is expected to be stored if not redistributed, to find out if it is advantageous from a cost-perspective to redistribute. The assumption for this analysis is that the difference in the number in the S classification between the distribution center and the central warehouse, is equal to how many years longer an item will be stored if not redistributed. For example, if an item is classified as S4 in DIC2 and S2 in DI37, it is expected to be stored for two extra years if not redistributed compared to being redistributed. To determine the cost where redistribution is lower than the opportunity cost, the following variables are introduced:

TCC = Total cost of capital

N = Number of extra years spent in storage if not redistributed

If the opportunity cost is higher than the redistribution cost, i.e.

$$TCC \times N > HC + TC \quad (7)$$

the item should be redistributed from a cost-perspective. In this formula, *TC* is the transportation cost and *HC* is the fixed order handling cost. Both were introduced in the previous subchapter. This calculation can only be done on items that are classified as slow-moving or moving in the distribution centers and in the central warehouse. As stated earlier, it is not possible to determine when an obsolete item in a distribution center is expected to move and will thus be excluded in the analysis. By using the above formula, a decision matrix can be created which will show when it is advantageous from a cost-perspective to redistribute based on item classification. This is done by applying formula 5 on every combination of S-classifications and M-classification an item can have in the central warehouse and in the distribution centers. As a result, a 6x6 matrix can be produced. The imaginary wear parts and spare parts and the two MOT used in Chapter 6 will be used when constructing the matrices. In this matrix, green indicates that it is advantageous to redistribute and red indicates that it is disadvantageous.

The amount of years it takes for the opportunity cost to be as high as the redistribution cost for a spare part worth 500 EUR and a spare part worth 5000 EUR was the same using sea as MOT. This means that the matrix will be identical and was for that reason combined into one. The spare part worth 50 EUR is excluded since it doesn’t fulfill criteria 1 and should therefore not be considered for redistribution. The results for the spare parts are seen in Tables 21-22.

	OSMI - code CW	M	S1	S2	S3	S4	S5
OSMI - code DC							
M							
S1							
S2							
S3							
S4					x	y	
S5							

Table 21: Matrix illustrating when it is advantageous to redistribute a spare part worth 500 and 5000 EUR using sea as MOT and 5000 EUR using air as MOT.

	OSMI - code CW	M	S1	S2	S3	S4	S5
OSMI - code DC							
M							
S1							
S2							
S3							
S4							
S5							

Table 22: Matrix illustrating when it is advantageous to redistribute a spare part worth 500 EUR using air as MOT.

The cell that is marked with an x in Table 21 is green. This means that it is from a cost-perspective advantageous to redistribute a spare part worth 5000 EUR that is classified as S5 in a distribution center and S4 in the central warehouse using air as MOT. This is because the redistribution cost by air is lower than the opportunity cost of storing the item for one year. The cell that is marked with an y in table 21 is red. This means that it is disadvantageous to redistribute a spare part worth 5000 EUR by air, that is classified as S5 in both a DC and the CW. This is because the redistribution cost is compared to an opportunity cost of 0 since the items are expected to be sold at the same time in both warehouses.

The same matrix was created for wear parts worth 1000 and 10000 EUR with both air and sea as MOT, using Formula 7 from above. However, for both MOT the matrices for the wear part worth 1000 and 10000 EUR were identical and were thus merged into one. This was because the amount of years for the opportunity cost to be as high as the redistribution cost was the same for the two items. The results are presented in Table 23-24.

	OSMI - code CW	M	S1	S2	S3	S4	S5
OSMI - code DC							
M							
S1							
S2							
S3							
S4							
S5							

Table 23: Matrix illustrating when it is advantageous to redistribute a wear part worth 1000 and 10000 EUR using sea as MOT.

	OSMI - code CW	M	S1	S2	S3	S4	S5
OSMI - code DC							
M							
S1							
S2							
S3							
S4							
S5							

Table 24: Matrix illustrating when it is advantageous to redistribute a wear part worth 1000 and 10000 EUR using air as MOT.

The above matrices can be used to understand when items that are categorized as slow-moving or moving, are advantageous to redistributed from a cost-perspective. However, two important scenarios are not present in the matrices, which will be discussed separately. The first scenario is that an item is classified as obsolete in the distribution center but moving in the central warehouse. For the slow-moving classification, the number indicates how many years' worth of forecasted demand is in storage. However, the number on the obsolete classification shows how many years an item has not been ordered, which means that no indication is given about the inventory levels for these items. Also, it was not possible to determine the OSMI turnover rate within the distribution centers. Creating a framework for this scenario under these circumstances would introduce a lot of assumptions which would decrease the validity of the results. However, it was concluded that the OSMI turnover rate for items classified as O1 was higher than for items classified as O4, which means that an O4 item is expected to be stored for longer than an O1 item. Also, if there was an order for an obsolete item with 1 unit in storage, it is 100 percent that the item will be utilized. If there instead is an order for an obsolete item with 100 units in storage, each item has a probability of 1 percent to be utilized. This means that the higher the inventory levels, the less likely it is that it will be utilized. Coupling these two facts together, a rule of thumb can be stated for this scenario:

The higher the obsolete classification is and the higher the inventory levels are for an item in a distribution center, the more advantageous it is to redistribute the item.

