Lund University

MASTER THESIS

Department of Industrial Management and Logistics

Forming a Strategy for Distribution Inventory Management

A study at Sandvik MRT

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PREFACE

This thesis, and the project from which it stems, concludes the two author's M.Sc. within Mechanical Engineering at the Faculty of Engineering at Lund University. The project was carried out in collaboration with Sandvik Mining and Rock Technology, product area Crushing and Screening, business unit Stationary, in Svedala Sweden. The author's would like to extend their sincere gratitude towards all involved actors at Sandvik for their invaluable guidance and support throughout the project. A special thank you to Marie Hallqvist and Miguel Rocha who have been of great importance in order for the project to be accomplished. Furthermore, the authors would also like to extend their gratitude towards Jan Olhager, supervisor from the Department of Industrial Management and Logistics at the Faculty of Engineering, for the valuable feedback and input he brought into the project.

Lund, June 2017
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ABSTRACT

Title: Forming a strategy for distribution inventory management: A study at Sandvik MRT

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Supervisors: Jan Olhager, Department of Industrial Management and Logistics
Marie Hallqvist, Sandvik SRP AB

Background: For most companies, especially the ones handling large flows of material there are buffers in different stages of the value chain, also referred to as inventory. By effectively managing inventories, businesses can see bottom line impact on financial performance factors such as revenue streams, costs and capital efficiency. Within the scope of managing inventories is a wide variety of areas, such as product segmentation, inventory control, network design, differentiation and postponement. These areas, were explored as they were applied while forming a strategy for inventory management at Sandvik.

Purpose: To improve supply chain performance through a strategy for inventory management

Research questions: (1) How should the items of Sandvik be segmented? (2) How should the different segments be differentiated in regards of inventory management? (3) How can the suggested strategy be realized at the case company?

Methodology: The authors built a relevant frame of references based upon theories within product segmentation, inventory control and management. By applying the methodologies found in literature on a case at Sandvik, a framework for product segmentation and inventory management could be developed. The framework was thereafter applied at the case company to form applicable strategies.

Conclusion: In order to fulfil the purpose, the most important factor to consider was material availability. Through a closer segmenting process, the products of Sandvik could be divided into the groups; *major components, components, commercial spare parts* and *wear parts.* It was concluded that in order to achieve availability a segmentation based on sales volumes for aftermarket and new equipment demand, taking regard to life cycle stages was to be conducted for major components. A segmentation based upon cost volume and frequency was to be carried out for components. Factors upon which the two product groups were to be differentiated were concluded to be *segmentation criteria, segmentation data, stockroom assortments, decoupling points* and *segmentation and inventory control process.* To realize suggested strategies at the case company the authors created decision support tools to be implemented at the case company.

Key-words: Product segmentation, product classification, inventory management, network design, aftermarket, spare parts, mining and construction market

SAMMANFATTNING

Titel: Utformning av en strategi för lageradministration inom distribution: En fallstudie på Sandvik MRT

Författare: Jacob Mauléon Lundberg, Joakim Beckvid Tranchell

Handledare: Jan Olhager, avdelningen för Teknisk Logistik
Marie Hallqvist, Sandvik SRP AB

Bakgrund: För alla företag, speciellt de som hanterar stora materialflöden, finns buffertar, också kallade lager, i olika delar av värdekedjan. Genom att effektivt hantera dessa lager så kan företag uppleva resultat på de mest fundamentala nyckeltalen: intäkter, kostnader och kapitaleffektivitet. Inom ramen för lageradministration ingår ett flertal områden, såsom produktsegmentering, lagerstyrning, nätverksdesign, differentiering och senareläggning, som är vidare utforskade i denna rapport då de appliceras vid utformning av strategi för lageradministration på Sandvik.

Syfte: Att genom en strategi för lageradministration förbättra prestationer utefter värdekedjan

Forskningsfrågor: (1) Hur bör Sandviks produkter segmenteras? (2) Hur bör de olika segmenten differentieras gällande lageradministration? (3) Hur kan föreslagen strategi realiseras hos fallstudieföretaget?

Metod: Författarna formade en referensram av relevanta teorier och koncept inom områdena för produktsegmentering, lagerstyrning och -administration. Ett ramverk för produktklassificering och lageradministration utvecklades genom att applicera funna metoder på en fallstudie hos Sandvik. Ramverket kunde därefter appliceras hos företaget för att forma applicerbara strategier.

Slutsatser: För att uppfylla syftet drogs slutsatsen att den viktigaste faktorn att ta hänsyn till under projektet var tillgänglighet av material. Genom en indelning av de olika produkttyperna som Sandvik hanterar kunde grupperna *major components, components, commercial spare parts* och *wear parts* tas fram. För att nå bättre tillgänglighet skulle en segmentering baserad på försäljningsvolym, med hänsyn till eftermarknads- och nymaskinsförsäljning, i kombination med livscykelstadier utföras för major components. Motsvarande segmentering skulle utföras på kriterierna kostnadsvolym och frekvens för components. För att differentiera hanteringen av produktgrupperna undersöktes följande områden; *segmenteringskriterier, segmenteringsdata, standardsortiment, frikopplingspunkter* och *segmentering- och lagerstyrningsprocesser*. Författarna utvecklade verktyg för att kunna realisera rekommenderade strategier hos fallstudieföretaget.

Nyckelord: Produktsegmentering, produktklassificering, lageradministration, lagerstyrning, nätverksdesign, eftermarknad, reservdelar, gruv- och konstruktions-marknaden

TABLE OF ABBREVIATIONS

3PL - Third Party Logistics provider

BA - Business Area

BB - Black Belt

BU - Business Unit

DC - Distribution Centre

DL - Director Logistics

ELM - External Logistics Manager

EOQ - Economic Order Quantity

ERP - Enterprise Resource Planning System

FGI - Finished Goods Inventory

IS - Inventory Specialist

LD - Logistics Developer

M3 - ERP system at Sandvik

OSMI - Obsolete or Slow Moving Item

PA - Product Area

PCM - Planning and Capacity Manager

PILM - Procurement and Inbound Logistics Manager

PLM - Product Line Manager

R&D - Research and Development

RLM - Regional Logistics Manager

ROP - Reordering Point

S21 - System 21 one of Sandvik's internal information systems

SC - Sales Coordinator

SKU - Stock Keeping Unit

SMC - Sandvik Mining and Construction

SMCL - Sandvik Mining and Construction Logistics

SMRT - Sandvik Mining and Rock Technology

SSC&S - Sandvik Stationary Crushing and Screening, also referred to as "Sandvik"

1. INTRODUCTION

This chapter presents the background of the subject for the project, describes the case company and the problem formulation. It will introduce the purpose of the project as well as focus area and delimitations.

1.1. Background

For most companies, especially the ones handling large flows of material there are buffers in different stages of the value chain, also referred to as inventory. The mismatch between supply and demand for any given time explains the existence of inventory (Chopra & Meindl 2013). Anupindi et.al. (2003) explains that holding inventory, both can help to keep up process throughput as well as achieve economies of scale. By effectively managing inventories, business can see bottom line impact on financial performance factors such as costs and capital efficiency (Silver, 1983). Furthermore, offering availability increases customer responsiveness which has impact on revenue streams (Chopra & Meindl 2013).

Within most inventories, a very wide range of items are present that have high variations in characteristics on several dimensions. To treat all items according to the philosophy "one size fits all" is not effective whereas handling every item separately is not feasible. Therefore, it is deemed favorable to segment the items into a smaller number of classes according to certain characteristics, thereafter, treat each class separately (van Kampen et al., 2012). The most well known technique, the ABC-analysis, meaning that A are a few products that represent the largest part of e.g. the cost-volume, C is vice versa and B in the middle. It is possible to use other criteria for the segmentation, as well as multiple that can be weighted together. Whilst deciding on criteria it is key that it serves the purpose of the segmentation. Criteria such as cost-volume, frequency, criticality and lead times are commonly used (Flores and Whybark, 1986).

In addition to product segmentation, inventory control is an important part for inventory management. Axsäter (2006) and Silver et al. (1998) describe a wide variety of tools, equations, measurements and mechanisms that serve the purpose of quantitatively optimize the controlling of inventory. Among others, concepts such as forecasting, inventory driven costs, ordering systems and service levels are central for inventory control.

Inventories' geographical locations and positions within the value chain are factors that have influence on the effectiveness of the inventory. For example, Billington et al. (2004) describes how Hewlett-Packard improved their supply chain profitability by analyzing their network design through different scenarios. Another tool that can help companies respond to diverging market demands and conditions is differentiation, Dell, for example, created different supply chains to handle diverging market demands (Simchi-Levi et.al, 2013). At last, the principle of postponing both geographical movements and value adding activities can increase flexibility towards variability in demand (Persson,1995). The areas mentioned above all play a role for this project, which takes a wide scope by exploring the process of forming strategy for inventory management.

1.2. Company description

This study has its background in Sandvik Mining and Rock Technology, product area, PA, Crushing and Screening, business unit, BU, Stationary, hereby referred to simply as Sandvik or the case company. This project stems from Sandvik's ambition to improve its supply chain performance through improved inventory management.

Sandvik Group was founded in 1862 by Göran Fredrik Göransson, since its inception until today the operations of Sandvik Group has been characterized by high focus on quality, investments in R&D, customer relationships and exports (Sandvik, 2017).

Sandvik Group is a global actor within its three BAs, business areas, Machining Solutions, Mining and Rock Technology and Materials Technology. Sandvik Group had an annual revenue of 82 Billion Sek in 2016. Sandvik has its headquarters in Svedala, Sweden, from which it serves a global customer base with equipment, wear parts and spare parts for stationary crushing and screening of rock.

The Svedala site is central for Sandvik's operations, the activities stretch from management to research and development to production. The production site has three major value adding activities: forging, machining and assembly of equipment.

1.3. Problem formulation

Sandvik serves a global customer base with stone crushers, also referred to as new equipment or equipment, and aftermarket spare parts. In order to fulfil the customer expectations, the right items have to be in the right place, at the right time to the right quantity. This makes effective management of inventory an important factor in order for Sandvik to achieve its goals.

Since the instating of the new CEO Björn Rosengren at Sandvik group, organizational changes have started to form and been carried out. Most important in relation to the project for the master thesis, is the decision to move from a centralized logistic function to a decentralized one. This has triggered the start for the development of an independent logistics function within the business area Sandvik Mining and Rock Technology. Furthermore, the business unit Stationary Crushing and Screening is now bringing home the aftermarket logistic function, which previously has been run by a separate legal entity from Ireland. The change from one organizational structure to another has not been entirely carried out resulting in some old structures still existing and leading to difficulties in re-organizing and creating new ways of working.

Because some structures from the old organization still exist they are not created to fit how the organization should be structured today. This requires Sandvik to develop a business unit strategy for managing their inventory for both new equipment and the aftermarket. Within this integration lies both challenges as well as opportunities, which will be explored in this thesis.

Furthermore, a catalyst for this project is the low ability to realize the business potential of aftermarket sales. According to Sandvik, poor performances along the supply chain have led to a reputation of poor reliability resulting in aftermarket sales being lost to competitors. According to Sandvik they only capture 30-45 percent market share of the aftermarket for their own crushers. How inventory is managed have had and will have impact on Sandvik's performance in terms of revenue streams, customer service, operational costs and working capital.

1.4. Purpose of study and research questions

The purpose of this study is to improve supply chain performance through a strategy for inventory management.

To carry out the purpose of the thesis the following questions are to be answered by the authors during the project:

1. How should the items of Sandvik be segmented?
2. How should the different segments be differentiated in regards of inventory management?
3. How should the suggested strategy be realized at the case company?

1.5. Project focus, delimitations and company directives

This report has its main focus on the process of forming a strategy for inventory management at Sandvik. This process involved the major steps of analyzing demand, product segmentation, network design, policies for inventory control and differentiation. This project was closely connected to the case company's development in the field of inventory management, hence a wide spectrum of analysis areas were touched upon. Furthermore, the feasibility and speed of implementation was considered especially critical for this project.

This project focuses solely on the BU Sandvik Stationary Crushing and Screening. First priority was to analyze the product group major components, thereafter, if time was given, components were to be handled. Demands and customers were analyzed on a global level where both new equipment and the aftermarket are within the scope of this project.

This project was limited in terms of time and data accessibility. Therefore, the following delimitations was decided upon: other manufacturing plants than Svedala, such as Pune in India and Jiading in China are not considered whilst analyzing the network design. Items connected to screening media within the BU are excluded. All types of return flows upstream the value chain are ignored in the analysis. For the product group components, the project is narrowed to studying a global serving assortment, however, the formed process and methodology is applicable whilst deciding on assortments and inventory levels in the regional distribution centers, DCs.

Due to the close connection to the case company's development and parallel projects, company directives play a major role in this project. In many cases with increased complexity and strict time constraints, company directives are followed. Although, new perspectives and insight from the authors was valued, experience and knowledge among stakeholders at Sandvik was necessary to keep up the pace of the project. All company directives are explained throughout the text, the most significant ones being the usage of the service test heuristic, exclusion of components with costs below 40 EUR and the priority of analysis among the product groups.

2. METHODOLOGY

This chapter explains and motivates which research strategy and design have been used for this thesis. It aims at explaining how this study was executed to help the reader better understand how and why insights and conclusions are found and made. Furthermore, the section also deals with the quality of this research.

2.1. Research strategy

According to Höst et al. (2006) the selection of methodology should depend on both characteristics and goals of the project. The strategy of a study can be either descriptive, exploratory, explanatory or problem solving.

The purpose of this study is based on a practical problem at Sandvik that was to be solved, hence this project is of problem solving nature. To fulfil the purpose, the strategy and answer the research questions a research strategy was laid out which is visualized in
Figure 1 below. By analyzing how relevant theory can be applied to the practical problem at Sandvik, a solution to the problem can be achieved. Furthermore, this analysis contributes with insights on how the application of theory within the field of inventory management should be performed based on the situational factors at Sandvik.

Figure 1: *Visualization of research strategy of this project (source: authors)*

Research questions 1 and 2 are both regarding how the application of theory should be performed at Sandvik as well as offers an actionable solution to the practical problem at Sandvik. Research question 3 is limited to the solution of the problem.

The unit of analysis for this project is the actual items, material flow, buffers, demand, information flow and administration of the value chain for major components and components at Sandvik. See Figure 18 in section 4.4. for a visualization of the supply chain. The value chain that is analyzed stretches from inbound buffers at the Svedala site and to aftermarket sales customer demand for components, furthermore within the study of major components new equipment customers is within the unit of measure.

2.2. Research design

In order to fulfil the strategy, a more detailed research design was constructed which is visualized in Figure 2 below.

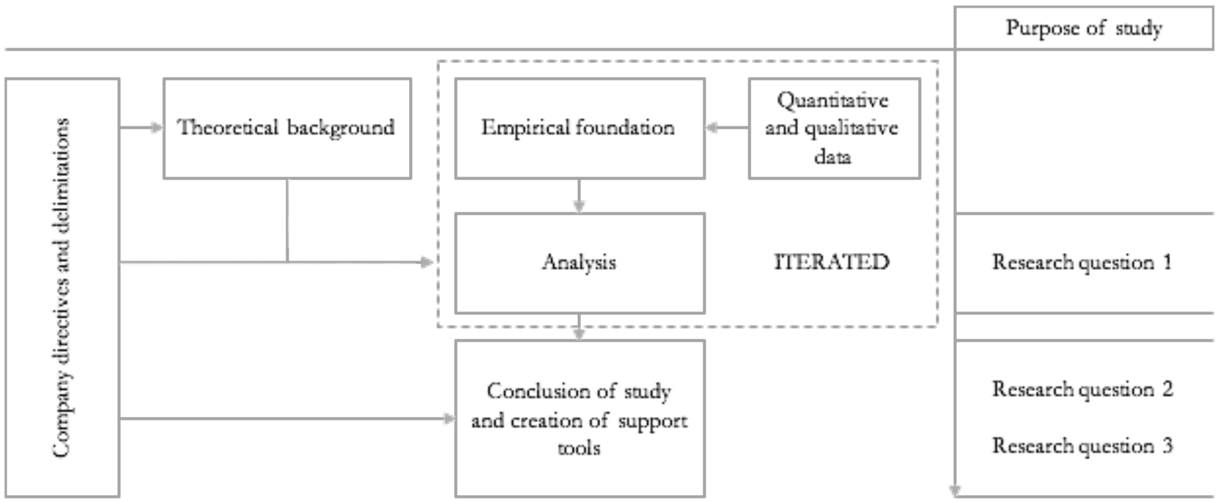

Figure 2: *Research design of this project (source: authors)*

For this project, a wide variety of areas that was to be covered, therefore company directives and delimitations had high influence on the course of this project. A theoretical foundation was first formed which then was to be applied to the situation at Sandvik. To understand the situational factors at Sandvik, both quantitative and qualitative data was collected to form an empirical foundation. In this case the quantitative data lay an important ground for the analysis since it could measure and evaluate the situation numerically, such as inventory levels, investments and costs. Qualitative data contributed to a deeper understanding of the situation at Sandvik, e.g. what criteria is important for the segmentation and what the impacts the organizational changes had on inventory management.

The process of gathering qualitative and quantitative data, forming empirical foundation and analysis was iterated first over the different areas of the project, see chapter 5:

1. Mapping of global demand
2. Product segmentation
3. Network design
4. Inventory control

First this was performed on major components. After that, the same process was iterated for the components. However, the results differed significantly among the product groups. Research question 1, regarding product segmentation was answered through the results of this analysis. For this process, company directives and limitations plays an important role in terms of what data was gathered and in some cases how the analysis should be performed.

When the analysis had been performed for the major components and components, the differences in the analysis results could be compiled into a differentiation table, answering research question 2. Furthermore, as the process itself could be compiled and form basis for support tools, that can help realize the strategy, answering the final research question.

2.3. Research execution

2.3.1. Forming theoretical background

Based on the outcome of the first phase of the project, such as a problem formulation and research questions, it was possible to identify which areas were to be of focus within the study. In order to gain sufficient knowledge within the field and to form a relevant framework of established theories and methods, a number of areas within academia were to be studied. Combining prior knowledge and consultations with the thesis supervisor with the problem discussion, certain areas of study could be identified. The primary areas of study and the areas' interrelations are presented in Figure 3.

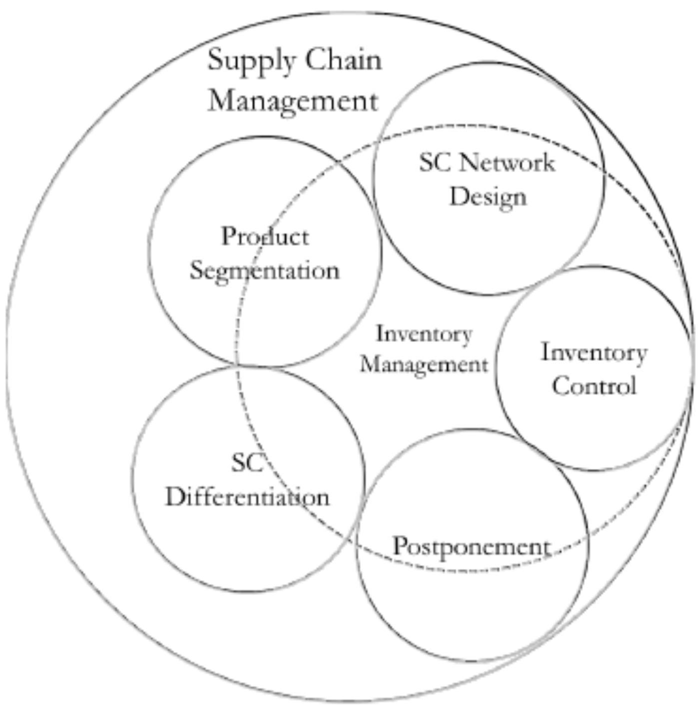

Figure 3: *Areas within academia for the theoretical foundation (source: authors)*

The study was initiated by a broad approach, gathering information within the outer layer of Figure 3, supply chain management, to further isolate relevant areas of study. Thereafter, each area deemed important, bordering the area of inventory management, were studied in such a way that concepts and methods could be compiled into section 3., *theoretical background.* Well established books and academic journals were consulted in order to find relevant information within the fields. Databases such as Web of Science, EBSCOhost and JSTOR were searched with the help of keywords to find literature sources. As earlier mentioned, the authors started with a broad approach using keywords such as “supply chain management” and “inventory management”. Further on the keywords became more specific and combinations were used, e.g. “Multi criteria ABC-analysis/inventory control”. Sources were partly verified by sorting on most citations, when possible, and also by cross referencing with thesis supervisor.

