# Mapping, development and optimization of internal logistics in a multi-stage production facility

**Action research at Sandvik**




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# Abstract


**Title:** Mapping, development and optimization of internal logistics in a multi-stage production facility

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**Background:** In highly dynamic and competitive environments, supply chain management and logistics can create important advantages against competitors. Since logistics costs and tied up capital also impacts profitability, these activities demand full attention and careful planning.

**Purpose:** By mapping and analysing Sandviks internal logistics, the aim is to develop and optimize related operations by providing tangible descriptions of the current practise, and solutions for improvements.

**Research questions:** **RQ 1:** Can Sandviks future storage requirements be met by the current storage capacity?
**RQ 2:** How can the current storage capacity be better utilized and improved?
**RQ 3:** How can the flow of goods be optimized?

**Method:** To be able to thoroughly map the current logistics operations and provide recommendations for implementation, an action research with an inductive and qualitative research approach was chosen. Primary data was collected through interviews and observations while secondary data was obtained through internal databases. Important tools for mapping and analysis was spaghetti diagrams, gemba walks value stream mapping.

**Conclusions:** The action research resulted in an accurate and rather detailed analysis of the current situation and operations. It can firmly be concluded that a VSM is a useful tool in order to identify waste within a logistics process and the outcome combined with the spaghetti diagrams enabled the researchers to provide recommendations for improvements. Sandviks storage capacity can meet future storage requirements, even though the rather poor utilization. However, it was established that the lack of system support for monitoring storage availability created difficulties for the warehouse and logistics staff.

# Preface

This action research has been carried out at the Svedala production unit for Sandvik Stationary Crushing & Screening. The researchers would like to thank all involved staff who helped and supported throughout the entire project. Especially thanks to; Conny, Marlies, Kenneth, Peter, Leif, Karin, David and Lilleman. Not only did the project help us develop as engineers, but was also a lot of fun!

The researchers would also like to send big thanks to Eva Berg at the Department of Industrial Management and Logistics. We received many valuable and tangible insights and a lot of support which helped accomplish this action research.

We wish you all a happy summer!

**Nils Jönsson & Björn Hofbard**

# Table of Contents

# List of figures

# List of tables

# List of abbreviations and definitions

| | | |
|---|---|---|
| SMS | Sandvik Machining Solutions | page 2 |
| SMRT | Sandvik Mining & Rock Technology | page 2 |
| SMT | Sandvik Materials Technology | page 2 |
| EQ | Equipment: finished products to customers | page 3 |
| AM | Aftermarket: finished components to customers | page 3 |
| VSM | Value Stream Map | page 10 |
| MTO | Make-to-order | page 20 |
| MTS | Make-to-stock | page 20 |
| ERP | Enterprise Resource Planning | page 20 |
| WMS | Warehouse Management System | page 21 |
| WIP | Work in process | page 23 |
| MRP | Materials Requirements Planning | page 23 |
| JIT | Just-in-time | page 27 |
| KPI | Key Performance Indicator | page 30 |

# 1 Introduction

*This section aims to explain the background and purpose to why this action research has been carried out. Additionally, a short description of the company and its products will be provided.*

## 1.1 Background

The direction of global goods flows and the growth of nodes in trading networks have a significant impact on the development of logistics hubs. Globalization, higher customer expectations and changing purchasing habits significantly impacts logistics processes as they face changing tasks and challenges within supply chain management. (Oláh et al., 2018) According to Jonsson & Mattsson (2011) logistics costs and tied up capital not only impacts logistics processes but also company profitability. Due to the market competition, Gu et al. (2007) argues that continuous improvement of design and operations in production distribution networks is required, which in turn creates a demand of higher performance from warehouses.

Sandvik Stationary Crushing & Screening, in this thesis report denominated Sandvik, and its supply chain network set-up is currently undergoing several changes with the purpose to gain a more competitive advantage globally. The production unit in Svedala, focusing on manufacturing of stone crushers and related spare parts, plays an important role in the global supply chain of Sandvik, with the internal logistics having a high impact on the production and performance of the site. This desire of efficient and optimized internal logistics is the main background to this thesis. In general, Sandvik have a need of efficient logistics operations regarding e.g. storage capacity, flow of goods and structured routines for put-away, picking and packing.