The second scenario is that the item is classified as slow-moving in the central warehouse and obsolete in a distribution center. For the same reasons as stated above, it is impossible to determine a threshold at which point redistribution will be advantageous. For the redistribution to be advantageous, the expected time the item will be stored should be as high as possible for the distribution center and as low as possible for the central warehouse. This is achieved by the slow-moving classification being low for the central warehouse, and the obsolete classification being high for the distribution centers. A rule is formulated:

The lower the slow-moving classification is in the central warehouse for an item, and the higher the obsolete classification is, and inventory levels are for the same item in a distribution center, the more advantageous it is to redistribute the item.

8 Conclusions

This chapter begins with the conclusion and discussion of the three formulated research questions presented in Chapter 1.3. It is followed by the contributions as well as suggestions for future work. The chapter will end with some reflections on the validity and reliability of the numbers used in this thesis.

8.1 Answering the research questions

(1) Does redistribution back to the central warehouse increase the probability that an item will be sold?

It could not be conclusively found that an arbitrary item classified as obsolete in both the central warehouse and a distribution center had a higher probability of becoming moving. However, it was found that most items that are obsolete in a DC are not obsolete in the CW. For these items it is, from an inventory level perspective, advantageous to redistribute because they have a higher probability of being moved in the central warehouse.

(2) What is the major cost-bearers associated with redistribution within SMCL?

The major costs associated with redistribution between the distribution centers and the central warehouse for SMCL were the logistics costs, the fixed order handling cost and the inventory carrying costs. The administrative cost was added to the fixed order handling cost, with the assumption that any given order line takes the same time to administer. The cost for loss and damages was according to company representatives too small to be worth included in the scope of this project. To compare the cost of redistribution with the cost of not redistributing, the opportunity cost was also investigated.

(3) What situations are redistribution advantageous from a cost-perspective?

Two criteria were identified for a redistribution to be advantageous from a cost-perspective. These criteria were:

1. Redistribution costs should be lower than the cost of producing a new item
2. The cost for redistribution should be lower than the opportunity cost for the extra time an item is expected to be stored

For items where criteria 1 and 2 are fulfilled, SMCL should consider redistribution. By applying the results from the analysis in Chapter 6, a decision matrix could be constructed to aid SMCL in understanding which components of different valuation fulfill these criteria. When creating the matrix, wear parts and spare parts as well as the two modes of transport, sea and air, were differentiated.

8.2 Contribution

This thesis has served a dual purpose. The first is the analysis conducted on the costs associated with a redistribution within SMCL. The second being the presented guidelines for which items a redistribution is advantageous from a cost-perspective. These two aspects will become useful when Sandvik creates a policy of which items should be redistributed to reduce excessive stock. As stated in Chapter 2.1, the results and conclusions from the analysis of a project such as this, are typically specific to the studied case. However, an argument could be made that general patterns could be found if another project done within a similar setting could produce a similar conclusion. While this might not be true, the employed methodology and the general process could be relevant for other studies conducted within the same field and with similar preconditions.

8.3 Future work

The thesis did not include an implementation phase of the produced framework. This means that the next natural step for Sandvik is to implement this framework and way of working to reduce their excessive stock while minimizing costs. Moreover, several interesting aspects and issues were found that could not be investigated due to the scope becoming too big, which could be looked upon in the future. To begin with, the company should investigate how scrapping should be handled as a complement to redistribution in regard to lowering their stock levels. From the presented framework, there are situations where redistribution costs are higher than the cost of the item. If they are categorized as obsolete, they will accumulate costs for being stored which means scrapping the product instead could be advantageous. Another aspect that should be investigated is the use of campaigns for their obsolete or slow-moving items. For some items, the redistribution cost would be a significant percentage of its total value. Instead of redistributing these, discounts could be offered to the customer. This could have the same effect on the inventory levels at a lower cost. Finally, other aspects such as service levels or strategic stock should be investigated in regard to redistribution to understand when the different modes of transport are advantageous. For example, to maintain good customer relations, it could be worth the cost to redistribute an item by air to have it available for a customer at an earlier time. By paying a higher cost now, the revenue can increase later. The same logic can be applied to strategic stock. This project did analyze the cost for the different modes of transport but did not provide any situation where air would be advantageous since the analysis was done from a cost-perspective. However, all these aspects could be interesting for Sandvik to investigate in their pursuit of lower inventory levels.

8.4 Methodical reflections

As stated in Chapter 2.4, reliability refers to the consistency of data collection, ensuring that the results are reproducible by others placed in the same situation. When calculating some of the numbers presented in the analysis, some assumptions had to be made since data was missing. An example of this happening was when the fixed order handling cost was calculated. Since there was no available data of the percentages of inbound and outbound labor costs, an approximate cost was calculated with some assumptions. By discussing the assumptions with company officials familiar with the process, the reliability of the results was kept as high as possible. By not having an inside perspective of the company that is investigated, some situations can occur where it is hard to know what numbers are correct and what numbers are wrong. An example of an issue regarding this phenomenon happened when the redistribution cost per kg was analyzed. The numbers of total kgs shipped over the different routes that were provided by a company official didn't account for a specific type of order. This resulted in the transportation cost being wrong with a factor of around 2. While it was easy for a company representative to see that the numbers were completely wrong, it was much harder from an outside perspective. By always discussing the results with a company representative for each step of the analysis, the validity was kept as high as possible.

9 References

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