2.3.2. Data collection

During the first phase of the project, the author’s main goal was to get acquainted with the situation at the case company and the problems which the stakeholders were facing. The phase was colored by being introduced to the different stakeholders of the company, see Appendix 1. During these meetings information was gathered about stakeholder roles and responsibilities within the organization. Open interviews and observations took place which started to build the foundation for forming an empirical foundation, and being able to formulate a problem discussion. Data was collected throughout the project in order to validate courses of action, explore the different problem areas and to be able to conduct the analyses. The area into which most data was gathered is the empirical foundation.

There are several ways of collecting data in order to carry out a study such as this one. Some of the most common ways are through: interviews, observations, surveys and literary sources (Denscombe, 2016). Certain degrees of freedom exist whilst choosing data collection methods but there are also some connections between collection method and research strategies. Furthermore, each method has its own strengths and weaknesses but it is important to bear in mind to try and apply those methods that work best in practice and in one’s particular context, rather than trying to find one which is better than the rest (Denscombe, 2016).

This study takes both qualitative and quantitative data in regard. Therefore, several data collection methods have been utilized. Below follow descriptions of each method used and how it has been put to use in this study.

Interviews

Interviews make out one of the most important modes for data collection (Yin, 2007). An interview can be held in three main manners; structured, semi-structured or unstructured

(Denscombe, 2016). The structured interview makes use of a set interview guide which is followed strictly and questions are answered face-to-face. A semi-structured interview makes use of a predetermined interview guide but the order of the questions and the exact format of the questions can be adjusted throughout the interview. The interviewer will also allow the interviewee to elaborate on further thoughts concerning their answers. During an unstructured interview the goal is for the interviewee to lead the discussion forward without necessarily being guided by further questions by the interviewer (Denscombe, 2016).

While in the early phases of the research process, large amounts of information were to be gathered. Primarily about the current situation at Sandvik but also information regarding different stakeholders and their take on the problems at hand as well as information leading to an understanding of how the case company functioned. Therefore, during this phase, the format of unstructured interviews proved to be the best course of action. Large amounts of qualitative information were possible to be acquired with little knowledge about the wanted outcomes. This type of interview could be held with many stakeholders, individual and several at a time, at short notice.

Since this project consisted of several stages, and multiple analyses, data gathering through interviews played a part throughout the majority of the project's time span. Although, a shift from unstructured towards semi-structured interviews took place the further into the project the interviews were held. Stakeholders were consulted when the project was in need of data input, guidance or directives. With better understanding of the project and current tasks at hand, more specific questions and interviews were possible to direct at the stakeholders within the company.

Interviews were conducted with stakeholders throughout the organization in Svedala. The choice of interviewee was based on referrals from previous interviewees, certain responsibilities held or specific knowledge which they possessed.

Observations

To observe a phenomenon first hand is a common way of collecting data for a project such as this thesis. An observation can be conducted with the observer's senses but also with the help of technologic aids to collect data from different situations (Höst et al. 2006). Because an observation is performed where and when a phenomenon takes place it is a useful tool to answer questions such as how and why.

According to Höst et al. (2006) there are certain degrees of participation one as an observer can utilize. They can be used in combination with different degrees of the observed subject's awareness of being observed. Table 1 describes four categories of observations which develop when combining the two.

Table 1: *Different categories of observations, adapted from Höst et al. (2006)*

Participation \ Awareness of observation	High	Low
High	Observing participant	Complete participant
Low	Participating observer	Complete observer

Observations were used throughout the study in situations such as meetings, workshops and tours around the production site. During these occasions all data collected was transferred into notes and thereafter documented. Observations served as efficient modes of data collection during meetings and such, due to the ability of taking in large portions of data. The roles taken by the authors in these situations were primarily participating observer or observing participant because of the subjects' knowledge about the project being conducted. The degree of participation varied based on the nature of the situation and the need for the author's involvement.

In the early phase of the project, the authors were guided around the Svedala site for a tour, this clarified the value adding processes at Sandvik. Furthermore, a workshop was held with a simulation software provider where current processes within the supply chain were discussed as well as problem areas. During the project, the authors were invited for a trip to the Netherlands observing the operations of another BU's warehouse within Sandvik group and the port of Rotterdam. The observation could in some senses serve as a benchmark within a few of the problem areas.

Documentation

For this project, the databases within Sandvik were crucial. The authors found demand data and data regarding current inventory balances necessary for this project. Most data needed for this project was scattered among different systems and access was also scattered among the different stakeholders at Sandvik. Figure 4 below visualizes how the data was structured and what data was used from the different databases at Sandvik. Because of the large spread among the sources of data, the data gathering and validation became challenging. Furthermore, there was limited metadata with definitions on what the different columns contained and how they should be interpreted. The main sources of this type of qualitative data were two enterprise resource systems; M3 and S21. Furthermore, data was collected through QlikView reports, operational reports and from master data bases.

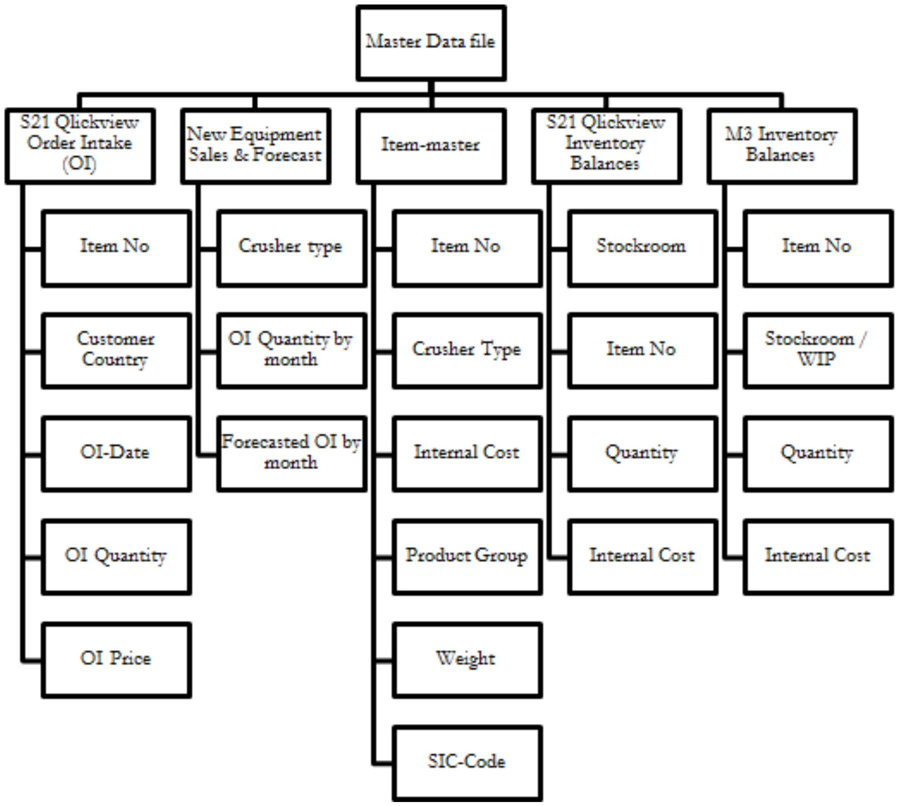

Figure 4: *Database structure at Sandvik and collected data (source: authors)*

In order to gather data from the databases, the authors needed to receive thorough instructions on how to utilize said databases and to access correct data.

In addition to database data there was other documentation used such as internal documents regarding organizational structure, company strategy and network design of global DCs.

2.3.3 Data analysis

After quantitative and qualitative data has been collected, an analysis needs to be performed. According to Yin (2007) data analysis in a study can be difficult to perform due to loosely defined strategies and techniques. Therefore, a general approach is sought after regarding what to prioritize and why.

Qualitative data analysis

Höst et al. (2006) present a framework in four steps for analyzing qualitative data. The different steps are repeatable since qualitative studies often times are flexible.

- Data collection: Includes performing interviews, observations, transcribing etc.
- Coding: Identifying key phrases or statements and couple these with certain key words
- Grouping: Text segments which have been coded are grouped so it becomes possible to study what different people have said in relation to the key words. It is thereafter possible to analyze patterns in what is stated about the key words
- Conclusions: Based on the grouped data it is thereafter possible to draw relevant conclusions

Qualitative data was collected mainly through interviews and observations as described in section 2.3.2. The output from the data collection methods were thereafter compiled and documented so as to perform partial codings and groupings in order to understand and analyze the entire situation at the case company. Coding and grouping played a specifically large part in the process of determining criteria for segmentation. This because large amounts of information were gathered on the topic from several data sources. Each data source also possessed different preferences based upon their respective role within the organization. This made it useful to be able to find patterns and commonalities between the different data groups.

Quantitative data analysis

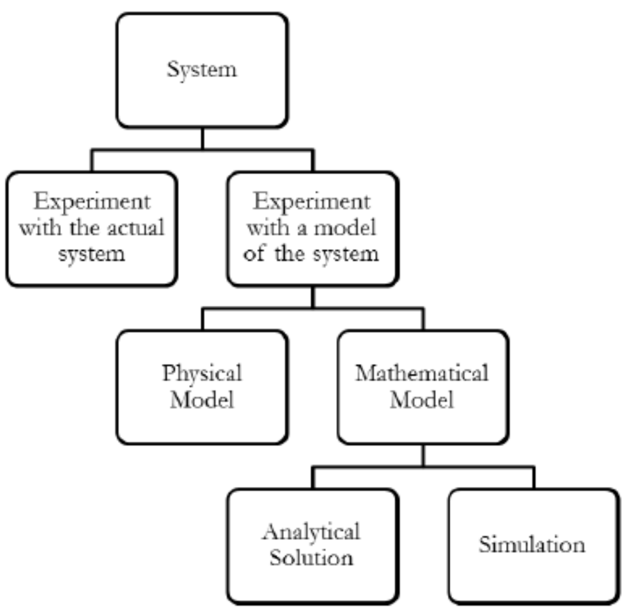

Figure 5: *Model for quantitative analysis as adapted from Law and Kelton (1997)*

For the more quantitative aspects of the thesis a quantitative approach to the analysis is needed. Law and Kelton (1997) presents a model to conduct a quantitative analysis of a system, see Figure 5. The system can be analyzed by either performing experiments on the actual system or on a model of the system. The approach chosen was to conduct experiments on a model of the system since the alternative would be to implement changes in Sandvik's current system which in different aspects would be impractical.

The next choice stands between a physical model and a mathematical model. Due to the project's characteristics a physical model is not a feasible alternative why a mathematical model is the logical choice. For the last branch in Law and Kelton's model the choice stands between an analytical solution and simulation. The choice will be a combination of the two since simpler simulations will be used in combination with the analytical solution.

For most parts of this project, analytical solutions were used e.g. when adding up the investments or mapping of the global demand. For the service test heuristic however, simulation was conducted in order to process the historic demand for the large number of items.

In order to synthesize the different databases shown in Figure 4, it was important to use the columns that was common for the databases, e.g. item number is used in most databases, hence information could be retrieved and aggregated thanks to this kind of link between the databases.

2.4. Research quality

Within research it is necessary to ensure a high credibility in order to reach a high quality study. The concept of credibility is based on two main factors; validity and reliability (Arbnor & Bjerke, 1997). To have validity is to measure what is intended with the research while reliability can be described as the stability of the measure, repeated measurements have the same results (Höst et al., 2006).

Gibbert et al. (2008) discuss four main criteria to use when assessing the rigor of a study such as this one.

- Internal validity: The causal relationships between variables and results
- Construct validity: "Does the study investigate what it claims to investigate?" The quality of conceptualization of relevant concept
- External validity: Theories should be shown to be applicable to situations different than the studied. Also known as generalizability.
- Reliability: The study should be possible to repeat with the same steps and still end up with the same results, random errors should be absent

Gibbert et al. (2008) discuss a number of ways to ensure research credibility. In Table 2 the tactics are presented along with selected measures taken in this case, for each of the four topics discussed above.

Table 2: *Ways of ensuring research credibility and how it has been achieved in the study. Adapted from Gibbert et al. (2008)*

Test	Examples of tactics	How it was incorporated in the study
Internal validity	• Formulate clear research framework • Pattern matching • Theory triangulation	• Matched collected empirical data with theoretical framework • Utilized multiple sources for theoretical foundation
Construct validity	• Clear chain of evidence • Triangulate data collection • Key informants review report	• Data collected through multiple sources and methods • Data validated and continuous reviewal with multiple informants within Sandvik
External validity	• Cross-case analysis • Use theory	• Developed theoretical foundation
Reliability	• Produce study protocol • Create study database	• Notes taken during observations • Documented meetings

Within this project the internal validity was created by thoroughly matching collected empirical data to the theoretical framework, that came from from a wide variety of sources which our supervisor confirmed as well established concepts. To construct validity, the authors collected data from multiple sources to triangulate the findings, furthermore the critical data was validated with relevant stakeholders at Sandvik. Regarding external validity, the analysis is based upon the situational factors at Sandvik, hence the generalizability of the result of this project is low. However, since the theoretical foundation is based on well established concepts, the considerations regarding application become generalizable. At last reliability was created through taking notes of observations and interviews. In regards of the quantitative data analysis, much of the steps were repeated to check that the results are the same to minimize the risk of errors.

3. THEORETICAL BACKGROUND

This chapter presents the theoretical foundation within supply chain management on which the thesis is based upon. Relevant terminology and concepts which is used throughout the project is described. Firstly, theory regarding inventory management and inventory control is discussed, followed by product segmentation. At last, a review of strategies and tools for inventory management are discussed. Figure 6 *illustrates the interrelation and hierarchy of concepts discussed in this section.*

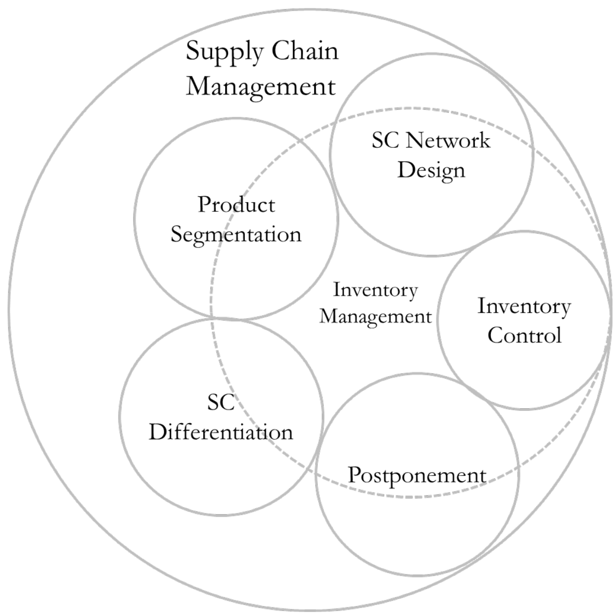

Figure 6: *Theoretical concepts map (source: authors)*

3.1. Inventory management

This section introduces the foundation of inventory management. It discusses the basic nature of business processes, flows and its relation to inventory. After that, the key drivers for carrying inventory are presented followed by an explanation of how managing inventory affects bottom line business performance.

3.1.1. A process view of an organization

To explain the concept of inventory and its purpose, Anupindi et.al. (2003) first introduced the process view of an organization as seen in Figure 7.

Figure 7: *The process view of an organization (adapted from: Anupindi et.al. 2003)*

According to Anupindi et.al. (2003) there are five elements that describe this flow and transformation from input to output. The five elements are described below and in Figure 8 their interrelations are illustrated.

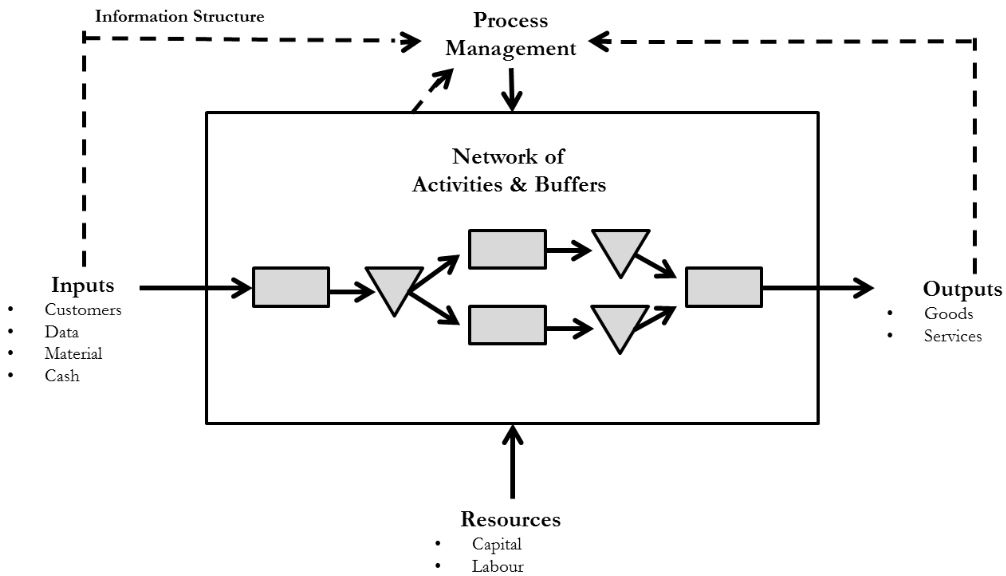

Figure 8: *A Process as a network of activities and buffers, source (Anupindi et.al. 2003)*

Inputs and outputs

As inputs flows through a process it is transformed to outputs as it leaves the process.

Flow units

Flow units is the type of item being transformed in a process, typical examples of flow units are: orders, products, components, cash and customers.

Network of activities and buffers

An activity is the simplest form of transformation; together activities are building blocks for processes. Buffers store the flow units that have finished one activity and are waiting for the next activity to start. All storage within a buffers and activities in a business process is referred to as inventory. The network visualizes how activities and buffers are linked and the sequential relationships that determines what activities has to be finished before initiating another can be started.

Resources

Resources are tangible assets that can be allocated to facilitate the transformation during a process. Resources can be categorized into two categories: capital and labor. Capital resources are fixed assets such as building, machines and information systems. Labor resources are people such as engineers, machine operators and sales staff.

Information structure
This structure shows what information is available and what information is needed to perform activities and take decisions.

3.1.2. Purpose for carrying inventory

Chopra & Meindl (2013) explain that the existence of inventory in the supply chain is due to a mismatch between supply and demand at a given time instance. Inventory buffers stock for anticipated future demand. Carrying inventory implies costs for any organization, which are described in (section 3.3.3). Yet organizations choose to use inventory through their processes. A part of this inventory is needed in order for the process throughput not to be reduced, which is called theoretical inventory. However, organizations often choose to carry inventory at levels far exceeding theoretical inventory, Anupindi et.al. (2003) elaborates on four drivers for this:

Economies of scale
A process has economies of scale when the average unit cost of output decreases with volume. Within supply chain management economies of scale usually arises within procurement, transportation and production. When there are economies of scale, managers find it more economical to order, produce or deliver with less frequency, leading to a higher average inventory.

Production and capacity smoothing
As demand can have foreseeable variability according to seasonal changes (see section 3.3.2) it might be more economical to have a constant processing rate, called a level production strategy. This implicates building up stock in low demand seasons and depleting them when demand is high. The opposite, chase demand strategy means producing to match demand for each time unit. If level production strategy or chase demand strategy is favorable depends on the relation between fixed cost for capacity and variable cost for holding inventory. High fixed cost for capacity and low variable holding cost favors level production strategy and vice versa favors chase demand strategy. Often the reality is somewhere in between, searching for the optimal combination of these strategies is called aggregate production planning.

Stock out protection
By holding inventory, organizations can be protected from unexpected disruptions of supply or surges in demand. Examples of disruptions could be strikes at suppliers, transportation delays or fire. This can result in reduced output of processes due to reduced input availability. As future demand is uncertain and forecast can be inaccurate, see section 3.3.1. Surges in demand that are not planned for can result in delivery delays, lost sales or customer dissatisfaction. By using safety stocks, see section 3.3.6 organizations can mitigate those risks.

Price speculation
For commodities with high price fluctuations organizations can hold inventory of inputs or outputs to profit from probable changes in prices. Furthermore, organizations can hedge for sudden price changes due to crisis e.g. oil shortages, wars et cetera.