The production site consists of four different production areas and is rather complex with manufacturing, sourcing and sub-contracting of components while delivering aftermarket parts as well as assembled complete crushers. Furthermore, the large scale of the site creates long distances between different production facilities and storage areas. A major part of the goods handled on the site is very heavy and bulky why internal transportation can be a bottleneck requiring both special handling equipment, spacious routings and easy accessible storage areas.

By observing processes and operations from a new and different perspective, this thesis can help identify problems and bottlenecks which are sometimes difficult to find from an inside perspective. Another valuable part for Sandvik is that the researchers have the time to implement and investigate solutions, something that Sandvik struggles with today due to the high utilization of the staff. Hopefully, by suggesting and evaluating changes and solutions, the research can help improve the internal logistics operations and overall performance of Sandvik.

## 1.2 Purpose and problem formulation

Having optimal utilization of storage capacity is a key issue for most companies, especially in cases of limited warehousing and storage spaces (Gamberini et al., 2008). For Sandvik, this is a critical question due to its rather large, bulky and heavy products in need of storage. Chackelson et al. (2013) also argue that warehouse design and layout is not only important for a company's customer service but also due to its impact on the total logistics costs.

The main purpose of this thesis project is to develop and optimize Sandviks internal logistics operations by suggesting solutions on how to improve utilization of storage capacity and reduce on site transportation through increased efficiency of goods flow. The goal was to make enhancements that will render in a streamlined logistics process with impact on Sandviks profitability and performance.

### 1.2.1 Research questions

The main tasks and problems addressed in the thesis project can be expressed in three research questions (RQ):

**RQ 1:** Can Sandviks future storage requirements be met by the current storage capacity?

**RQ 2:** How can the current storage capacity be better utilized and improved?

**RQ 3:** How can the flow of goods be optimized?

## 1.3 Company description

Sandvik Group is a global leading engineering group within materials technology and industrial processes. With unique expertise, extensive knowledge, close customer cooperation and with continuous investments in research and development, Sandvik are in the forefront within tools and tooling systems for industrial metal cutting, service and technical solutions for the mining and construction industry and advanced stainless steels and special alloys. (Sandvik AB, 2018) The Sandvik Group operates in the three business areas Sandvik Machining Solutions (SMS), Sandvik Mining & Rock Technology (SMRT) and Sandvik Materials Technology (SMT).

### 1.3.1 Svedala production unit and products

Within the business area SMRT, the production unit in Svedala is focusing on manufacturing stone crushers and related aftermarket products to the global mining and construction industries. The production unit operates within the product area Crushing & Screening and covers the business unit Stationary Crushing & Screening with its two main products; cone crushers and jaw crushers. (Sandvik AB, 2018) The production unit utilizes upstream vertical integrated production with casting of parts, machining, assembly and painting. The production unit in Svedala manufactures both equipment (EQ) i.e. finished stone crushers, as well as aftermarket (AM) parts to customers and sales areas globally.

## 1.4 Focus & delimitations

For Sandvik, the cone crusher is the most frequently produced product, why this specific product was in focus in this thesis. Specifically, the research focus on six particular items in the cone crusher which drives a major part of the logistics resources. Since the cone crusher itself is assembled in one single area before delivery, the handling and storing of this was not considered to have a large impact on the logistics, why the finished crushers plays a very small part in the research. Besides only focusing the research on a set of focus items, the thesis will be delimited to focus only on the internal logistics and warehousing operations, hence outbound and inbound flows will not be considered. Furthermore, production processes such as assembly and machining will neither be evaluated though these activities may have a large impact on the logistics performance. Because of other ongoing initiatives, the use and implementation of digital solutions will not be investigated.