3.1.3. Objectives and bottom line impact of inventory management

Anupindi et.al. (2003) discuss 3 types of financial metrics that constitute the performance of any profit making organization:

Absolute performance
Profit is the key performance indicator, it measures the difference of the value provided to the customers and the cost of delivering the product or service. Profit is defined as the difference between revenue and costs.

$$Profit = Revenue - Costs$$

Performance relative asset utilization
Profit relative to assets, inventory or capital employed can have many different terms but the logic is the same, profit divided by used investment.

$$ROI = \frac{Revenue - Costs}{Investment}$$

Survival strength
Cash flow indicates short term financial status of an organization and its ability to "survive" in the short term. Chopra & Meindl (2013) states that *"The objective of every supply chain should be to maximize overall value generated"* (p. 15). This value, which is called the supply chain surplus, consists of the difference between value to customer minus the costs of the supply chain.

$$Supply\ chain\ surplus = Customer\ value - Supply\ chain\ costs$$

Increasing said surplus along the supply chain this will have influence on key financial metrics for the organizations. Two of the most important being Return on Equity (ROE), from a shareholder's perspective, and Return on Assets (ROA), from the firm's perspective.

$$ROE = \frac{Net\ income}{Average\ shareholder\ equity}$$

$$ROA = \frac{Earnings\ before\ interest}{Average\ total\ assets}$$

Being part of supply chain management, inventory management should play its part to support the objective of the whole supply chain. Chopra and Meindl (2013) identifies inventory being one of six key drivers for supply chain performance, the others being facilities, transportation, information, sourcing and pricing.

In accordance to these financial metrics, Silver (1983) breaks down inventory managers objectives into 6 priorities:

1. Profit maximization
2. Maximization of rate of return on stock investment
3. Cost minimization
4. Maximization of chance of survival
5. Ensuring flexibility of operation
6. Determination of a feasible solution

With this said, Silver (1983) points out that previous research within operations research mostly have focused on cost minimization, indirectly assuming that inventory management have low potential impact on the revenue streams. When there is demand for an item that is out of stock there are two possible outcomes, the order is backlogged or the potential sale is lost. In most contexts both of these outcomes can occur. Chopra and Meindl (2013) confirm that high availability in inventories increase customer responsiveness, hence, affects the revenue streams. However, this requires large inventories which lead organization to balance availability according to two key factors:

- Cost of overstocking the product
- Cost of understocking the product

Anupindi et.al. (2003) explains that the intangible consequences of stock outs are very hard to translate into monetary terms. Therefore, managers usually have to determine targets for levels of customer service, see section 3.3.6, and adjust other parameters given these set levels.

3.2. Product segmentation

This section explores reasons to why a product assortment should be segmented and the existing techniques which are currently being used according to literature. Possible types of criteria to segment by are also presented.

3.2.1. Purpose of segmentation

The amount of products which a company produces, sells or handles is oftentimes very high. The characteristics of these products are most times of a large variation. The variations can appear in anything ranging from size, value, functionality to physical appearances or possible storage modes. According to Silver et al. (1998) the decision making within inventory management is more or less equivalent to “a problem of coping with large numbers and with a diversity of factors external and internal to the organization”. Furthermore, the products are handled differently within functions of the organization based on their respective characteristics (van Kampen et al., 2012). Therefore, it is most times deemed favorable to establish a smaller amount of product classes based on certain characteristics. Thereafter, products can be controlled, e.g. within inventory management, based on their respective classes instead of each stock keeping unit, SKU, separately (van Kampen et al., 2012).

The classes into which SKUs are to be divided will be determined by pinpointing which characteristics are most important to consider for the given situation. Through thorough analysis and empirical research, the most important variables can be determined and thereafter help in reducing the complexity of inventory management decisions (Silver et al., 1998).

According to van Kampen et al. (2012) in inventory management a classification of SKUs is oftentimes conducted in order to establish parameters such as reorder points, safety stock levels or order quantities.

3.2.2. ABC analysis

ABC analysis is one of the most well-known classification techniques used (van Kampen et al., 2012). According to Flores and Whybark (1986) the analysis is based on the argument that it is possible to classify a portfolio of products into three major classes:

- A -class: few number SKUs that account for the majority of the cost-volume
- B-class: intermediate amount of SKUs accounting for a moderate share of the cost-volume
- C-class: large number of SKUs with low cost and/or usage

The three classes should then be managed differently. It is often suggested that the class labeled A is of highest importance and should require most management attention (Flores and Whybark, 1986).

The technique of ABC-classification is often used in combination with the rule of thumb first described by Vilfredo Pareto (Flores and Whybark, 1986). The theory evolved from the idea that a small percentage of a country’s population contributes with the majority of said country’s output. Quantifying the theory resulted in the 80-20 rule i.e. in this case translated into; 20 percent of the population creates 80 percent of the country's output (Flores and Whybark, 1986). According to Silver et al. (1998) the same principle can be applied on products handled by an organization. As an example 20 percent of the total amount of SKUs typically accounts for 80 percent of the total money usage. The appearance of this phenomenon is illustrated below in Figure 9.

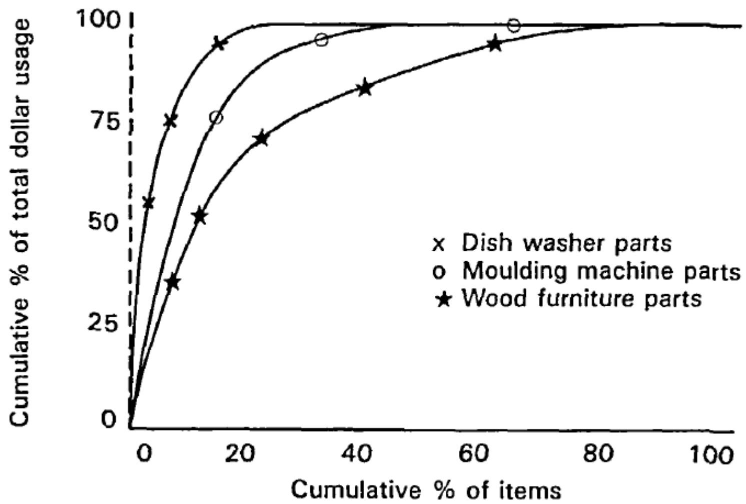

Figure 9: *The appearance of the pareto-principle is illustrated in the figure. ABC analysis can be used in combination with the pareto-principle to divide SKUs into three different classes. The figure illustrates that a small fraction of items represent a large portion of the total money usage (Flores and Whybark, 1986)*

Deciding upon cut-off points for the different classes will be based on trade-offs between the amount of SKUs to be treated within a class and the respective money usage. But what is argued for is that the number of SKUs in the A-class should be strictly kept at a low level as not to defeat the purpose of reducing the complexity related to managerial decisions regarding the products (Flores and Whybark, 1986).

3.2.3. Multi criteria ABC analysis

According to Flores and Whybark (1986) it is common that it is difficult to determine one single characteristic or classification criteria to base an ABC analysis on. Depending on where in the organization and from which perspective the products are viewed from, various criteria might be deemed most important. For certain situations it is suggested that the classical ABC classification, based on a single criterion, is not sufficient to carry out a classification of an organization's products. Several criteria might be equally important to consider for certain managerial decisions (Flores and Whybark, 1986).

The complexity of the classification increases with an increasing number of criteria considered as important. According to Flores and Whybark (1986) classifying when considering just two types of criteria can be difficult and the task will become even harder by including more criteria. Although, it is suggested that it is usually possible to only include two criteria since all criteria are seldom equally important.

To classify a product portfolio based on two criteria the joint criteria matrix can be utilized. The matrix is constructed by classifying the products on two criteria separately and then combining the classifications in a matrix. Figure 10 illustrates the process of classifying with the help of a joint criteria matrix.

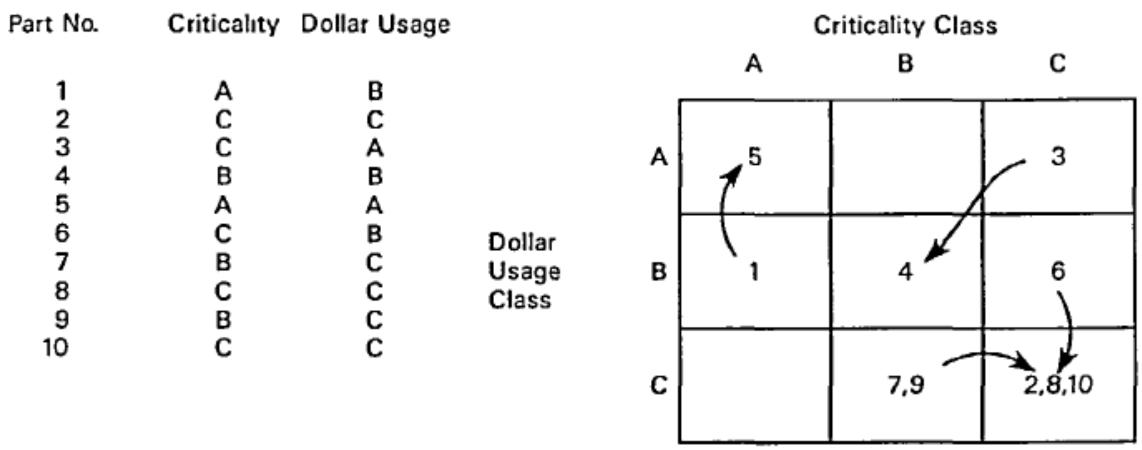

Figure 10: *Joint Criteria Matrix. The products are first classified according to the two criteria separately and are thereafter joined together in a matrix. Values that end up outside the diagonal joint classes are re-considered and placed in either of the classes AA, BB or CC (Flores and Whybark, 1986)*

The aim of the joint criteria matrix is that all products should be placed in any of the three classes AA, BB or CC. This in order to not extend the classification into more than three classes and thereby increasing complexity. The items which are placed outside the diagonal classes are re-classified so not to require any special treatment compared to the diagonal three (Flores and Whybark, 1986).

3.2.4. Classification criteria

According to Flores and Whybark (1986) the most common criterion to segment upon in an ABC analysis is money usage also called cost-volume. But there are many alternative ways to classify and segment. Flores and Whybark (1986) discuss that depending on within which function of an organization the classification is needed and for what purpose, different criteria are considered most important. Examples of criteria which could be considered important to take into account when classifying products are: obsolescence, lead times, substitutability, repairability, criticality and commonality. Lovell et al. (2005) discuss the importance of product value density, PVD, the ratio between a product's value and its physical weight and volume, as well as criteria such as throughput and demand variability, being regarded as some of the most important factors. Christopher et al. (2009) present a classification system for matching products with supply chain strategies, based on five criteria; duration of life cycle, time window for delivery, volume, variety and variability.

When classifying products there are many different ways to proceed and many criteria to choose from. No standard way of classifying products or selecting criteria exist. Regardless, the importance of choosing criteria based on situation and purpose is stressed in literature.

3.3. Inventory control

This section aims to explore and explain theories and terminology related to theme of inventory control, such as forecasting, reorder points and service level.

3.3.1. Forecasting

Forecasting is used as an important tool for decision making within inventory management (Silver et al., 1998). The need to forecast within inventory control stems from the need to order items before customers have demanded them. There are two main reasons to why it is a good idea to order items before the demand has arisen: lead times and ordering costs (Axsäter, 2006). In most cases a certain lead time exists between order and delivery making it necessary to order ahead of time. Secondly the existence of so called ordering costs result in ordering in batches instead of unit per unit being preferred economically. Therefore, an idea of future demand would give guidance on how large the batch size would need to be (Axsäter, 2006).

According to Silver et al. (1998) forecasting can be based on extrapolation of historical data, such as historical sales figures, as well as on known information about future events. Such information could be regarding promotions, pre-planned shipments or general economic conditions. Furthermore, an important factor to consider when forecasting is the forecast error. Silver et al. (1998) present three reasons to measure the forecast error:

1. The amount of safety stock needs reflect the size of forecast error in order to withhold desired service levels (See: safety stock and service level in section 3.3.6)
2. Since a forecast most times is based on a mathematical model the forecast error will suggest suitable changes to the model in order to reach a more accurate forecast
3. The forecast error reflects the performance of the subjective components entered into the forecasts

3.3.2. Demand models

According to Axsäter (2006) the most common way to forecast demand in inventory control is to extrapolate historical data. But to efficiently be able to do this a number of typical demand models based on several assumptions have been established to simplify the process of forecasting demand. Silver et al. (1998) discuss five different components of which any time series can be composed of:

- Level: A demand which is purely level is constant over time without fluctuations
- Trend: The component which shows the rate of increase or decrease over time
- Seasonal variations: Describes variations over time based on either natural forces, such as weather conditions, or human decisions or customs such as sales going up during Christmas season
- Cyclical movements: Resulting from business cycles, expansion and contraction of economic activity
- Irregular random fluctuations: Arise due to unforeseeable events and can represent an inability to accurately model other factors affecting the time series

3.3.3. Costs

This section will give a brief explanation of a few of the common costs associated with inventory control and management. These costs are often part of the basis in which models in inventory control are developed from (Axsäter, 2006)

Holding costs

Holding costs are the costs associated to keeping items in stock. By holding inventory in a warehouse for example, capital is tied up and prevented from being used for other purposes. If this capital would have been used alternatively it could possibly have generated a return on investment, therefore, the holding costs related to bound capital should be coupled with the return it could have generated (Axsäter, 2006). According to Axsäter (2006) all variable costs related to the inventory level should be included in the holding cost, e.g. costs of storage, damage, obsolescence and handling.

Ordering costs

Ordering costs are costs associated with the handling of orders or replenishments, often irrespective of batch size. Ordering costs can be made up of several fixed costs such as transportation, material handling or setup costs in production. But an ordering cost can also consist of components such as costs of order forms, authorization or dealing with invoices from a supplier (Axsäter, 2006)

3.3.4. Ordering systems

By establishing an inventory control system, the goal is to determine how much to order and when to order. Decisions which should be based on stock situation, demand and cost factors (Axsäter, 2006).

Inventory position versus inventory level
Inventory position and inventory level are two central expressions regarding inventory situation. The need for inventory position arises when realizing that it is necessary to include further factors than just physical stock on hand while making an ordering decision (Axsäter, 2006). What should also be included is backorders, demand which could not be met, and outstanding orders, orders which have been placed but have not yet arrived.

- *Inventory position = stock on hand + outstanding orders - backorders*
- *Inventory level = stock on hand - backorders*

(R,Q) - Policy
An (R,Q) ordering policy is one of the most common ordering policies. It is based on two main parameters, reordering point R and batch quantity Q. The logic behind the policy is that when the inventory position, IP, reaches a level equal to or below R a batch of Q units is ordered (Axsäter, 2006). If a batch of Q units is not enough to bring the IP above R, the minimum multiple of Q is ordered. In the case of continuous review: $R \leq IP \leq R+Q$, since the replenishment order will always be triggered as soon as IP hits R. With a periodic review it is possible for IP to decrease below R before a new order is triggered (Axsäter, 2006). The changes in IP and inventory level, IL, can be seen in Figure 11 below.

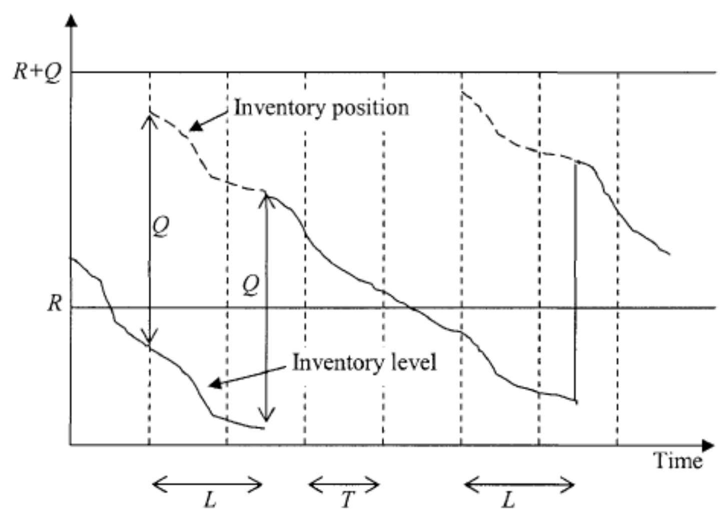

Figure 11: *Changes in IP and IL over time for an ordering system with (R,Q)-policy. Source: Axsäter, 2006.*

3.3.5. Economic order quantity

The economic order quantity, EOQ, is one of the best known results in inventory control (Axsäter, 2006). As the name hints, the goal for the EOQ-formula is to derive the optimal batch size or order quantity. The formula is based on a number of assumptions (Axsäter, 2006):

- Demand is constant and continuous
- Ordering and holding costs are constant over time
- The batch quantity does not need to be an integer
- The whole batch quantity is delivered at the same time
- No shortages are allowed

The optimal batch size is derived from minimizing corresponding costs (Silver et al. 1998). The costs affected by the ordering quantity in this case are: holding costs and ordering costs. Following notations are used when deriving the EOQ-formula:

h = holding cost per unit and time unit
A = ordering or setup cost
d = demand per time unit
Q = batch quantity
C = costs per time unit

With the above notations the total costs can be expressed as follows:

$$C = \frac{Q}{2}h + \frac{d}{Q}A$$

By minimizing C, taking the derivative of C in respect to Q and setting equal to zero, the expression for the economic order quantity is derived as follows:

$$Q^* = \sqrt{\frac{2Ad}{h}}$$

3.3.6. Safety stock and service levels

Safety stock is defined by Silver et al. (1998) as the amount of inventory held on average to cover for the uncertainty in both demand and supply on a short time horizon. Safety stock is closely related to the concept of service levels.

Axsäter (2006) describes three different ways of measuring service levels:

S_1 = probability of no stock out per order cycle
S_2 = "fill rate" - fraction of demand that can be satisfied immediately from stock on hand
S_3 = "ready rate" - fraction of time with positive stock on hand

Axsäter (2006) describes the first definition, S_1, as easy to use but also associated with disadvantages. S_1 does not take the batch quantity, Q, into account and can therefore be misleading in some senses. It is not recommended for inventory control purposes (Axsäter, 2006).

According to Axsäter (2006) both S_2 and S_3 make computation of a service measurement more complex but at the same time more accurate than S_1.During constant demand the two measurements are equal except for if a customer is allowed to order more than one unit a time. For instance, S_2 will be low while S_3 is high if the positive stock on hand is not enough to fulfill large customer orders. Axsäter (2006) argues for the importance of service levels being clearly defined within an organization. What is also argued for is the need for different service levels for different items. But as different service levels for all products might be impractical it is recommended to divide products into groups and define service levels group wise.

3.4. Review of strategy for inventory management

This section explores a collection of strategies, cases and tools within inventory management relevant to this project. First, supply chain differentiation will be exemplified with a case study, followed by another case study covering network design. Lastly, the principle of postponement of processes is discussed.

3.4.1. Supply chain differentiation

Fisher (1997) argues that organizations should strive to understand the nature of customer demand, before forming the supply chain. By identifying two types of products, innovational and functional, there are two types of supply chains that fit accordingly, market responsive and cost efficient. This suggests that the theory of "one size fits all" within is not applicable within supply chain management. When an organization experiences a move from homogeneous demand into heterogeneous demand, because of e.g. new technology, there is a need for differentiating the supply chain accordingly (MacCarthy et.al. 2016). There are two major steps for differentiation; first the market needs to be segmented and afterwards, based on these segments, the supply chain can be differentiated.

Simchi-Levi et.al (2013) describes how Dell Inc. in 2008 experienced how their market for personal computers was diverging. Previously, they had won market shares through offering highly responsive configure-to-order offers through their online store. This however did not match the demand within their fastest growing market, the physical retail channel. For this new market the customers were much more price sensitive, which the very responsive configure-to-order setup could not respond to. To capture market shares in different market segments with different natures of demand, Dell Inc. decided, instead of compromise, to form multiple supply chains, see **Error! Reference source not found.** below.

Table 3: *Dell's multiple supply chains (Simchi-Levi et.al. 2013)*

Criteria	Build to Order	Build To Plan	Build To Stock	Build To Spec
Customer Segment	Online/ Low-Volume Configurations	Retail	Online/ Popular Configuration	Corporate Clients
Products	Configuration defined by customers	Small number of configurations designed for market	Small number of configurations designed for market	Designed for customer
Production Batch Size	One	Large	Large	Large
Production Strategy	Assembly is driven by individual order	Smooth production to cut cost	Smooth production to cut cost	Quantity and schedule defined by customer order
Finished Goods Inventory	No	Yes (At retailer)	Yes (At Dell)	No
Lead Time	Short (Air) to achieve responsiveness	Long (Ocean) to reduce shipping cost	Long (ocean) from manufacturing to stocking locations and short (parcell) to customer locations	Long (Ocean) to reduce shipping cost
Planning Horizon	Short	Long	Medium	Long

MacCarthy et.al. (2016) discuss eight potential dimensions that can have influence on differentiation decisions:

1. Supply network configuration
2. Product delivery strategy
3. Customer-order decoupling point positioning
4. Strategic inventory positioning
5. Strategic capacity positioning
6. Transportation mode

7. Process choice
8. Supply chain relationships

3.4.2. Supply chain network design

The objective of any distribution network according to Chopra & Meindl (2013) is to ensure that customer needs are met at lowest possible cost. In terms of distribution network design, customer needs consist of: Response time, product variety, product availability, customer experience, time to market, order visibility and returnability. There are four cost drivers that are directly affected by network design decisions: Inventories, transportation, facilities and information.

Billington et al. (2004) describes how Hewlett-Packard improved their supply chain profitability for digital camera business by analyzing their network design through different scenarios. The different scenarios were based on location of three activities, see Figure 12.

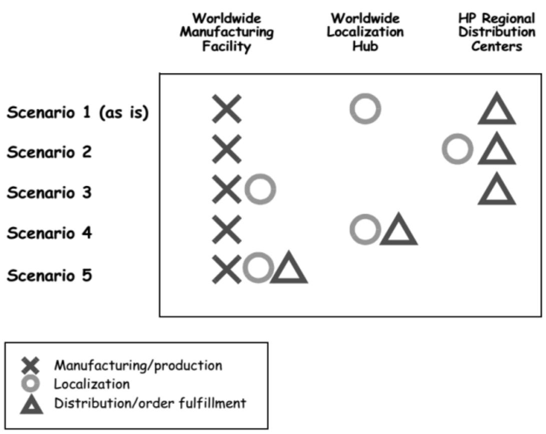

Figure 12: *Five scenarios for HP's digital camera supply chain configuration (Billington et al, 2004)*

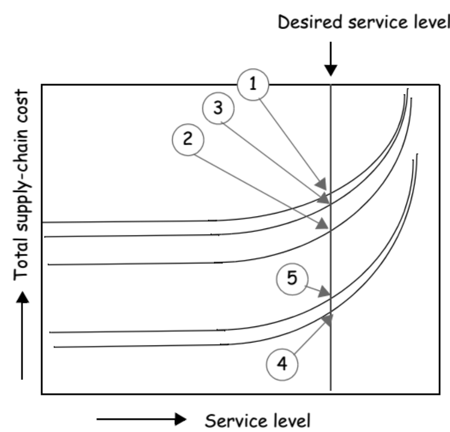

Figure 13: *The total supply chain costs based on different scenarios and service levels (Billington et al, 2004)*

A model for calculating total supply chain cost was then created based on the different scenarios. The different group of costs accounted for were variable, fixed and inventory driven. By using this model, cost data and demand data, HP could calculate total supply chain cost for the five different scenarios for any desired service level, see Figure 13. Based on the calculations Hewlett Packard implemented the fourth scenario's configuration. The project and implementation of the new supply chain configuration had three major impacts:

1. HP realized an optimal inventory policy, giving confidence in the model.
2. Reduced inventory driven costs and total capital tied in inventory.
3. Reduced downside risk in the supply chain.

3.4.3. Postponement

Van Hoek (2001) introduces the meaning of postponement as "...delaying activities in the supply chain until customer orders are received with the intention of customizing products, as opposed to performing those activities in anticipation of future orders". Postponement can be applied along the whole end-to-end supply chain. Table 4 compiles how a postponement approach compares with a traditional approach.

Table 4: *The postponement approach in operations (van Hoek, 2001)*

	Traditional operations	Postponement opportunities
Uncertainties	Limit operations; uncertainty about order mix and volume	Reduce risk of volume and variety mix by delaying finalization of products
Volume	Produce volumes (flow shop) with large economies of scale	Make batches of one (job shop for customization, flow shop elsewhere)
Variety	Create obsolescence risks	Prosume, customize, requiring flexibility
Lead times	Involve long response times	Offer accurate response, yet perform activities within order cycle time
Supply chain approach	Limit variety to gain efficiency advantages	Reduce complexity in operations, yet possibly add flexibility and transport costs

Persson (1995) discuss postponement as the opposite of speculation. "...while postponing an activity means to carry it out as late or as close to the actual need in time as possible". Within logistics there are two major types of postponement: geographical postponement and postponement of value adding processes. With geographical postponement, one should avoid sending material until it is absolutely necessary, whereas postponement of value adding activities is about keeping the items at component level until an actual customer order.

Van Hoek (2001) describes the key objective of postponement is to achieve mass customization for the customers, whereas Persson (1995) identifies key benefit from using postponement is that it offers both the customer and organization a higher level of flexibility.

4. BACKGROUND TO SANDVIK AND ITS SUPPLY CHAIN

This chapter aims at giving the reader an understanding of the case company and its supply chain. It explores the organizational structure and recent changes as of the instating of the new CEO. Thereafter, it gives insights to the customers and what needs Sandvik's products satisfy. After that, an introduction to the characteristics of items, components and products being handled by Sandvik is presented. At last, a bird's eye overview of Sandvik's current supply chain network is illustrated and explained. All facts and data that are presented in this chapter without reference are based on internal documentation and/or the author's observations at the case company.

4.1. Organization

Sandvik Group's strategy is influenced by its historic focus on quality, customer relationship, R&D investments and exports. Strategy within the different parts of the company is dependent on what phase the BA or PA is going through. The first phase is to achieve stability; the second phase is profitability from which it at last can achieve the last phase growth. The three BAs of Sandvik Group, see Figure 14, have different positioning in the phases, hence strategy differ amongst them. Machining Solutions is the most profitable BA and thereby focusing on growing whereas Mining and Rock Technology still is in the phase of achieving stability by being more reliable to the customers and increasing profitability by reducing costs and working capital.

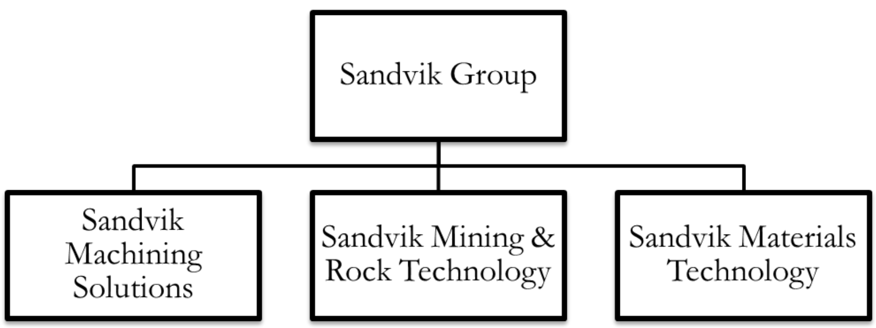

Figure 14: *Sandvik Group's three Bas (source: authors)*

The BU Sandvik Stationary Crushing and Screening, the object for this study, is part of the BA Sandvik Mining & Rock Technology. The organizational structure of this BA can be seen in Figure 15.

In 2015 the new CEO, Björn Rosengren, introduced a new direction for the organizational structure. As opposed to the direction of the previous CEO, Sandvik Group is now decentralizing the organization by increasing autonomy and accountability down the hierarchy of the organization. This has led to the initiative of Sandvik now taking control of the aftermarket logistic function for its products, which previously has been orchestrated by SMCL in Ireland, see Figure 15.

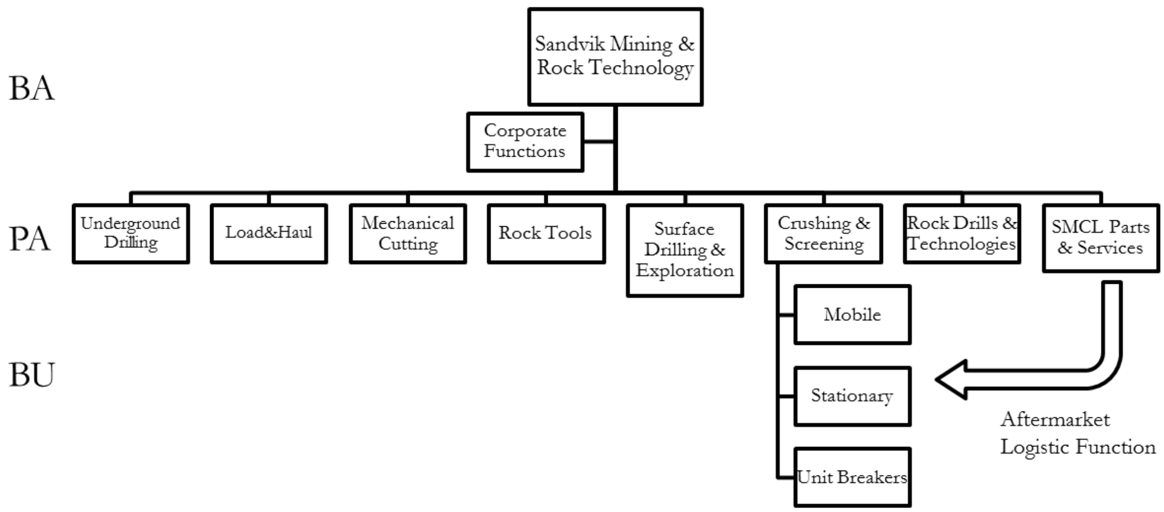

Figure 15: *Organizational structure of SMRT (source: authors)*

4.2. Market and customers

Sandvik's market is divided into two categories: new equipment and aftermarket. New equipment is the type of sale where customers invest in new crushers. Buying these crushers are significant investments for many customers leading to buying behaviors being dependent on the customer's industry business cycles. At the time of writing for instance, the mining business is accelerating after a long downturn, resulting in a large increase in order intake for new equipment. There are few competitors to Sandvik's new equipment. A business with high barriers of entry because of factors such as high complexity of products and economies of scale.

The aftermarket is the complementary market category that supplies existing customers with items that keeps the crushers running. This market is signified by high profit margins. These items are mainly wear parts and spare parts for the crushers. Since demand for these products are generated through customers running the crushers, it is not as business cycle dependent. Within the aftermarket category the competition is high. It is relatively easy for pirate manufacturers to copy parts of Sandvik and sell them at lower prices. Furthermore, Sandvik has had a low focus on the aftermarket and the supply chain has offered low availability and reliability to its customers. The combination of these factors has led Sandvik to lose significant market shares. Sandvik estimates that it only has a 30-45 percent market share for the aftermarket of its own equipment.

Sandvik customers can be grouped into two major segments: mining and construction. These two groups have different needs and buying behaviors which affect the requirements of the upstream supply chain.

4.2.1. Mining customers

Mining customers are spread throughout the globe but with larger presence in countries where the mining industry dominates, such as Chile. Actors within the segment generally own a variety of crushers with the purpose of processing and crushing material from the largest pieces into smaller pieces further down the process chain. Since the size of a crusher is directly connected to the size of the material it can process, the “crushing chain” starts with large machines closest to the mine and crushers of decreasing size along the chain. Crushers at mining sites run during long time intervals because of continuous operation hours. To decrease sensitivity towards operation stops, many mining customers store crusher spare parts at the construction sites. Minimizing disruptions in production is of high importance for this customer segment since the value of the output oftentimes is high. Availability and the ability to deliver swiftly are identified as key preferences for mining customers regarding aftermarket products.

4.2.2. Construction customers

A typical example of a construction customer is a road building contractor. Typically, these customers do not own as many crushers as the mining counterparts and not of the same variety. These customers are of a wide variety of size, from small local contractors to large national or international companies, why the buying patterns can differ significantly within the segment. Construction customers generally do not stock any spare parts for their crushers and are not as “proactive” in their buying behavior as their mining counterparts. This results in construction customers seeking fast deliveries for spare parts when a breakdown occurs.

4.3. Product types and items

Sandvik sells stone crushers of many different sizes and varieties. As discussed in section 1.5 this project has been delimited to study stationary crushers and the aftermarket products related to these. Below follows a description of the product types which have been central to the study. At the start of the project at the case company a loosely defined and unofficial categorization of the products existed. After identifying differences between products defining characteristics could be set in order to create an official product categorization. The categorization resulted in four major product groups; major components, components, commercial spare parts and wear parts. These four product classes will be used in order to analyze products separately in smaller groups. See Table 5 below for descriptions of the product groups.

Table 5: *Each product group described with defining characteristics and examples of typical products within the group*

Product group	Defining characteristics	Example of product descriptions
Major components	• Produced by Sandvik • Either top shell, bottom shell or main shaft	• TOP SHELL ASS. EXCL. CONCAVE RING CH440 • BOTTOMSHELL ASSY CH/CS430 • MAIN SHAFT ASSY EXCL MANTLE CH660
Components	• Sandvik specific • Has a technical drawing	• TURBO CAVITY WEAR PLATE SET TOP • SPIDER BUSHING
Commercial spare parts	• Bought from suppliers	• SCREW M6S 36x160 8.8 • FLOW SWITCH
Wear parts	• Produced by Sandvik • Made out of manganese	• CONCAVE MF-EC2 M1 • MANTLE A M1

4.3.1 Stationary crushers

Stationary crushers are primarily divided into two types of crushers, cone- and jaw crushers. Besides differing in appearance the area of use is also different between the two types.

Jaw crushers have the largest capacity in terms of size of the material which they process. Therefore, in a crushing line, the jaw crushers will appear at the beginning, crushing the largest stones. A jaw crusher is made up out of a large welded frame in which a crushing chamber is worked by a crusher plate, see Figure 16 below for an image of a jaw crusher. The so called crusher plate is exposed to the largest wear and must therefore be replaced sporadically (see section on wear parts below). Jaw crushers range in sizes from 14 to 58 m^3 in shipping volume.

Figure 16: *Illustration of a stationary Sandvik jaw crusher to the left and a stationary cone crusher to the right*

Cone crushers consist of a bottom and a top shell which together create a cavity in which stones can be crushed by a cone driven by a main shaft. Cone crushers are produced in several sizes ranging from about 8 to 80 tons in weight but also in two variants, CH and CS. The two variants have common bottom shells but vary when it comes to top shell and main shaft (see section major components). As can be seen in Figure 17 below the CS crusher has a higher top shell which requires a longer main shaft than the CH models.

4.3.2. Major components

Major components are the largest products that go into the production of crushers. In general terms there are three main types of major components; top shell, bottom shell and main shaft. The products are characterized by being bulky, heavy and incur both large costs and value. There are about 40-50 active items classified as major components today. Major components is the product group which has been given most focus in this study. This is because, from an aftermarket perspective, they have the greatest impact on Sandvik's performance. Major components are all defined by being durable and play critical roles within the crushers. If a major component breaks down, production comes to a halt which is a second criterion making them of such large importance. In order to reach a high customer satisfaction, Sandvik must be able to deliver a major component as soon as it is demanded by a customer. One of the premises on which this project is based is that major components will be handled separately from the other items since they are of such a large value, they are rather slow moving and do not sell in large quantities (see section 4.2.1).

Main shafts are placed in the center of cone crushers. They drive the crushing mechanism by pressing the cone and concave towards each other, creating a crushing effect when a crusher contains material (see Figure 17 for better understanding of the main shafts appearance). Top and bottom shells are mounted together to create the cavity in which material is crushed when the crusher is in operation. They are generally speaking the components which contain the rest of the crusher.

Major components are today partly treated as slow moving spare parts and are stored in warehouses both close to production but also close to customers regionally. The cost of keeping major components is lower the closer to production the products are held. That is why this is a situation which is sought after by Sandvik today, to keep the stockpile close to production. The management of the inventory situation regarding major components is today not defined. According to several sources within Sandvik in Svedala many regional warehouse managers or sales representatives create strategic stock close to customers due to uncertainties within the supply chain. A fear which exist within Sandvik is that many of the major components, and for other project types as well, that are stored regionally have become obsolete.

Despite being handled as spare parts, major components are also used for the production of new crushers. The products are then stored separately from when they are meant to go to the aftermarket. As an aftermarket product the major component is covered with protective plastic, so it can be stored outside, and given a new item number, while a major component assigned to production is stored on pallets in a warehouse.

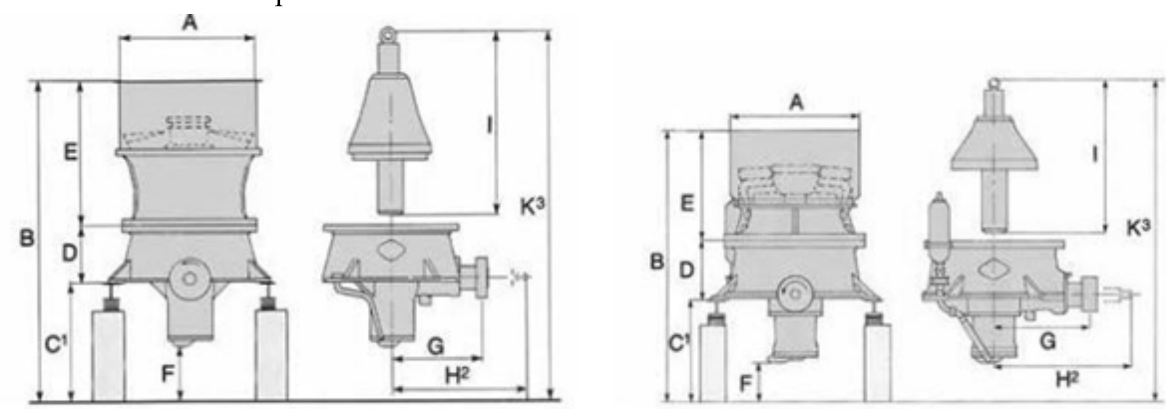

Figure 17: *To the left a CS crusher and a CH crusher to the right. Main shaft marked with I, top shell between letters A and E and bottom shell can be seen by the G mark*

4.3.3. Components

Components that are not major components are of less value and typically smaller sizes than major components. However, these are designed, produced or developed by supplier for Sandvik equipment. These products are of a high strategic importance regarding Sandvik's aftermarket, since they cannot be sourced elsewhere. The number of active products classified as components is much larger than for major components. The number is in the ranges of 20,000 different item numbers. However, this study will not include all of these in the analysis due to delimitations and directives given by Sandvik. Components are held in warehouses both centrally and regionally.

Because of their lower level of complexity in comparison with major components, these components have shorter lead times.

4.3.4. Commercial spare parts

Products under the category commercial spare parts are products which are not necessarily produced by Sandvik. They are products which a customer would be able to source from a wide range of suppliers. Sandvik does not regard this product segment as strategically most important at this stage, but feel that focus needs to be with products which are specific to Sandvik.

4.3.5. Wear parts

Wear parts are products that are, during rock processing, in contact with the stone. Wear parts need to be replaced over time since they are worn out. In cone crushers there are two main types of products classified as wear parts, concaves and mantles. These are the parts which are worked against each other in order to crush the material contained within the crusher. The main wear part represented in jaw crushers is the jaw plate which serves a similar function as the concaves and mantles.

The material used to produce wear parts is a metal called manganese. Therefore, wear parts are often referred to simply as “manganese”. Wear parts are partly produced in Svedala since a large part of the site in Svedala is a foundry. The production in Svedala is presently limited to 12,000 tons per year due to local regulations.

4.4. Supply chain network and operations

Sandvik’s current supply chain network is presented in Figure 18 below. Starting upstream, the supply base is global, Sandvik sources both to the inbound warehouse in Svedala and to the global DC in Eindhoven. The Svedala site has a wide range of value adding activities: machining, foundry, assembly, testing and painting. Given the wide variety of items and products the flow at the site has a high complexity. New equipment is either MTO (manufactured to order) or ATO (assembled to order) depending on the sales volume of the product; hence there are no stocks of finished equipment because they are shipped directly to the customer.

There is also a flow of material directed for the aftermarket. At the Svedala site there is a transition of internal ownership occurring when items are moved to the FGI, finished goods inventory, Svedala 07, the ownership is moved from Sandvik to SMCL with an internal transaction price. There is also a transition of ERP-system from M3 which covers the site operations to System 21 that covers the global aftermarket. There are no integrations between the systems and there is limited visibility into M3 for SMCL. C1 in Eindhoven is the global DC for aftermarket items. The DC is handled by a 3PL, third party logistics partner. In addition to serving the European market, C1 also acts as a hub shipping aftermarket items to the worldwide regional DCs in Chicago, Singapore, Johannesburg, Brisbane and Perth. There is no clear structure nor policy for what assortments should be available in the different tiers for SMCL. Sales representatives order replenishments to the local stocks in anticipation of future demand, in order to increase availability and reduce lead times.