### 1.4.1 Research focus items

The chosen research focus items in this research was; top shell, bottom shell, main shaft, head center, mantle crushing chamber and concave crushing chamber (see Figure 1). The items rather deep product structures, with the need of sourcing but also processing the items through the entire production site, is argued by Jonsson & Mattsson (2011) to impact the logistics complexity and costs. It was found that these items demands a great need of resources, not only handling equipment but also machining, painting, rust protecting and assembling, why efficient handling and operations is a prerequisite to avoid unnecessary costs and lack of space. Furthermore, since these items also are separately delivered as AM products, the need of having a good inventory control is of high importance to Sandvik.

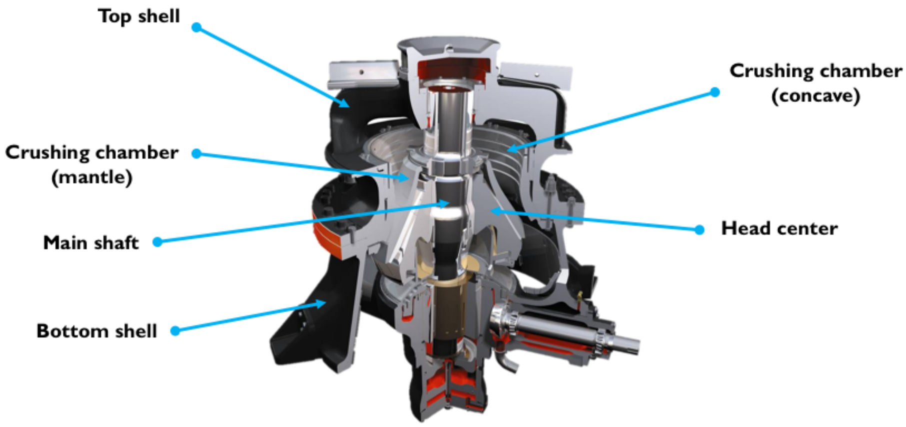



***Figure 1*** *Research focus items*

# 2 Methodology

*This section aims to determine and structure the frames and principles for how the thesis should be conducted. While it will not describe what should be done in detail, it will support the research in going from a general target towards increased knowledge about the subject.*

## 2.1 Research design

The chosen methodology depends on the goal and character of the project and can have different purposes such as being descriptive, exploratory, explanatory or problem solving. (Höst et al., 2006) In this thesis, a problem solving methodology was applied since the overall purpose is to find a suitable solution to a identified problem. According to Höst et al. (2006), one of the most relevant methods for a master thesis within applied science is the action research. Robson (2004) describes action research as a suitable approach for a project with the purpose of improving a phenomenon while at the same time studying it. This approach and methodology was more thoroughly described in the strategy section.

### 2.1.1 Approach

In every scientific research there is a desire of constantly develop a better understanding of the theory or hypothesis one is working with (Magne & Solvang, 1997) and two main approaches are stated when studying a phenomenon, the inductive and deductive. Based on a hypothesis drawn from empirical studies and observations, the inductive approach suggests a corresponding theory to the discovered situation. In contrast, the deductive approach aims to finding a suitable established hypothesis to the phenomenon by literature review, which later on is tested and confirmed. (Magne & Solvang, 1997) Initially in the project, a data collection provided a base for an as-is analysis of the situation and current status at the Svedala production unit. Followed by a thorough evaluation, the researchers was able to draw conclusions and formulate corresponding hypothesis. This way of working obviously aligns with a inductive approach. However, in a different phase of the project, a deductive approach could have been appropriate. For instance, an identified problem or situation could be expressed with a certain hypothesis according to a theory found in a literature search. Through this approach, an appropriate solution might very well be found in the theory reviewed, and could be the best way of working in a problem solving phase.