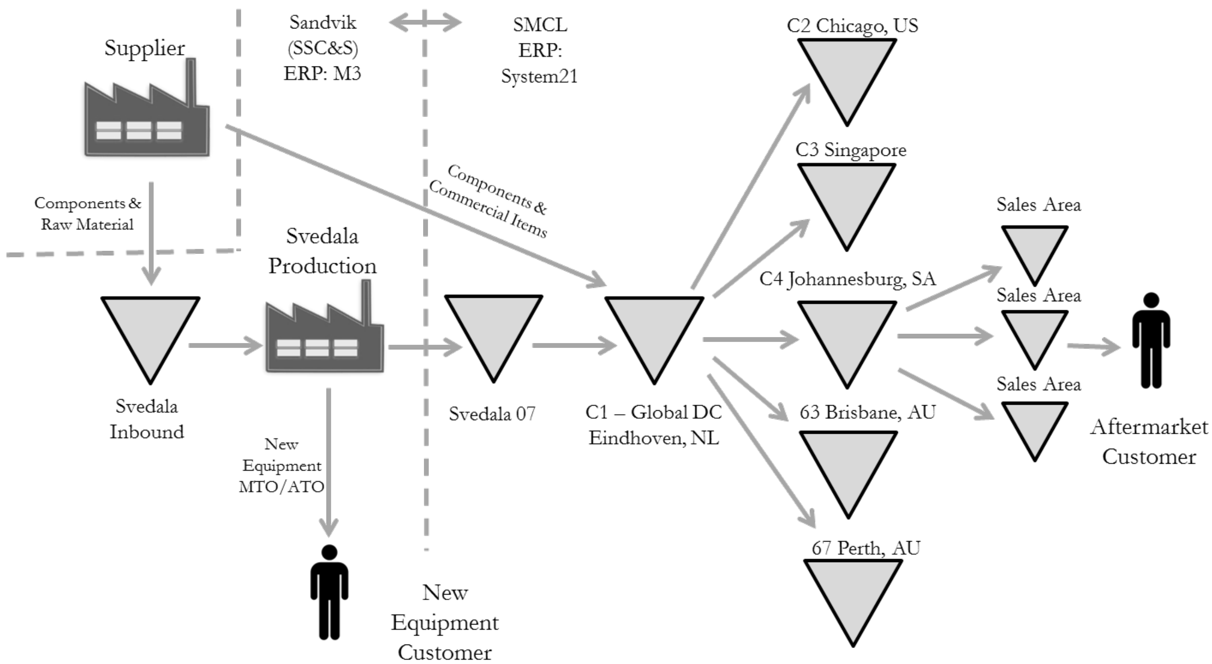

Figure 18: *Bird's eye view of Sandvik's current Supply Chain Network (Source: Authors)*

5. FORMING A STRATEGY FOR INVENTORY MANAGEMENT

This chapter seeks to explain the process of forming strategy for Sandvik's inventory management. Since the process at the case company was highly iterative, this chapter presents both empirical data and analysis for each major step of the process. According to company directives, major components were of primary focus and implementation of set strategy was initiated within the scope of this project. After that, components were analyzed; however, decisions and strategy on network design and inventory control were not finalized. First, the global demand is discussed, followed by the process of product segmentation. Thereafter, policies and parameters for inventory control are discussed. Lastly, the areas of network design, differentiation and postponement are elaborated on. All facts and data presented in the empirical of this chapter without reference are based on internal documentation and/or the author's observations at the case company.

5.1. Mapping of global demand

Both according to company directives and theory, understanding the demand for the products is the first step and the basis in this project. For this part item numbers have been hidden due to sensitivity of data. The tables in this section only show demand patterns for a limited number of items, however, the presented ones have been chosen due to being representative.

5.1.1. Empirics

Sandvik has a wide range of customers within mining and construction throughout the world. The spread of customer demand is visualized in Figure 19 below.

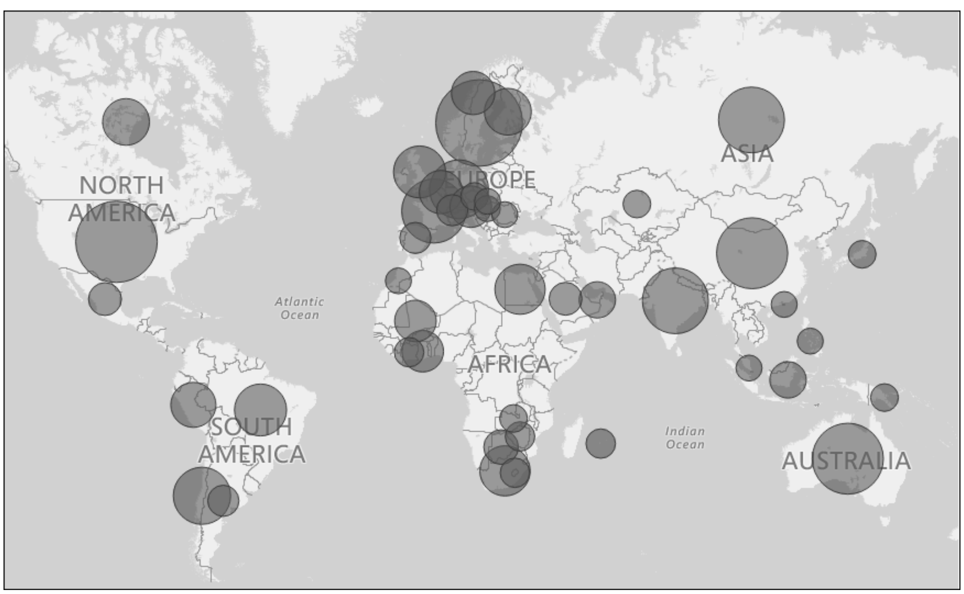

Figure 19: *Global aftermarket demand, based on order intake value 2015-1016. The bubble's sizes correspond to respective region's order intake size (source: authors)*

Table 6: Order Intake quantity by month 2016 for two crusher models

	Demand Patterns by Month 2016												Total
Item Type	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	
Crusher XX	2	2	3	6	4	4	-	2	4	2	2	2	33
Crusher XY	1	-	-	1	2	3	-	-	1	1	-	-	9

New equipment sales also reach a worldwide customer base. Table 6 exemplifies order intake quantities for two crusher models over the course of 2016. One being a high runner and the other having medium high demand.

Both components and major components make up a significant part of the aftermarket sales. Through gathering data regarding active components and major components on the aftermarket, Table 7 compiles the characteristics and differences between the two item categories.

The demand quantity, both aftermarket and usage in assembly for new equipment, for three different major components is shown in Table 8 below. Looking closer at MC XX, the global demand is compared to different regional demand patterns in Table 10.

Components have on average higher order intake quantities for the aftermarket, Table 9 below exemplifies a high running component's aftermarket order intake quantity.

Table 7: *Characteristics of components and major components*

	Components	Major Components
Nbr of Items	1 500	41
Average Internal Cost	2 000 EUR	30 000 EUR
Typical Weight	1-2 000 KG	300 – 10 000 KG
Typical Inbound Leadtime	20 Days	120 Days

Table 8: *Aftermarket order intake by month and usage for new equipment assembly 2016 for three major components*

	Aftermarket Demand by Month 2016													New Equipment
Item Type	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total	Usage for Assembly
MC XX	1	1	2	2	2	2	2	6	4	1	1	-	24	33
MC XY	-	-	-	-	-	1	1	-	-	-	-	1	3	10
MC XZ	-	1	-	-	1	-	-	-	1	-	1	-	4	-

Table 9: *Example of one component's order intake quantity globally and by three different regions*

Component YY	Aftermarket Demand by Month & Region 2016												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Global	51	56	39	57	62	58	35	50	34	82	40	27	591
Africa	2	-	-	-	-	-	4	4	2	-	-	-	12
Europe	19	35	19	16	24	24	14	32	26	48	22	13	292
USA & Canada	22	8	16	12	16	4	8	8	-	-	4	0	98

Table 10: *Global order intake quantity 2016 compared to regional for a certain major component*

MC XX	Aftermarket Demand by Month & Region 2016												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Global	1	1	2	2	2	2	2	6	4	1	1	-	24
Africa	-	-	-	-	-	-	-	2	-	-	-	-	2
Europe	-	-	1	-	-	-	1	4	1	1	1	-	9
USA & Canada	1	-	-	-	-	1	-	-	-	-	-	-	2

5.1.2. Analysis

The demand patterns in combination with the lead times throughout the processes of Sandvik favor the use of inventories as buffers. The geographical spread of the aftermarket demand poses challenges for the logistic function. Besides the European market, there are few significant clusters with geographically concentrated demand. If Sandvik were to offer high availability close to the customers, by stocking the full assortment in every regional DC, this would implicate very high investments. Looking closer at the example of major component XX in Table 10, there is a continuous global demand, but for e.g. Africa the regional demand is very unstable. For Component YY in Table 9 there is a similar situation but with higher volumes. This situation altogether, calls for decision taking and setting of policies on what assortment should be stored in the different tiers of the aftermarket distribution network. Primarily, order intake quantity is an important criterion for these decisions and policies, section 5.2 will discuss other criteria.

Analyzing the demand for major components, both for new equipment assembly and aftermarket, examples of both seasonality and trends can be seen in the demand patterns. Comparing the usage for new equipment and aftermarket demand there are heavily varying ratios between the MC XX-XZ, see Table 11 below.

Table 11: *Ratio between aftermarket demand quantity and usage for new equipment quantity*

Order Intake 2016	Aftermarket	New Equipment Usage	Ratio Afm/NE
MC XX	24	33	0.72
MC XY	3	10	0.3
MC XZ	4	0	N/A

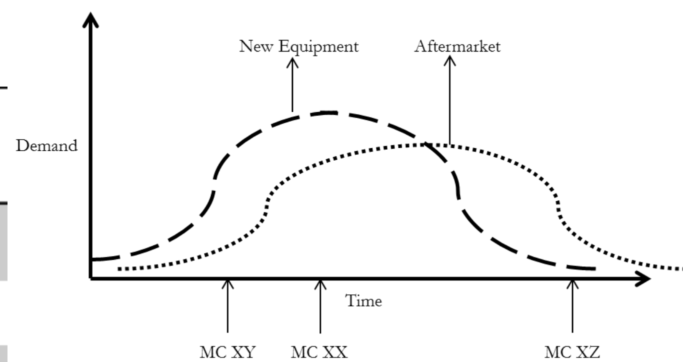

Figure 20: *Demand phases for new equipment and the aftermarket. (Curves are made for visualization and they are not based on real data). (Source: authors)*

These differences can be explained by an offset in time for the product life cycle between new equipment and aftermarket for a crusher and its parts. This offset is visualized in Figure 20. MC XY for example, is likely to experience an increase in demand for the aftermarket whereas MC XZ is going through an out phasing stage. The data and analysis for this project do not further investigate the characteristics of these cycles. However, these different phases have important implications for the product segmentation which is discussed in section 5.2.

5.2. Product segmentation

This section describes the process of performing a product segmentation, from identifying relevant classification criteria to structuring product classes. Finding ways to differentiate products and the way they are managed is one of the central themes of this project. Gathered information relevant to the product segmentation is presented first and is thereafter followed by the analysis.

5.2.1 Empirics

Purpose of product segmentation

As is mentioned in section 3.2., in order to successfully perform a product segmentation it is important to establish why the segmentation is carried out in the first place. From observations and discussions with the stakeholders within the organization the following areas in Table 12 have been identified or mentioned as important regarding the purpose of the segmentation.

Table 12: *Describes the main areas mentioned and identified as important within the case company to consider for classification*

Example of purpose	Source	Stated reason
Operational cost	- DL - LD	- Products are handled with "one-size-fits-all" methods which has incurred too large costs regarding nuts and bolts
Administrative capacity	- PCM - ELM	- By effectively segmenting products the sheer number of orders planners handle could be reduced
Product availability	- RLM - DL	- We need to put the items on the shelf in order to capture our own aftermarket
Working capital	- RLM	- Classification can help identify where best to place our working capital
Stock room assortments	- LD - DL	- A classification can help us establish and manage standardized assortments for the different stock rooms
Customer satisfaction	- DL - PLM	- Closer management of our assortment will make sure that we deliver and will keep customers happy

Previous classifications

The use of classification techniques regarding inventory management is presently used within Sandvik, e.g. an initiative was taken during the fall of 2016 to closer examine the inventory management principles regarding wear parts produced in Jiading. The project aimed to properly manage inventory levels in order to reach desired service levels towards customers. Within projects such as this the classes used historically are A, B, C, D, I, N and the criteria on which they are based are e.g. sold quantity or number of order lines. During instances when the above classes are used the classes A, B, and C correspond to 80 percent of the accumulated criteria, D and I make up 10 percent collectively and the N class represents 10 percent. See Table 13 below for a compilation of classifications, criteria and cut-off points.

ABC-classifications are used both during individual improvement projects but also used within S21. In S21 products are appointed a class, A, B or C, based on the criterion sales price and frequency. The classification is performed automatically for everything being sold through S21 and across all product lines. It is primarily used in order to be able to set certain product parameters within the system. The classification performed within S21 is based on the cut-off points 80 percent, 15 percent and 5 percent of the accumulated criterion for A, B and C respectively. According to LD within Crushing and Screening the S21 classifications is seldom used within the planning function for their product lines.

Table 13: *Previous ways of using ABC-classification systems within the case company*

Previous classifications	System 21	Improvement projects
Classification criteria	• Sales price • Frequency	• Sales volume • # of order lines • # of customers • Frequency
Classes and cut-off points	• A – 80% • B – 10 % • C – 10%	• A, B, C – 80% • D ”Strategic” & I ”Introductory” – 10% • N ”Non stocked” – 10%

Identifying criteria for classification
As Table 13 above describes there have been several methods to classify items within Sandvik in the past. Below follows a description of how different criteria have played a part within these classification projects.

Sales volume is a criterion which is commonly used within Sandvik while performing product segmentations. The products are divided into classes based on how large quantities are sold, where high volume items are placed in the higher classes.

An alternative criterion to sales volume which has been used is the *number of orderlines* an item has been present on for a given period of time. The reason to use this instead of sales volumes is according to Sandvik because of their product mix. The classification on purely number of items is not as fair in certain instances when products differ much in characteristics. Hence, for some situations it has been more effective to use how many times an item has been demanded instead of how many of the item has been demanded. A criterion which is used in the same way with slight differences is the criterion *frequency*. Based on the amount of orderlines an item is sold on, it will be appointed a certain SIC code. The SIC code classification is continuously updated by a moving average. These codes can hence also be used to further classify items. The SIC codes used for frequency are as follows in Table 14 below.

Table 14: *How SIC-codes, which represent product's ordering frequencies, are divided at Sandvik*

SIC code	**W**	**X**	**Y**	**K**	**L**	**Z**	**0**
Number of order lines per year	>30	11-30	8-10	5-7	3-4	1-2	0

In a similar way the criterion *number of customers* has been utilized. Sandvik then bases the importance of an item on how many customers buy the specific item.

A common criterion which is used within Sandvik in conjunction with another criterion is to classify upon *product life cycle stage*. This criterion corresponds to the three classes D, I and N mentioned in Table 13 above. Each class is associated with a stage of a product's life cycle. Items placed in D, also referred to as "strategic" items, are mostly slow movers at the end of their life cycle. According to a PLM within Sandvik items which have stipulations in contracts towards customers where Sandvik has committed to always have a certain quantity available is placed in the D class. Items which rarely sell but amount to a high value and are of critical importance can also be placed in the D class. The class called I, or "introductory" items, contains just that, products which recently have been introduced. According to several sources within the organization this serves as an effective way to keep track of which items might experience relatively large changes in demand within a short time horizon. The N class, "non stocked", contains items which are at the very end of their life cycle, are not of any strategic importance, such as the D-items, and are about to be phased out.

Products at Sandvik are appointed with *criticality* codes. Depending on product, there might be occurrences of more than one system of criticality codes. According to several people within the organization, criticality codes are not among the more frequent criteria to manage products by. Also, certain confusion has been expressed regarding the ways in which products have been appointed criticality codes.

5.2.2. Analysis

As can be seen in Table 12 above several ideas exist within the case company as to why a classification is important to perform. The identified purposes are not mutually exclusive but differences among them have been distinguished. Therefore, it was possible to identify which purpose has been stressed and generally been focused upon when discussing the primary reason to manage inventory through a classification; *product availability.* The strive for increasing material availability has permeated the analysis regarding classification as well as later on in the process.

Choosing criteria for classification for major components

What was made clear from the start was that when producing a classification scheme for the products referred to as major components both the aftermarket sales volumes and the volumes going into production for new equipment would need to be considered collectively. This because of the new company directives discussed in 4.1. to manage both the aftermarket and equipment from Svedala. Furthermore, the long inbound lead times for major components favors a consolidation between new equipment and aftermarket demand. Components can be sourced for new equipment orders or forecasts without causing disruptions thanks to shorter lead times; however, major components would cause major bottlenecks if they were to be sourced to order.

Narrowing down the alternatives among criteria to base the segmentation on resulted in two options; *sales volume* and *cost volume*. Sales volume is a previously used criterion while segmenting within Sandvik while cost volume is not, but is as mentioned in 3.3.4. one of the most extensively used and recommended criteria to use.

A type of multicriteria ABC-classification was performed based on the two different criteria mentioned above, weighing together both aftermarket sales and new equipment volumes. The distributions of items in the two alternatives can be seen in Table 15 and Table 16 below, see Appendix 2-5 for respective pareto curve.

Table 15: *Distribution of items in the weighted ABC-classification on the criterion of sales volume. Rounding of numbers has been used to simplify, therefore sum does not add up to one hundred percent. Aftermarket demand along rows and new equipment demand along columns*

	NBR of Items	New Equipment A	B	C
AFT	A	22%	5%	7%
	B	5%	7%	15%
	C	7%	7%	24%

Table 16: *Distribution of items in the weighted ABC-classification on the criterion of cost volume. Aftermarket demand along rows and new equipment demand along columns*

	NBR of Items	New Equipment A	B	C
AFT	A	15%	10%	7%
	B	15%	5%	7%
	C	5%	0%	37%

The general distributions of number of items between the classes in the two classifications differ. The way the items have been distributed according to cost volume is closer to what was expected than the classification on sales volume. But further investigating how individual items qualified into their respective classes turned out to in some cases oppose the goal of focusing on material availability. When segmenting on the criterion of cost volume the classification becomes skewed in such a way that slow moving items with high value can be appointed a high class such as A or B. The objective is to manage the higher classes with the closest attention why the criterion must be closely linked to the purpose of classification, material availability. The conclusion could therefore be drawn that it was most important to focus on the quantity sold rather than the value of the quantity sold. As can be seen in Table 17 and Table 18 below, the deviation between average cost of each class and the average cost of all major components is positive in the AA class for criterion cost volume while it is negative in the corresponding class for criterion sales volume. This shows that items of higher values are favored in this classification technique, which is not relevant during this instance.

Table 17: *Criterion sales volume. The average cost in class AA is lower than the average cost for all major components*

	Deviation from AVG Item Cost	New Equipment A	B	C
AFT	A	58%	116%	188%
	B	76%	160%	54%
	C	95%	236%	83%

As discussed in section 5.1.2. the effects of an item's placing in its life cycle will have an impact on the matter in which it is demanded. This concurs with the criterion discussed in section 5.2.1. *product life cycle stage.* The combination of enabling Sandvik to closely monitor introductory, out-phasing and "strategic" items while capturing the impact of life cycle stages on sales within the classification lead to the decision of incorporating the classes D, I and N described in 5.2.1.

Table 18: *Criterion cost volume. The average cost in class AA is higher than the average cost for all major components indicating that the classification criterion favors costly items. A phenomenon which in this case contradicts the purpose of enhancing material availability*

	Deviation from AVG Item Cost	New Equipment A	B	C
AFT	A	126%	51%	236%
	B	160%	62%	40%
	C	134%	-	64%

Performing the classification for major components

Because of the rather low number of items major components constitutes and the great strategic importance they have for Sandvik, a manual consideration of the classification would be permitted. Primarily, major components were classified on the criterion of sales volume both for aftermarket sales and volumes for production. The two classifications were merged according to the directives given by Sandvik in Table 19 below. The reason for merging classes is to reduce complexity of the classification scheme and to strive towards being able to manage the major components efficiently.

Table 19: *The classes obtained from the weighted classification, seen in the second row, were merged into the final classes in the first row in order to reduce complexity of the classification*

Final class	A	B	C
Multi criteria classes	AA, AB, BA, AC, CA	BB, BC, CB	CC

The cut-off points which previously have been used within Sandvik for improvement projects such as this one, described in Table 13, were used. This implies that the three classes A, B and C would constitute approximately 80 percent of the sales volume, while D and I items make out 10 percent collectively and N items 10 percent by themselves. But because of the somewhat manual process of performing the classification the cut-off points were not exactly met. See Table 21 and Table 20 below. The items included in the three classes D, I and N were mainly identified through information about crusher types' life cycle stages given by a PLM and LD, while simultaneously studying sales patterns for the different items.

Table 21: *Shows the distribution of number of items between the different classes in the final classification for major components. As can be seen the A class includes a rather large share of the items if comparing to conventional ABC-classifications. Numbers are rounded, therefore summations are not exact between columns*

Class	Fraction of Items	Cut-off
A	22%	
B	10%	
C	20%	51%
D	20%	
I	12%	32%
N	17%	17%

Table 20: *Describing the fraction of sales volume each class represents and respective cut-off points*

Class	Fraction of Sales Volume	Cut-off
A	59%	
B	11%	
C	11%	82%
D	5%	
I	11%	17%
N	1%	1%

As can be seen in Table 20 the A-class represents 59 percent of the sales volume which is in line with the intent of having an A-class which represents a majority of the sales volume. And the fact that the accumulated fraction of sales volume for the A, B and C classes amounts to 82 percent coheres with the goal of following Sandvik's defined cut-off point of 80 percent. The number of items in the A-class, 22 percent, Table 21, is rather high in comparison to conventional ABC-classification schemes but is a result of Sandvik's directive to treat each item which was appointed an A-class either for the aftermarket or equipment demand, as an A-class in the merged classification, see Table 19.

The accumulated fraction of items and sales volumes for the classes D and I is not something which was possible to steer since the items in these classes were placed there due to qualitative factors such as life cycle stage.

Choosing criteria for classification for components

The treated products in the product family components amounts to a larger number of items than the major components, as can be seen in Table 7, 1500 compared to 41. This calls for a more automated way of performing a classification, with less manual considerations than used for the major components.

As mentioned above it was necessary to consider both aftermarket and new equipment demand when constructing the classifications for major components. However, for components this is not of the same importance. Major components are of all the items going into the assembly of new crushers, those who have by far the longest lead times. Therefore, the production lead time for a crusher is not as limited by the lead times of components why the availability for these in Svedala is not as essential. The decision was taken to only focus on aftermarket demand.

The alternatives for criteria to classify upon were narrowed down for components to *sales volume, cost volume* as well as *frequency*. Because of the large spread of characteristics among the group components, such as size, cost and function it was deemed necessary to try and capture the potential of items with a high cost volume, thus weighing together cost and sales volume. But as earlier discussed, the risk with the criterion cost volume towards availability for lower-value high runners is that slow moving items with high values are favored among the higher classes. Thus a second criterion was considered, frequency. By utilizing internally defined SIC-codes, see Table 14, a multiple criteria analysis could be performed. The use of frequency as a criterion would enable a further dimension towards illustrating continuity and predictability in demand through the classification of the items. Regarding major components, the objective for Sandvik was to manage and store a majority of the items collectively in a central location. This is not the case for components. Components which have a predictable and stable demand within a specific region, which Sandvik serves with stocking locations and sales units, has the possibility to be stored in this region. Therefore, it was the desire of Sandvik to be able to both perform and analyze a classification scheme based on regional demands to be able to create regional assortments. The criterion frequency was deemed a necessary tool to avoid placing stock in a region where it would run the risk of becoming obsolete.

The use of SIC-codes as an additional criterion would result in a classification with 3X7 classes in the multicriteria analysis. In order to reduce complexity, the decision was made to appoint SIC-codes with an A, B, C or N classification which would reduce the number of classes from 21 to 16, after adding the N class on for the criterion cost volume as well. The class N is used in the same manner as it was utilized for the major components. The applied method for reducing classes can be seen in Table 22 below. The decision to merge SIC-codes Y, K, L and Z into C was based upon the small intervals between the different SIC-codes. The idea is as theory in section 3.3.2. suggests, to capture the majority of the products in the C-class while being strict and selective as to which products can be placed in foremost, the A-class but also in the B-class.

Table 22: *The division of SIC-codes into ABC-N-classes. The purpose was to reduce the final amount of classes and complexity*

SIC code	W	X	Y	K	L	Z	0
Number of order lines per year	>30	11-30	8-10	5-7	3-4	1-2	0
ABC-class	A	B		C			N

Performing the classification for components

The amount of different types of items within the class components calls for a simple and automated way of performing the classification. No manual consideration of the distribution of items into respective class was to be made.

Firstly, the ABC-classification was performed based on cost volume. A directive was given by Sandvik to perform the analysis with the following cut-off points; 70 percent of the accumulated cost volume for the A-class and 90 percent for the B-class. The C-class constitutes the remaining items which have experienced demand while the N-class is items which have not been demanded. The pareto-curve for the performed analysis can be seen in Figure 21.

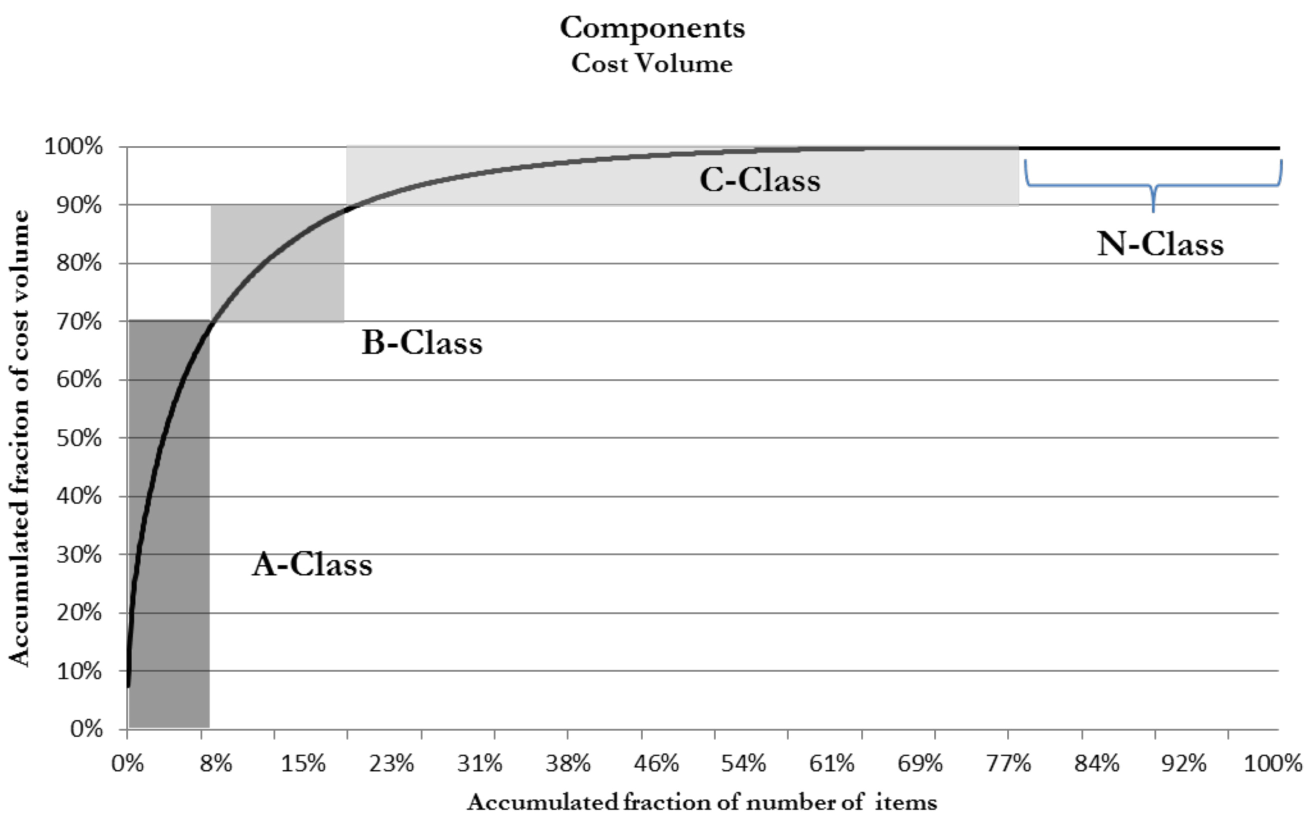

Figure 21: *Pareto-curve for components classified on the criterion cost volume*

Table 23: *Classification of components based on the criterion frequency*

SIC code	W	X	Y	K	L	Z	0
Number of order lines per year	>30	11-30	8-10	5-7	3-4	1-2	0
ABC-class	A	B		C			N
Fraction of items in class	11%	15%		52%			22%

As earlier mentioned all items within Sandvik's product assortment are assigned with SIC-codes which are based on a continuously updated moving average of number of orderlines per product per year. Applying the classification based on SIC-codes rendered the results presented in Table 23. As can be seen in Table 23, the majority of the components end up in C-class, while the A- and B-class are significantly smaller.

By merging the two classification techniques the multicriteria analysis was performed and each product was assigned a final class. The results of the classification can be seen in Table 26-27 below. As can be seen, the AA-class is made up of four percent of the total amount of items but corresponds to almost 43 percent of the total sales value and 41 percent of the total sales quantity. It is evident that these items are of great importance and should be managed closely to maximize the potential they carry. On the other hand, the CC-class is made up of 41 percent of the items but only contributes with less than six percent of the sales value, and about nine percent of the sales quantity.

As can be seen in Table 24 and 27, items which were classified as N-products for the criterion cost volume does not contribute anything to sales value or quantity. This is because they have not experienced any demand during the period from which the data is extracted. However, items classified as an N-product for the criterion frequency do sell. This is because the SIC-codes are based on moving averages, so it is possible for a product to have sales history during the period even though it has a 0 as SIC-code.

Table 26: *The percentage of the total number of items placed in each of the sixteen classes. The CC-class has by far the largest amount of items, approximately 41 percent*

		Cost Volume			
	NBR of Items	A	B	C	N
SIC	A	4,1%	3,4%	3,8%	0,0%
	B	1,9%	4,0%	8,7%	0,2%
	C	1,3%	4,3%	41,1%	5,4%
	N	0,1%	0,7%	5,3%	15,6%

Table 24: *The table illustrates how much of the total sales value each class contributes with. The AA-class corresponds to approximately 43 percent of the total sales value*

		Cost Volume			
	Sales Value	A	B	C	N
SIC	A	42,6%	5,8%	1,1%	0,0%
	B	14,4%	6,3%	2,5%	0,0%
	C	12,2%	6,8%	5,6%	0,0%
	N	0,7%	1,2%	0,8%	0,0%

Table 25: *The table illustrates how much of the total sales quantity each class contributes with. The AA-class corresponds to approximately 41 percent of the total sales quantity*

		Cost Volume			
	Sales Quantity	A	B	C	N
SIC	A	40,9%	17,2%	8,8%	0,0%
	B	3,5%	5,4%	10,6%	0,0%
	C	0,6%	1,9%	9,1%	0,0%
	N	0,0%	0,5%	1,5%	0,0%

5.3. Network design

This section gives insights to the network design and the inventories throughout the chain. It maps out the network for major components and components. Furthermore, it analyses and identifies room for improvements regarding inventory allocation and levels at different tiers of the value chain.

5.3.1 Empirics

Network design for major components

The network design for major components is visualized in Figure 22 below. Major components start their journey at one of the suppliers' foundries. The lead time for this activity is long, which have led Sandvik to drive an initiative lead by BB, black belt, to contract availability at the key suppliers' finished stock. This could significantly reduce the inbound lead times for Sandvik. When the raw material arrives in Svedala it is stored outside of a machining workshop called Machining West. When a work order is released, the machining activities for the item are queued; if the work order is based on a customer order the priority can be higher. According to PCM, the processes for utilizing economies of scale at machining west are not in place. Therefore, the EOQ is calculated to be 1 piece for all major components at machining west. Machined parts are then stored on site, from where they can go both to new equipment and the aftermarket. There can be slight variations in configurations between aftermarket and new equipment. For example, they are packed in different ways and aftermarket customers may order a wear part assembled onto the major component. After the major components are assembled they are ready for new equipment assembly. If they are directed to the aftermarket they are first assembled. After that they are

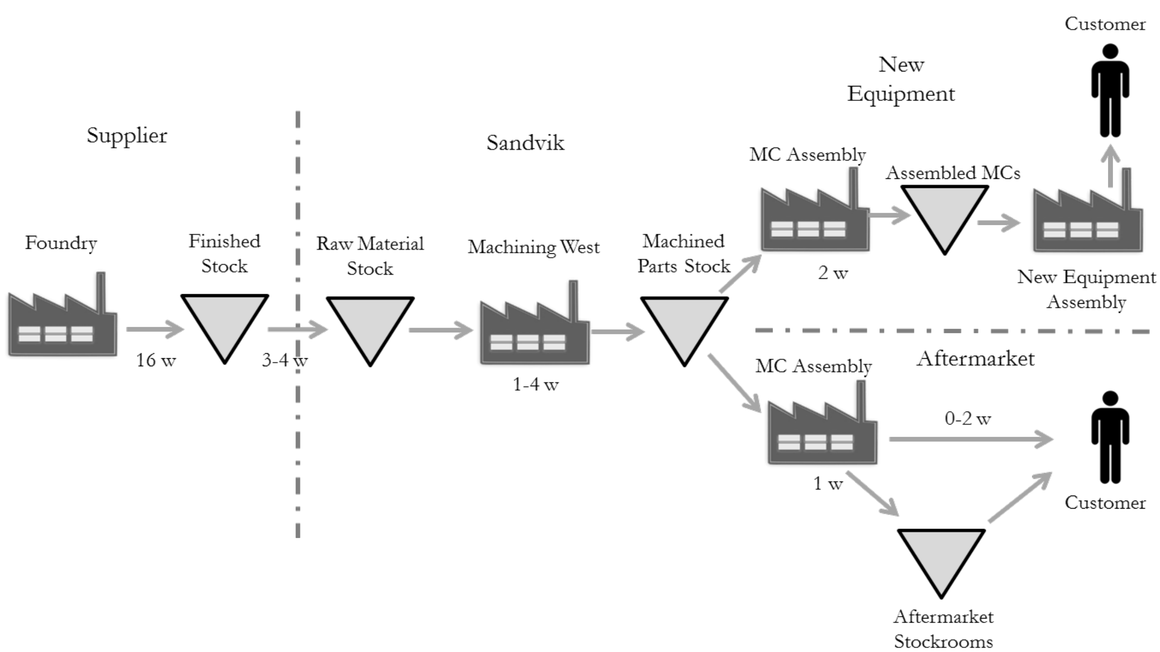

Figure 22: *Network design for Major Components, shows activities, stockrooms and lead times. Some lead times have been excluded since the variety is so high depending on region (source: authors)*

shipped to customer if there is a customer order or stored at an SMCL DC. As the items move downstream through the value adding activities and movements the internal cost for the item increases.

Table 27 below shows a snapshot of inventory balances at the different tiers of the major components value chain. Investment is calculated as the internal cost at the actual stockroom multiplied with quantity on hand in each stockroom, due to sensitivity of data this number has been transformed to an index instead of absolute numbers.

Table 27: *Snapshot of inventory balances and investment index*

Stockroom	Raw Material Stock M3	Machined Parts Stock M3	Assembled Major Components M3	Total for Aftermarket Stockrooms/DCs S21	Total
#Pieces, all MCs	159	50	23	56	288
Investment Index	23.4	15.5	17.6	43.5	100

Network design for components

In general, the components have much higher variation than major components on criteria such as size, lead time and complexity. Therefore, the network design is less uniform for components. Figure 23 below shows a bird's eye view of the network design for components. Since the lead times can vary so much among different components, they have been excluded from the map.

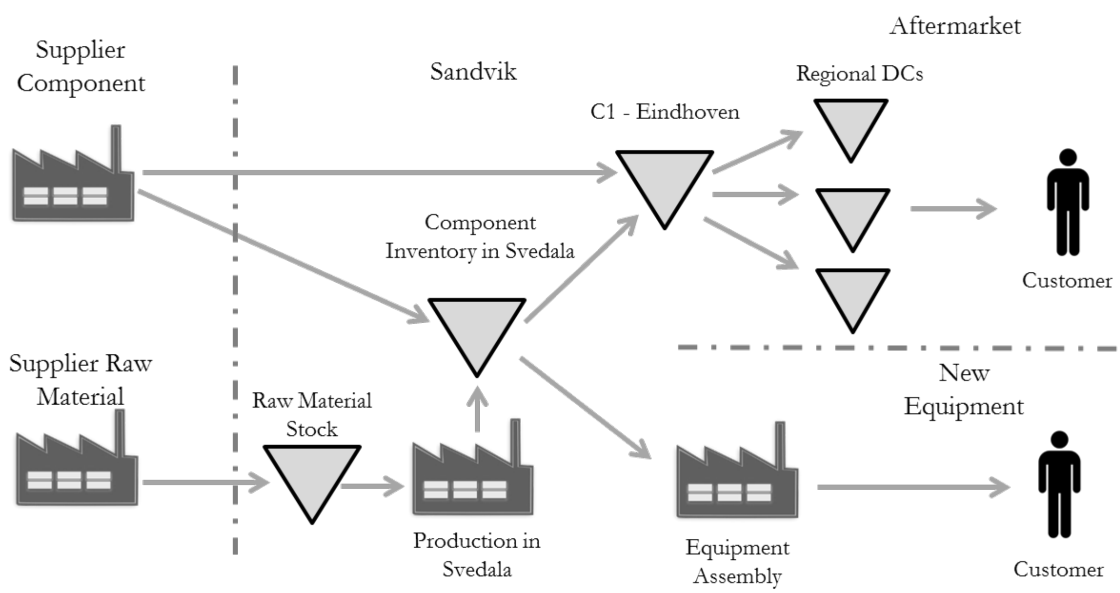

Figure 23: *Network design for components (source: authors)*

Some components are produced at Sandvik and sourced as raw material. Others are produced by suppliers. These can both be directed to Svedala, mainly with the intent of being used for assembly of new equipment. They can also be shipped direct to C1 in Eindhoven and distributed through the tiers of the aftermarket distribution network.

Table 28 below, compiles a snapshot of the inventory balances of SMCL (S21). Due to difficulties with accessing data, the balances in M3 are not presented. Also here the investment index is used to show the distribution of the total investment.

Table 28: *Inventory snapshot for components*

Stockroom	Svedala 07	Eindhoven C1	Chicago C2	Singapore C3	Johannesburg C4	Brisbane 63	Perth 67	Total
#Pieces, all Components	683	4909	826	973	242	281	115	8029
Investment Index	6.7	63.1	8.7	11.8	3.8	3.6	2.1	100

The stockroom C1 in Eindhoven that currently holds a large portion of the components has close proximity to the port of Rotterdam and major European airport hubs. The DC is handled by a 3PL that charges based on two dimensions:

- Cost of movements, e.g. cost per inbound and outbound order line
- Cost of capacity, e.g. cost per pallet position per time unit

PCM and RLM have expressed their concern that some really large items that move very slowly are stored in C1, which implicates high cost of capacity. This cost is much lower at the Svedala site.

5.3.2. Analysis

Analyzing the network design for major components

The value adding activities that major components go through have different characteristics along the chain. Through understanding these processes there is a clear step when the product variety increases in the chain. During the steps until assembly of major components there is no addition of product variety. By postponing the activities after machining until customer order is received, either for the aftermarket or new equipment, Sandvik can increase availability for the customers and reduce needed investment to the cost of increased lead times, see Figure 24 below.

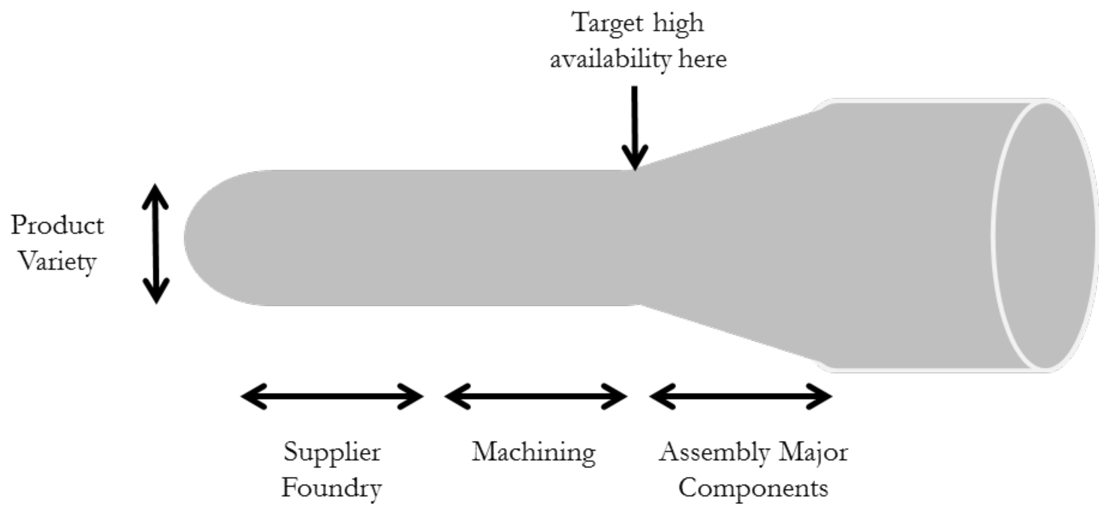

Figure 24: *Product variety throughout the value chain for major components (source: authors)*

With the current setup for stocking major components the reliability for customers is unstable. As can be seen in Figure 22, the lead time to customer is dependent on where in the chain there is availability of demanded product. In best case the customer can have the major component within one week, but in worst case it will take half a year resulting in a lost sale and customer dissatisfaction.