## 2.2 Research strategy

### 2.2.1 Action research

Action research is described by Cohen & Manion (1989) as "research on location" with the purpose to address a tangible problem in the current situation. This approach is especially attractive for researchers who have identified a problem and also sees a value of exploring it while improving the situation (Bartholomew, 1971; Cope & Gray, 1979; Raven & Parker, 1981). In general, the action research approach is based on the belief that generalised solutions don't fit all companies and organisations why the purpose therefore is to find an appropriate solution for the dynamics in a certain situation. The research consists of a routine that provides the researcher with a powerful framework; look, think and act. These steps works together in a interacting spiral, shown in Figure 2.

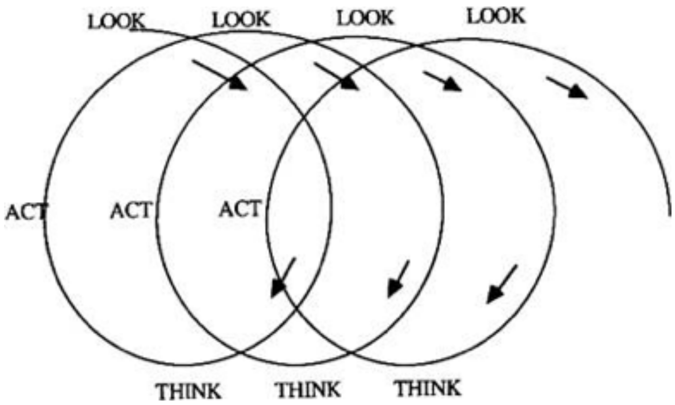



***Figure 2*** *The look, think and act framework (Stringer, 1999)*

This routine enables the researcher to begin and structure inquiries in a straightforward way. The research is grounded in a qualitative research pattern whose purpose is to gain better clarity and understanding of a question, problem or issue. (Stringer, 1999)

## 2.3 Research process

McNiff (2013) originally presents a basic action research process in six steps. This acted as guidance for the researchers, and helped form an appropriate five step process used in this thesis project. The research process and its corresponding activities are described and explained below:

1. **Review current situation**
   Collect empirics, analyse and map Sandviks current warehouse operations, storage locations and flow of goods to make an as-is analysis

2. **Identify areas in need of improvement**
   During and after the mapping processes, areas of improvements were identified.

3. **Create solutions and improvement actions**
   By using literature and evaluating concepts and methods from similar environments, valuable solutions was generated.

4. **Measure, evaluate and get insights**
   Evaluate how the solutions could be implemented and measure and analyse their impact. Obtain insights and reflections from various staff and stakeholders to assess the achievability. Repeat step 3 if necessary.

5. **Make final suggestions**
   Provide thorough analysis and tangible solutions with clear measures of the impact

## 2.4 Literature review

In all research, it is necessary to investigate what previously has been done in the field of study, which Bell (1999) describes as the main purpose of a literature review. As another important advantage, Frankel et al. (2005) explains that the literature review could provide enough knowledge for the researchers to identify and analyze gaps between theory and practise. However, it is not enough to collect facts and information and simply describe it (Bell, 1999). According to Verma & Beard (1981) the researcher also needs to identify and explain relevant relations between the facts by building a theoretical structure or framework. Bell (1999) also stresses the importance of a well planned and structured literature review to minimize the risk of getting into non profitable paths and being overwhelmed by low value information. In this thesis, the most often used sources for retrieving literature have been Google Scholar and LUBSearch, which combined provides a sufficient range of relevant and valuable journals and articles within the field of study.

### 2.4.1 Keywords

Bell (1999) argues that it is important to avoid a far to narrow search which can limit the references and information and suggests that a studied subject could be divided into groups of different themes. According to Bell (1999) various keywords of each theme group was generated, shown in Table 1, and provided a sufficient number of valuable searches.

***Table 1*** *Used keywords in the literature review*

| **Theme group** | **Keyword** |
|---|---|
| Logistics | Efficiency, optimization, operations |
| Warehouse | Storage, fill rate, utilization, layout |
| Materials handling | Slow moving goods, |
| Flow analysis | Bottlenecks, optimization |
| Production site | Logistics, streamline, goods flow |

In the search process, the keywords was then combined with each theme group to generate the searches.