In accordance to the analysis above, company directives was to target high availability at the stage machined parts stock in Svedala. This stage has been decided to serve as a decoupling point for both new equipment and aftermarket orders. Connecting to the classification in 5.2, all classes of major components should be stored as machined parts stock except for the N-class. Current inventory balances do not support high availability at the machined parts stock, since most of the value is either raw material or consigned in an aftermarket regional DC. This can be partly be explained by the previous focus on working capital, that prevents planners from releasing machining work orders since the value add at this stage raises internal cost/value of the item, which implicates higher working capital.

As opposed to planners in Svedala, the sales areas focus on maximizing revenue, leading to high stock levels in the aftermarket stockroom that in many cases turn OSMI, obsolete or slow moving item, or obsolete. By breaking down the demand, Table 29 below gives a closer look at inventory held in the aftermarket worldwide stockrooms compared to the local demand for the corresponding regions. If there is no movements the last twelve months the item is accounted as OSMI where it in stages is depreciated before it turns totally obsolete after 24 months.

Table 29: *Distribution of value in aftermarket stockrooms*

Latest order in corresponding region	Percentage of total value	Accounted as
0 to 12 months	47 %	Active
12 to 24 months	6 %	OSMI
No orders in 24 months	47 %	Obsolete

As can be seen there is a large portion of the stored major components that is either OSMI or obsolete. All these items was decided to be shipped back to Svedala where it can be either used for new equipment or sent to another region where the item is more frequently demanded.

Downstream through the aftermarket distribution tiers there is much value of major components being held in C1 Eindhoven and the regional DCs. Storing the major components in the regional DCs can bring benefits in terms of response time and customer experience. As some customers can have their process disrupted until delivery, time is in these cases especially critical. However, storing full assortments in all the regional DCs would implicate a significant investment and high risk for stock turning obsolete. Which favor the concept of geographical postponement as described in section 3.4.3, where products are only shipped when customer order arises.

To evaluate what assortments of major components should be stored in the different regional DCs, both cost of understocking as well as overstocking needed to be taken into account. These costs were found hard to quantify within the scope of this project, therefore, company directives was to set a qualifying criterion: If a major component have been demanded ten or more times the last 24 months in a given region, it should be stored at the corresponding regional DC.

Analyzing the network design for components

The final strategy regarding network design for components have yet to be decided upon given the timeframe of this project. As opposed to major components, components consist of a large number of items that have high variety of characteristics. Some have a high weight and volume which favors storing them in Svedala due to the cost of capacity in C1, whereas others are very compact and C1 can be favorable because it can offer shorter lead times due to its proximity to ports and airports.

Table 9 in section 5.1 shows the variability in demand for the different regions. Compared to the HP case, described in section 3.4.2, where scenarios were created based on localization of activities, Sandvik's nature of demand for the aftermarket, further have to take in consideration how distribution activities (localization and order fulfilment) also can vary among items depending on the assortments in the different tiers of the distribution echelon. Customers can, in most cases, only be supplied with components from Sandvik. Which can make lead time and regional availability especially critical if a crusher is out of operation until delivery of spare part. Similar to major components, this is a factor that has to be taken into account when deciding on assortments down the aftermarket distribution echelon.

5.4. Policies for inventory control

This section describes the process of forming policies for inventory control. It gives insights to Sandvik's current ways of managing inventory control policies which is followed by an explanation of developed decision support tools and initial results achieved by these. At last, it compares the results with the current situation in a gap-analysis.

5.4.1. Empirics

Current use of inventory control policies
The planning organization at Sandvik works with daily responsibilities of planning purchasing and production. As earlier mentioned it is not until recently that the organization in Svedala has had the mandate over planning both for new equipment production and aftermarket sales. The reorganization has resulted in the planning organization working with daily operational planning in both of the systems, S21 and M3.

The most important factors planners work towards are re-order points, order quantities and safety stocks. Incorporated into the systems M3 and S21 are forecasts for production and demand. With the help of these, the systems trigger suggestions for the planners to take action on. Based on the ROP, reordering point, the order quantity, the safety stock and lead times different purchasing suggestions of differing sizes will reach the planner. The planner can, by comparing actual demand with the forecast, decide whether to place an order in the system or not, place an order of the same size suggested by the system or larger or smaller, earlier or later. The order quantities are not based on EOQ, since the ordering cost has not been calculated in the system.

Working capital
Through the observations and discussions held within the organization it has been concluded that one of the main goals of the planners at Sandvik has been to focus on the management of working capital. E.g. it is mentioned: "There is a traditional mindset of the planning organization to keep the working capital low".

What also has been expressed is a worry regarding the continuation of this mindset since there has been a clear statement of shifting focus towards material availability at the expense of increasing working capital in different tiers of the supply chain. The worry is that a continuing focus on keeping working capital low leads to planners holding off on placing orders when suggested and in too small quantities, leading to delays in production and not being able to meet demands.

Use of classifications within the planning organization

The use of classification strategies of products as a part of the daily planning operations is not in place at Sandvik at the moment. As mentioned in section 5.2.1. there are classifications being performed within systems, but it is not utilized within the organization in any great extent. It has been expressed by several of the stakeholders involved in the project that the general way of working as applied a "one size fits all" methodology when planning for different product types.

5.4.2. Analysis

Reliability of demand data

All demand data presented is based on order intake from customers. This data does not fully represent the actual customer demand. Orders are logged in S21 when the customer accepts the presented lead time. In cases of no availability or lead times being too long for the customers to accept, the order will not be logged in S21 by the sales representative. This gap weakens the reliability of the data.

Developing support tool for inventory control

What became clear while investigating Sandvik's general methods working with product classifications in combination with their inventory planning was that the analysis carried out in this project needed to become repeatable. It was the wish from Sandvik that the process could be carried out during set time intervals to make sure the classifications were kept relevant and up to date. By continuously making sure the right products are placed in the right classes the planning organization at Sandvik can also make sure that they are treating products with the right inventory policies and parameters.

Goal for the support tools

The support tool was to be able to handle both major components and components. Therefore, it was decided upon that two separate tools were to be developed. This because already in the product classification schemes the product groups major components and components were separated from each other. However, the main goals of the two tools are common: to enable the planning organization to incorporate a product classification scheme in their work to plan and manage inventory. Firstly, the tools were to be able to carry out product classifications based on a data-set loaded into the tool. Thereafter, by treating products in respective classes it should be possible to produce simple simulations in order to visualize what inventory balances and investments are required to reach different service levels. Thereafter by incorporating a model for calculating safety stocks, which is already developed by Sandvik, the support tools would be able to go from specified in-data, via product classification and simulation of inventory- and service levels to finally suggesting minimum- and maximum scenarios regarding safety stocks.

Simulation instruments

Within the two decision support tools two simulation instruments can be utilized, one regarding simulating service levels based on different levels of stock and one regarding safety stocks based on desired service levels. The latter was developed by Sandvik during a previous improvement project and it was their wish that it would be implemented in combination with the classification methods as well as the other simulation tool hereby referred to as *the service test.* Both are simple simulation tools based on heuristic models which can be used each by itself or in unison in order to set up guidelines for inventory control parameters. The tool developed by Sandvik will not be explained further than that it calculates safety stocks and ROPs with the help of historic demand and lead times.

The service test

The service test is a heuristic developed during the project in order to simulate what service level corresponds to different inventory levels by utilizing fill rate or S2, see section 3.3.6. By inserting historic demand over twelve months for a specific item the mean demand over these twelve months can be calculated. This is thereafter used to represent one month of demand in inventory or in multiples for higher inventory levels. The heuristic will thereafter compare the inventory level with the historic demands to see what service level would have been fulfilled if the inventory levels would have been held at the simulated one, see Table 30 for an example of how the service test is used.

Table 30: *An example of how the heuristic service test can be used. Demands are analyzed by simulating what service levels are achieved by different levels of inventory*

Demand patterns by month														
Type of product	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total	Mean demand per month
Item XX	3	3	0	1	5	4	5	2	1	3	0	12	39	3,25

Months of Inventory	Quantity	Backorders	Approximate Service Level
1	3	14	64%
2	7	5	87%
3	10	2	95%
4	13	0	100%

The idea is to use the service test in combination with grouping of items into their respective classes. An entire class can thereby be analyzed through finding common strategies or policies for inventory levels per class.

As the service test is a simple heuristic the results the model produces should be used with caution. It is an easy and swift tool to use but should not be considered to be entirely reliable. The purpose of the simulation model is to illustrate data and to produce pointers which can lead in certain directions. That does not mean that the exact inventory levels, which are suggested by the model, should be used. As mentioned above, the historic data used is representative but may not be equal to the true demand experienced by certain products and is not equal to a product's future demand.

Decision support tools overview
An overview over each of the two tools can be seen in Figure 26 and Figure 25. As earlier described the two tools differ from each other in the sense that the item types handled by each tool differ. This difference has been discussed throughout the analysis of this project and has resulted in the different methods which should be applied, from which data is relevant to study and which classifications should be performed to the policies and strategies that should be applied to effectively deal with the item types in terms of inventory management and control.

The general way of working with the tools is similar but the dissimilarities can be seen by comparing the columns in Figure 26 and Figure 25. The general steps of performing an analysis with tools are described below.

1. **Data mining**: all relevant data needs to be extracted from respective source such as M3, S21 and item master-database
2. **Perform classification(s)**: based on current data each item will be appointed a class
3. **Perform second classification**: primary classifications will be used in order to perform multi criteria analyses
4. **Simulate**: use service test and safety stock simulations to find relevant policies for different classes

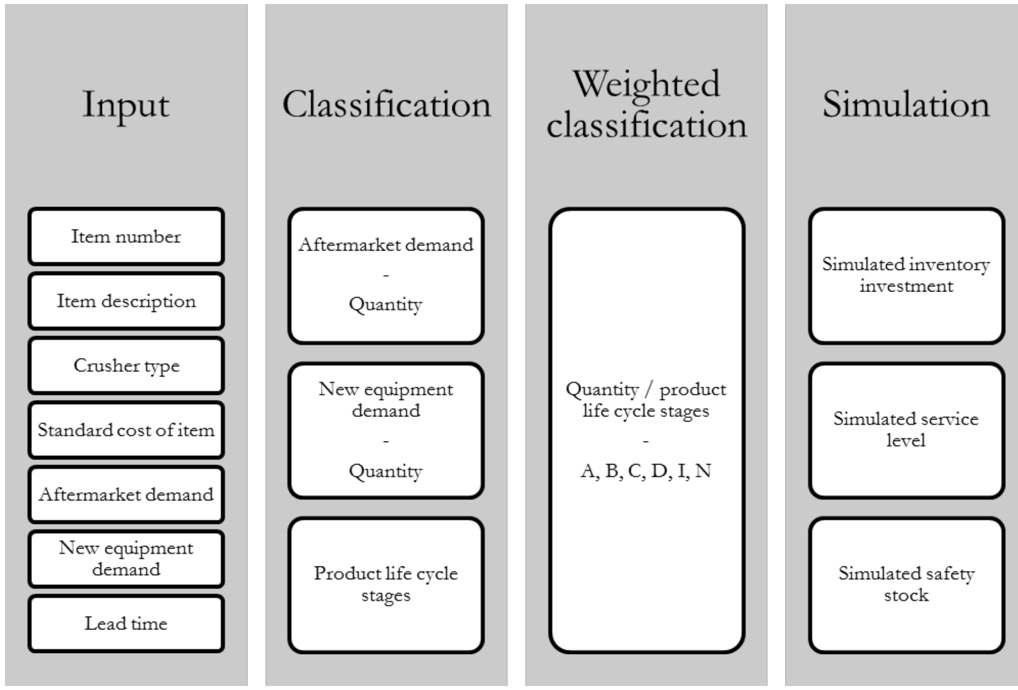

Figure 26: *An oversight of the support tool regarding major components. The leftmost column describes the input data needed for the tool. The three remaining columns describes the outputs produced by the tool*

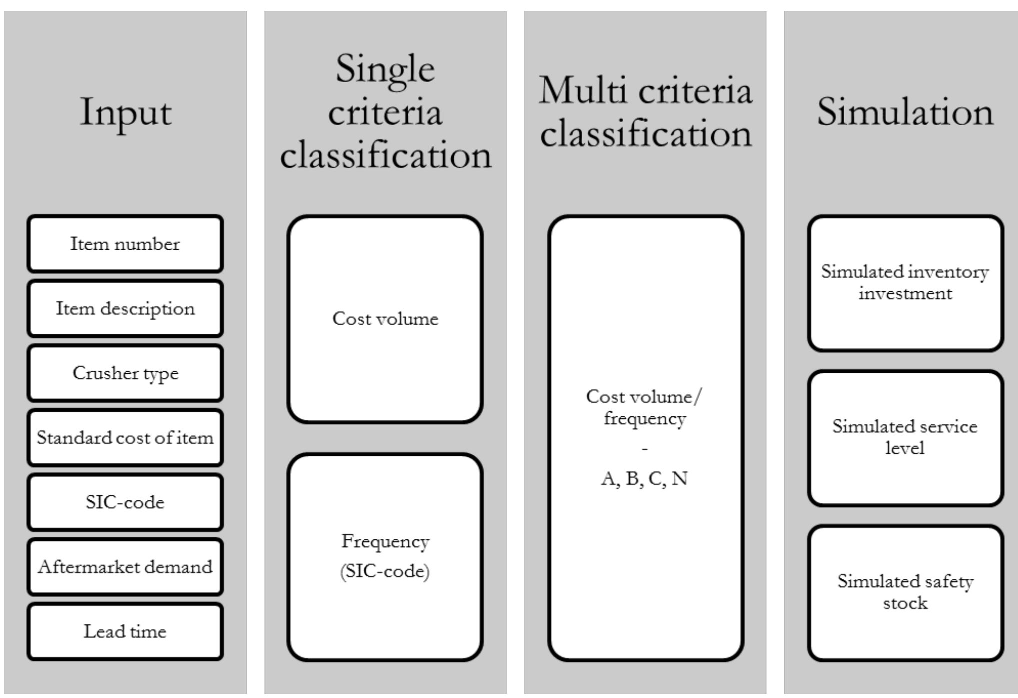

Figure 25: *An oversight of the support tool regarding components. The leftmost column describes the input data needed for the tool. The three remaining columns describe the outputs produced by the tool*

Simulation results and gap analysis for major components

After the major components had been classified by the support tool, the demand data, both new equipment and the aftermarket, on a global level was used to simulate service levels based on different inventory levels. The demand data used for new equipment was decided to be based on forecasted demand instead of historic demand data. The reason for this is that the historic demand does not capture the trend of increasing demand for new equipment that has high volatility as explained in section 4.2. By instead using the forecast for the service test the simulation was considered more reliable among the responsible planners PCM & SC. Company directives was clear that 98 percent service level (S2) should be the basis for the calculations regarding major components. With this input the tool calculated target inventory levels for each class expressed in months of mean demand. The results can be seen in Table 31.

Table 31: *Results from simulation on 98% service level for major components*

Class	Months of demand Service level > 98%
A	3
B	5
C	3
D	6
I	3
N	-

Using these results, the targeted inventory levels for each major component could be set for the machined parts stock. Since the value chain for major components contain so many steps and the lead-times are long, a simple (R,Q)-system (as explained in section 3.3.4) was not feasible, since there needs to be a continuous flow of major components from suppliers and through machining west. Instead target levels of inventory was set according to the service test for machined parts, of which the rule of thumb by company directives was to target a ratio for supplier:raw:machined of 2:1:3. By having these target stocks the planners can closely monitor the gaps from target and adjust these for e.g. large new equipment orders. This was favored over the (R,Q)-system that only tells you when to order and to what quantity. This increases the administrative complexity, however, for major components that has so high value and business impact this was considered reasonable.

The assembled major components stock is close connected to production and will not be changed under the scope of this project. According to section 5.3.2 the major components in the aftermarket stockrooms have been decided to be sent back to Svedala if they have been demanded less than 10 times the last 24 months in the corresponding region. With these targets set, they could be compared to current levels; this comparison can be seen in Table 32, Figure 27 and Appendix 6.

Table 32: *Target inventory balances and investments compared to current*

	Raw Material Stock		Machined Parts Stock		Assembled Major Components Stock		Aftermarket Stockrooms		Total	
	As-Is	To-Be	As-Is	To-Be	As-Is	To-Be	As-Is	To-Be	As-Is	To-Be
#Pieces	159	76	50	226	23	23	56	6	288	331
Diff	-52%		+ 352%		-		-89%		+14.9%	
Investment Index	23.4	13.4	15.5	79.6	17.6	17.6	43.5	3.0	100	113.6
Diff	-42%		+413%		-		-93%		13.6%	

The results show that in order to raise availability only a 13.5 percent increase of investment was needed, the large changes was where the value chain the inventory of major components should be held. By looking closer at the targets versus current inventory levels for each major component an actionable gap analysis on item level, see Table 33 below, can be conducted for the raw material stock and machined parts stock. MC YX falls short in total, therefore it should be sourced,

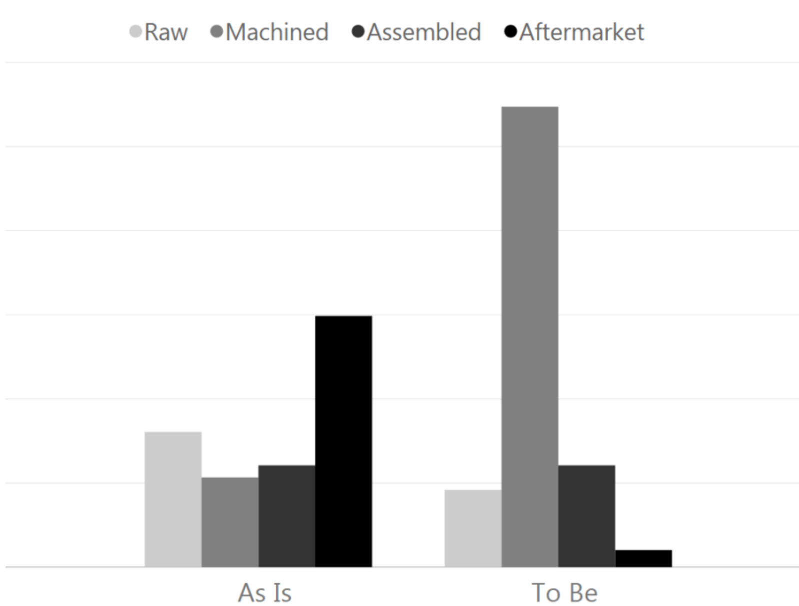

Figure 27: *Inventory investment targets compared to current levels*

since there is raw material available machining orders should be released. For MC YY total fall short as well and should therefore be sourced, however, no machining orders can be released until delivery of raw material. At last MC YZ is overstocked in total compared to target, yet there is an imbalance, the action needed for this item is to release machining orders to reach target inventory balance for machined parts stock. Appendix 6 shows how the availability in terms of lead times are distributed for the as is and to be situation.

Table 33: *Gap analysis for major components*

	Raw material stock		Machined parts stock		Action
	As Is	To Be	As Is	To Be	
MC YX	9	4	1	11	Source & Machine
MC YY	0	3	3	10	Source
MC YZ	19	4	1	11	Machine

Simulation test results for components

The global component aftermarket demand data was fed into the service test tool. A dashboard showed the service levels based on different months of inventory which can be seen in Appendix 7. Table 34 below exemplifies the service levels for each class if the global serving inventory was to store 1 month of demand of each item.

Using the results from this dashboard each class would need the following inventory levels expressed in months of demand, see Table 35 below.

The tool is applicable both for global aftermarket demand as well as regional demand. Sandvik can in the future use this tool for regional demands by filtering the demand data based on customer region. By doing this, the tool will provide support to take decisions on regional assortments. The simulation can also be used on a repetitive basis which allows Sandvik to keep track on changes in demand.