## 2.5 Data collection

The collection of empirical data is an essential part in this project for the researchers to be able to make a thorough and accurate as-is analysis. The empirics collected can be sorted into two main categories, primary data and secondary data. The former can be described as the data actually collected and gathered directly by the researchers while the latter is defined consists of already collected and existing data (Ghauri & Grønhaug, 2002). In this thesis report, both primary data and secondary data was gathered through interviews, observations, surveys and various databases. In table 2, the necessary data is described.

***Table 2*** *Empirical data needed from the data collection*

| Primary data | Secondary data |
|---|---|
| Items flow | Inventory levels |
| Activity time | Cycle time |
| Item touch points | Article numbers |
| Warehouse layout | Item characteristics |
| Storage location areas | Item demand |
| Travel distance | |

### 2.5.1 Interviews

An interview can provide a researcher with opinions and proposals to eventual solutions (Höst et. al, 2006) and according to Opdenakker (2006) it is a good technique of obtaining qualitative data. Höst et al. (2006) defines a qualitative interview as selecting and interviewing staff in one specific area and receive their point of view on e.g. potential problems. Also, three main interview techniques are explained; the unstructured interview where the questions are not specific but within a specific area, the semi-structured interview which is a mix of set up questions with fixed answers and open questions and the structured interview which only consist of set up questions and fixed answers.

In this thesis several interviews has been held with both specific key staff and random selected employees on the site. The questions has been both open and strict about a certain topic, meaning a semi-structured technique has been used. This because the interviewed persons own opinions, of how they experience their work and its processes was desirable. Strict questions about the topic was also needed in order to collect the required information.

### 2.5.2 Observations

To get an understanding of how processes, routines and activities are done and how they are connected, it was clear that the research could benefit from using observations. This approach not only provide a general overview of the situation (Yin, 2009) but also gives tangible first-hand information which helps gathering relevant and essential knowledge (Frankel et al., 2005). However, the researchers agree with Ghauri & Grönhaug (2002) that the data collected from observations needs to be carefully validated and reviewed in order to transcribe it to scientific information. Due to the rather large and complex production site, it was decided that observations could provide valuable information to the research that would have been difficult and time consuming to obtain in other ways.

The observation approach was chosen to be open which Holme and Solvang (1997) describes as when the observed person is aware of it, rather than the opposite. This was due to the often long activity and processing times which was far more easily understood by simply asking staff and workers while walking through the site.

### 2.5.3 Flow analysis

To be able to answer RQ 3, a thorough flow analysis of the focus items was needed. The flow analysis include movement of goods across a site and is  different depending on what activity is needed.

By analysing the flow of goods, bottlenecks, defects and improvement areas was identified. According to Meyers and Stewart (2002), it helps identifying the following problems:

- Cross traffic - Points of intersection between paths that causes congestions and delays
- Backtracking - Items moving backward, and not from receiving to shipping point of the plant.
- Distance travelled -  Unnecessary travels of people and material.

There are several literature resources available of how to map a supply chain, its flows and its processes. In this thesis report, a flow chart in terms of a spaghetti diagram and a value stream map was used to analyse the product flow.

**Spaghetti diagram**

One method that can be used to graphically identify the movement of an item through different processes is according to Gladyez et al. (2017) the spaghetti diagram.  This tool was used in this thesis in order to provide an overview of the items flow by mapping each processing location and the routes between these, but not the activities within each process. Allen (2010) states that the main purpose to use this tool is to identify and reduce unnecessary transportation routes to achieve a streamlined movement of items, which is desirable in this research. Allen (2010) describes a 8 step method when constructing a spaghetti diagram, which was used as a basis when the spaghetti diagram in this research was constructed:

1. Obtain a map of the site and its facilities
2. Site tour together with warehouse and logistics staff describing the flow and facilities
3. Draw of a continuous curve from the first location to the remaining locations on a map

4. Measure the distances and calculate all travel times between the different locations
5. Study the drawn diagram and identify unnecessary travel times and touchpoints
6. Improve the flows by decreasing distances and travel times
7. Repeat step 4-7

**Value Stream Map**

Tyagi et al. (2014) states that a value stream map (VSM) describe and identifies all touch points and the non-value adding actions in a "door-to-door" process. In order to get a more thorough analysis of the flow, the researchers saw several benefits by using a VSM as a complement to the spaghetti diagram. The purpose and focus with the VSM was to identify and eliminate bottlenecks, unnecessary touch points and inefficiency. Rother & Shook (1999) describe a three step method to use when making a VSM which was used in this thesis;

1. **Pick a product family**
   Making a VMS is a time consuming activity and can be very complicated if to many products are involved (Rother & Shook, 1999). Hence, the VSM was only made on one item; wear parts for AM and EQ. This was due to the extensive processing activities requiring a lot of resources and staff, where the benefits of a VSM could impact the most.
2. **Current state map**
   According to Rother & Shook (1999) the second step of the mapping method is to draw a current state map for each products "door-to-door" process. This is also the first step in Mcniff et al. (1996) six step process. In this VMS, it was only the processes within the areas mentioned above that was mapped. The VSM method used in this research was:

   a. **A gemba walk**
      According to (Tyagi et al., 2014) a current state map can be developed by a gemba walk. It is where the researcher follows the items through their whole process. During the walk, the researchers will use pen and paper and denote the processes

and different data indicators. The processes symbols, the data indicators and its calculations are presented below.

b. **Interviews**

   Interviewing key persons that covers all areas of the door-to-door process, and write down their point of view of things.

During the mapping problem areas were identified, and denoted. This is according to Rother & Shook (1999) important since ideas often come to mind during observing processes.

3. **Future-state map**

   After the current-state map was completed it was analysed, and further problem areas besides from the ones already found were identified. This cohere with step two in the research process (Identify areas in need of improvement). Once the problems were identified they and eventual solutions were discussed with responsible personnel of the area.

   The next step was drawing a future-state map, where according to Rother and Shook (1999) the identified problems should be removed. The current-state map was further analysed and excognation of potential solutions was made in order to remove the problems identified.

   The future-state map was then evaluated with a manager, which is aligned with step five in the research process (Obtain feedback and other perspectives, repeat step 3 if necessary). Modifications were made and finally a new future state map was made.

### 2.5.5 Storage capacity

To be able to improve the storage capacity for Sandvik for the major components and wear parts, a thorough analysis of all relevant storage locations was needed, requiring several different data such as item dimensions and weight, inventory levels, storage locations (warehouses and outside storage areas) and storage capacity. This data was mainly collected through the database of Sandvik providing item details and inventory information. However, storage data such as measurements, sizes and locations of warehouses and areas was primarily gathered by observations on the site and by interviewing warehouse staff. The researchers constructed an easy to use framework to manage and evaluate the storage capacity:

1. **Get an overview of all storage locations**
   Obtain site locations and storage locations names/id and observe main layout e.g. inbound/outbound areas

2. **Calculate current storage capacity**
   a. Classify storage locations as indoor / outdoor storage
   b. Calculate available indoor and outdoor storage capacity (e.g. $m^2$)

3. **Calculate required storage capacity i.e. inventory levels**
   a. Classify items processing level to determine storage requirements
   b. Determine items dimensions
   c. Determine average item inventory level
   d. Calculate indoor and outdoor required space

4. **Compare and evaluate current and required storage capacity**

## 2.6 Credibility

When describing credibility, Bell (1999) mentions two main parts, reliability and validity. According to Björklund & Paulsson (2014) and Yin (2009) reliability and validity is of great importance when ensuring a study's credibility why these terms was carefully evaluated in this thesis.