Table 34: *Results of 1 month of demand for the different classes*

		Value			
	1 Month	A	B	C	N
SIC	A	84,23%	81,18%	70,57%	-
	B	65,50%	65,99%	62,79%	-
	C	34,96%	34,18%	17,63%	-
	N	0,00%	26,01%	9,18%	-

Table 35: **T***ool results: levels of inventory for 98% service levels for components for each class*

Class	Months of Inventory	Class	Months of Inventory
AA	2	**AC**	6
BA	2	**BC**	6
CA	4	**AN**	6
AB	4	**BN**	6
BB	4	**CC**	6
CB	4	**CN**	6

As stated above, the final decisions on assortments and inventory levels throughout the aftermarket distribution network are yet to be decided on, this tool however, will be valuable as for future decision taking as key stakeholders at Sandvik has been taught how to use it. In regards of ordering systems, an (R,Q)-system is seen more favorable for components, both since the amount of items is so much greater, but the value chain is less complex and the lead-times are shorter.

6. Conclusions

In this chapter the conclusions drawn throughout the study are presented and discussed. Firstly, the research questions, which the project is based upon, are answered. Thereafter the chapter is concluded by a discussion of the project.

6.1. Answering the research questions

6.1.1. Research question 1

How should the items of Sandvik be segmented?

This question is mainly answered through the concepts and methods discussed in section 5.2. What was realized early on during the project was the need for a defined distinction between different product groups handled by Sandvik. This resulted in the first division of products into the four general product groups; major components, components, commercial spare parts and wear parts.

Delimitations and company directives resulted in the project only touching upon further segmentation for products included in the groups major components and components. Because of the central purpose to focus on material availability the criteria upon which major components were segmented by were sales volume and life cycle stage taking regards to both aftermarket and new equipment demands. The segmentation resulted in the classes A, B, C, D, I and N. For components where only the aftermarket demand was to be regarded and capturing items with high sales volumes and values as well as continuous sales patterns turned out to be important, the criteria to segment upon became cost volume and frequency. The multicriteria segmentation resulted in 4X4 classes with A, B, C and N on each axis.

6.1.2. Research question 2

How should the different segments be differentiated in regards of inventory management?

From performing this project, the authors found two dimensions for the differentiation and strategy: item groups (major components & components) and the classes within each of the segments. Due to lack of time the differentiation for the classes within components have not been decided upon.

Table 36 below compiles the differentiation and strategy for the item groups: major components and components. As discussed above, the classification criteria differ among them. Because of the long lead times of major components, the demand for new equipment and aftermarket are aggregated, whereas they are kept separated for components. Major components should be stored with full assortment in Svedala, for the cases where a major component have been ordered 10 or more times the last 24 months they can be stored in corresponding regional DC. In regards of components, final decisions on assortments are yet to be made. The decoupling point for major components should be the machined parts stock where they can be used both for the aftermarket

Table 36: *Differentiation on item group dimension*

	Major Components	Components
Segmentation Criteria	• Sales volume • Product life cycle stage	• Cost volume • Frequency (SIC code)
Segmentation Data	Aggregate aftermarket and new equipment demand	Separate new equipment from aftermarket
Assortments	Full assortment available as machined in Svedala, store in regional DC if demanded in corresponding region >10 times last 24 months	Decisions to be made by the case company
Decoupling Point	Machined part inventory	Depending on assortment in the different tiers of the network
Segmentation and Inventory Control Process	Allow for manual activities	Automated process
Ordering System	Continuous and manual monitoring with target levels	(R,Q)-system
Suggested Actions	• Ship back OSMI and obsolete MCs from regional DCs • Balance value chain inventories according to gap analysis • Continually reuse decision tool to revise classification and inventory control parameters	• Decide upon grouping among classes • Use tool to decide on assortments globally and regionally • Use decision tool to perform gap analysis globally and per region • Continually reuse decision tool to revise classification and inventory control parameters

and new equipment. For components the decoupling point will vary depending on the decisions to be taken on assortments. The process of analyzing and revising the classification and inventory control parameters can be allowed to contain manual activities for major components since they are a few number of items with very high business impact, however, components need to be a much more automated process due to the number of items. As discussed the ordering policies is recommended to differ among the two product groups. Also compiled in the table are the suggested actions for the case company.

As of the results from the service test in section 5.4.2, the different classes of major components should be stored as machined parts with quantities as months of demand according to Table 37 below. All major components should be stored in Svedala, for some A-class items, if demands in specific regions are 10 or above items during the last 24 months; they should also be stored in corresponding regional DC. The A-class items have high business impact and the order intake and usage for new equipment should be monitored closely, for B and C class a quarterly review is seen as sufficient. For the introductory I-class and strategic D-class planning should have continuous communication with PLM for potential changes. The I-class should also be monitored for surges in demand.

Table 37: *Differentiation on item classification criteria for major components*

Major Component Classes	A	B	C	D	I	N
Months of demand inventory in Svedala	3	5	3	6	3	-
Storage location	Svedala & for some in Regional DCs	Svedala	Svedala	Svedala	Svedala	-
Review Period and Planning Actions	Monitor closely, monthly basis	Quarterly basis	Quarterly basis	Contact with PLM	Contact with PLM, monitor for surges in demand	No action

6.1.3. Research question 3

How can the suggested strategy be realized at the case company?

In order to realize a process which could be repeated and updated continuously the project was summarized into two spreadsheet models which could act as decision support tools, see Figure 26 and Figure 25. A product segmentation process in combination with creating inventory management strategies such as this project is not a one-time occurrence. Since both the items which are included in Sandvik's assortment and their sales patterns are under continuous change, the classification must also be possible to update. The suggestion is to incorporate the decision support tools into the tactical work for the planning organization. By revising the classifications and thereafter the ways in which the products are managed on a quarterly basis the case company will ensure that each item is handled properly regarding inventory management principles.

6.2. Concluding discussion

6.2.1 Generalizability and contribution to research

The theoretical foundation, on which this report stands, is based on well-known concepts, frameworks and tools for inventory management. By applying these on the case company with influence from situational factors at the case company, the main contribution to research can be found in the process of application. This makes the analysis and conclusions of this project relatively ungeneralizable, since situational factor may vary between companies and industries. However, the described process of using the concepts, frameworks and tools can be applicable for other companies and used in future research.

6.2.2 Future work at the case company

The first thing which is suggested for the case company to perform is a thorough evaluation of the process once the results have been carried out and implemented. Areas which would need to be explored are criteria for segmentation and cut-off points as well as effectiveness of applied inventory policies on desired result areas such as product availability and customer satisfaction.

An area which has presented itself as a problem throughout the project is the availability of data and the cumbersome process of mining correct data. Gathering data is an important factor for the analyses to function properly and a process which also needs to be revised by Sandvik. Since the decision support tools are to be continuously updated so is the data going into the models. Preferred is that a query is created which simply collects data from all data sources in a manner matching the model.

As earlier mentioned due to resource constraints a complete analysis regarding components has not been possible to conclude. Therefore, Sandvik needs to decide upon principles on how to manage the decided classes. This project has provided a basis upon which further analyses can be conducted by Sandvik. One such analysis which is suggested for Sandvik to perform is to create regional assortments for the regional warehouses in order to gain closer control of what products are stored where.

By introducing the methodologies and tools developed by and discussed throughout this thesis, it is the belief of the authors that it will be possible for Sandvik to be able to capture a larger share of the aftermarket for their products. As mentioned within section 1.3., problem formulation, at the time of writing, Sandvik estimated that they only realize sales for 30-45 percent of the aftermarket. To experience the results which the methodologies will incur, will not take place over a night. But, since the focus on product availability has permeated this project and specifically the analysis the outcome will be a higher precision regarding which products are available and to which extent.

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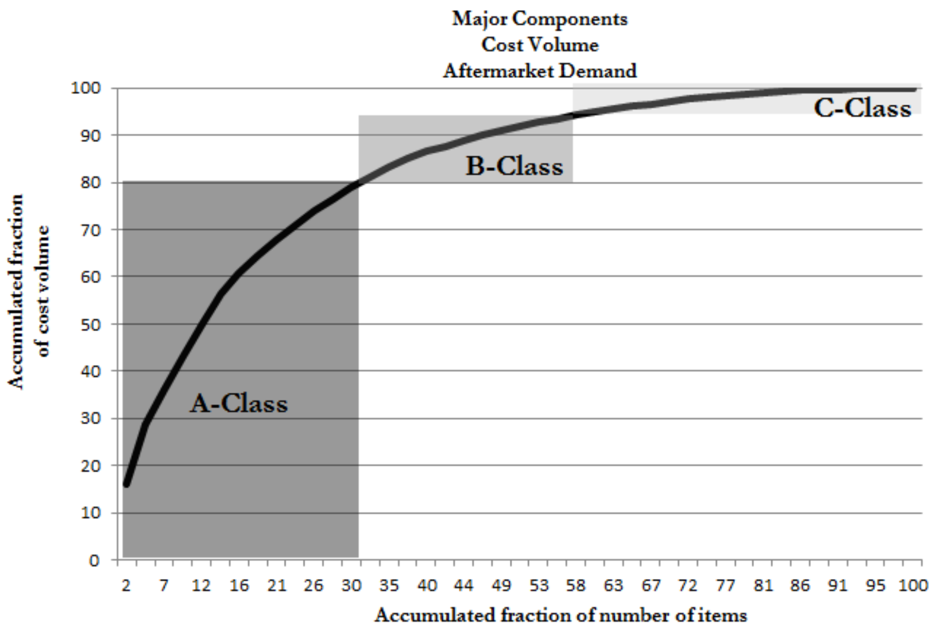
APPENDIX

A.1.

Appendix 1: *Stakeholder names have been removed in respect of the privacy for each stakeholder*

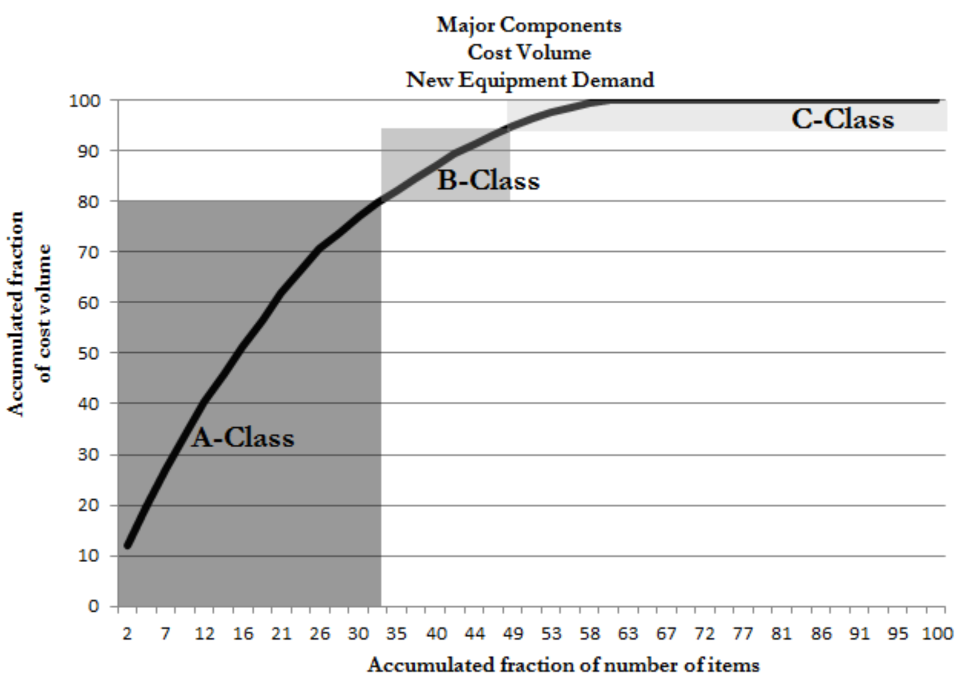
Stakeholder Registry		
Name	**Role**	**Abbreviation**
---	Black Belt	BB
---	Inventory Specialist	IS
---	Planning and Capacity Manager	PCM
---	Regional Logistics Manager	RLM
---	Sales Coordinator	SC
---	External Logistics Manager	ELM
---	Logistics Developer	LD
---	Procurement and Inbound Logistics Manager	PILM
---	Director Logistics	DL
---	Product Line Manager	PLM

A.2.



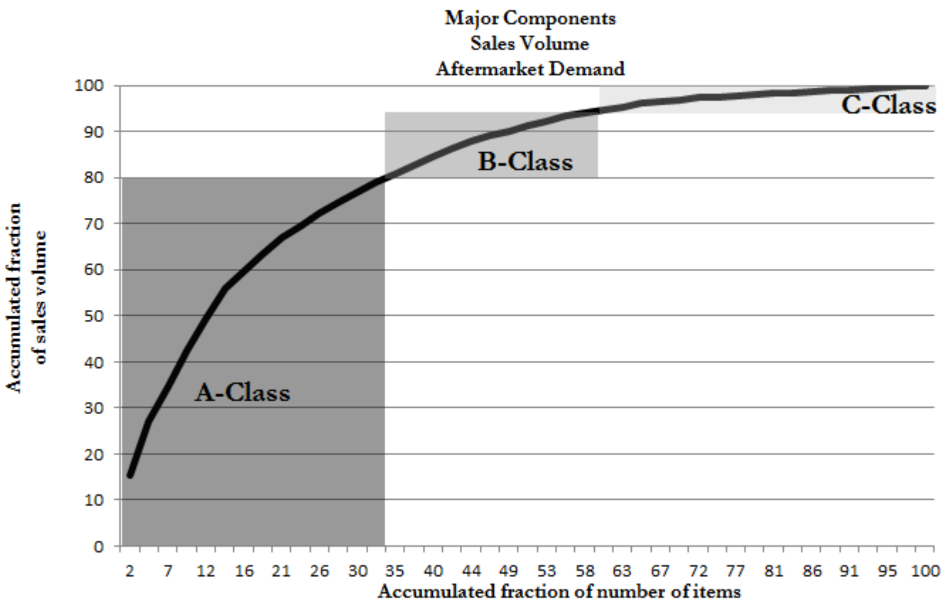
Appendix 2: *Pareto curve for the ABC- analysis conducted on major components with the criterion cost volume for aftermarket demand.*

A.3.



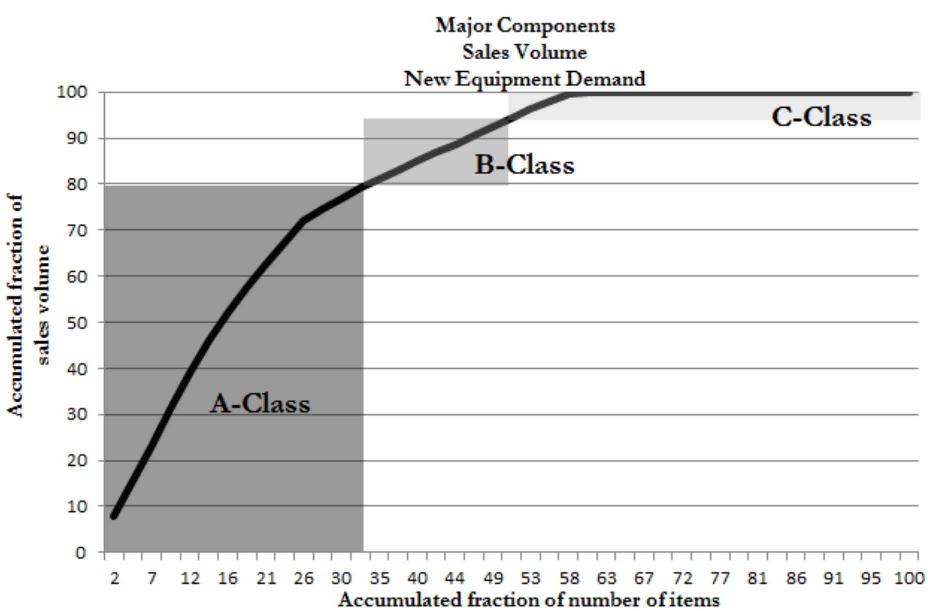
Appendix 3: *Pareto curve for the ABC-analysis conducted on major components with the criterion cost volume for new equipment demand. Not all items included in the analysis has an equipment demand, why the curve reaches 100 percent on the Y-axis while only at approximately 60 percent on the X-axis.*

A.4.



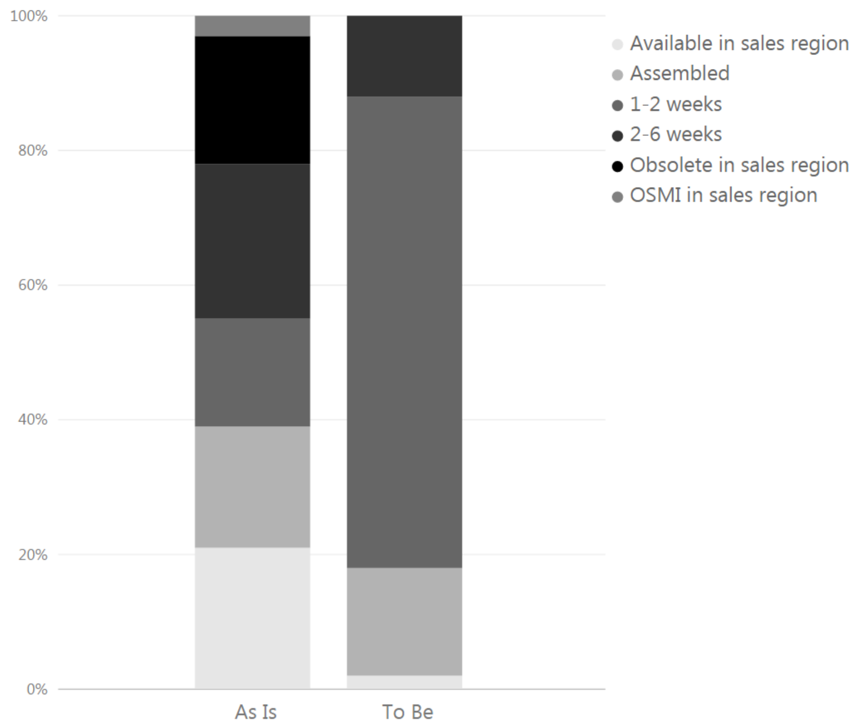
Appendix 4: *Pareto curve for the ABC- analysis conducted on major components with the criterion sales volume for aftermarket demand*

A.5.



Appendix 5: Pareto curve for the ABC- analysis conducted on major components with the criterion sales volume for new equipment demand.

A.6.



Appendix 6: *Shows the distribution of major components along the supply chain. The presented times are remaining lead times to delivery.*

A.7.

Appendix 7: *Dashboard for the decision tools. Inventory levels versus service levels.*

1 Month		Value A	B	C	N
SIC	A	84,23%	81,18%	70,57%	-
	B	65,50%	65,99%	62,79%	-
	C	34,96%	34,18%	17,63%	-
	N	0,00%	26,01%	9,18%	-

5 Months		Value A	B	C	N
SIC	A	100,00%	100,00%	99,90%	-
	B	99,80%	98,64%	99,14%	-
	C	83,13%	77,59%	62,10%	-
	N	50,00%	48,94%	39,08%	-

2 Months		Value A	B	C	N
SIC	A	98,77%	98,06%	90,82%	-
	B	87,81%	91,62%	87,30%	-
	C	62,84%	56,35%	38,43%	-
	N	50,00%	40,33%	21,23%	-

6 Months		Value A	B	C	N
SIC	A	100,00%	100,00%	100,00%	-
	B	100,00%	99,07%	99,73%	-
	C	100,00%	98,94%	92,94%	-
	N	100,00%	99,01%	87,36%	-

3 Months		Value A	B	C	N
SIC	A	99,87%	99,78%	96,81%	-
	B	96,12%	96,68%	95,09%	-
	C	76,70%	72,19%	55,83%	-
	N	50,00%	44,04%	34,79%	-

7 Months		Value A	B	C	N
SIC	A	100,00%	100,00%	100,00%	-
	B	100,00%	99,22%	99,84%	-
	C	100,00%	99,05%	93,29%	-
	N	100,00%	99,67%	87,66%	-

4 Months		Value A	B	C	N
SIC	A	100,00%	100,00%	98,51%	-
	B	98,74%	98,43%	98,13%	-
	C	80,85%	74,83%	58,70%	-
	N	50,00%	47,36%	35,47%	-

8 Months		Value A	B	C	N
SIC	A	100,00%	100,00%	100,00%	-
	B	100,00%	99,34%	99,85%	-
	C	100,00%	99,63%	94,20%	-
	N	100,00%	100,00%	90,28%	-

12 Months		Value A	B	C	N
SIC	A	100,00%	100,00%	100,00%	-
	B	100,00%	100,00%	100,00%	-
	C	100,00%	100,00%	100,00%	-
	N	100,00%	100,00%	100,00%	-