Briefly, reliability relates to whether or not a certain method or approach will generate the same results over several iterations. In other words, this term takes into consideration how much or if a result varies from time to time using the same method. (Bell, 1999)

The expression validity measures if a certain question or method describes what is desired. Even if a result is near identical in several occasions, it might still not be measuring what is intended. (Bell, 1999) In particular, the external validity is highlighted by Björklund & Paulsson (2014) as an important part of an academic thesis. Aronson et al. (2007) also stresses the importance of ensuring the external validity and describes it as to what extent the results of the research can be generalized to other situations.

### 2.6.1 Literature review credibility

According to Höst et al. (2006) different sources have different credibility why the researcher needs to evaluate these carefully. Bell (1999) further describes several tests for determining reliability and validity in a literature review but argues that it is usually not necessary in common research. However, while it may not be necessary to use explicit tools or methods to determine the credibility, Höst et al. (2006) suggests a set of questions every researcher should consider when evaluating literature:

- Is the material reviewed and if so by who?
- Who acts as a guarantor for the credibility?
- Is the research methodology trustworthy?
- Is the results produced in a context relevant for this research?
- Have the results been confirmed or led to acknowledgements and been referred to in other credible contexts?

In this research, the questions above was adopted and work as a routine framework when reviewing and evaluating literature.

### 2.6.2 Data collection credibility

Since large parts of the data gathered and used in this research was obtained from internal databases, systems and observations it was important to critically review the data to determine its credibility. To ensure reliability when collecting data, Altrichter et al. (2008) suggests that triangulation by combining multiple observers, theories, methods, and empirical materials, can give a more detailed and balanced picture of a situation. This approach was adopted by the researchers who constantly seeked additional sources and opinions about subject and situations. In practical, an identified problem or data information was confirmed by at least two independent sources before regarded as reliable and correct. However, when collecting primary data, it was not always needed to use the triangulation approach to ensure its reliability since the researchers on their own could gather the data. Examples of reliable primary data collected by the researchers was own manual measurements of goods and storage locations, actual viewing flow routes and touch points.

### 2.6.3 External validity

To be able to contribute with this research to other companies and organizations, the researchers identified the external validity, in qualitative research also known as transferability, as a subject of high importance. Since the result of this research have not been evaluated and tested in other situations and environments, the researchers can not prove that the findings can be applicable in such contexts. However, Given (2008) suggests providing thick description as a strategy of increasing the external validity i.e. giving the reader a complete description of the context, participants and research design. By doing this, the reader can on its own determine the external validity.

Since the methods and procedures used in this research have been easy and straightforward while also thoroughly and clearly explained, the reader have been given good possibilities to assess the external validity of the obtained results. Furthermore the rather familiar and basic warehousing activities addressed in the project e.g. materials handling and storing supports the transferability to any similar environment. However, the project have been carried out in an environment with complex items in a rather large production site, which might not be common or normal which may decrease the applicability of the results in different environments.

## 2.7 Summary of methodology

To comprehend the methodology used in this thesis and describe how it helped answering the research questions, a brief summary is presented in this section. In Table 3 below the research methodology and its processes are summarized.

***Table** 3 Summary of research methodology*

| | |
|---|---|
| **Research approach** | Inductive / qualitative |
| **Research design** | Action research |
| **Primary data** | Interviews, observations |
| **Secondary data** | Database information |
| **Interview approach** | Semi-structured |
| **Analysis** | Literature review, calculation, logical reasoning |
| **Tools** | VSM, spaghetti diagram, gemba walk |

Different methods and approaches were used to answer the research questions. To answer R**Q 1**, collection of primary data such as available storage and capacity was needed. Further, secondary data in forms of database information of order quantities was analysed. To answer **RQ 2**, the findings from **RQ 1** together with the literature review result was used to find improvements. The first step towards answering **RQ 3** was through primary data collection by observations and semi-structured interviews. By then apply proven methods discovered from the literature review, the flows could be analysed and improved.

# 3 Theoretical framework

*This chapter explains and defines concepts, methods and strategies used as a framework in the research. It covers essential parts to answer the research questions; supply chain management and logistics, warehouse design and operations, flow of goods, lean production and performance measurements.*

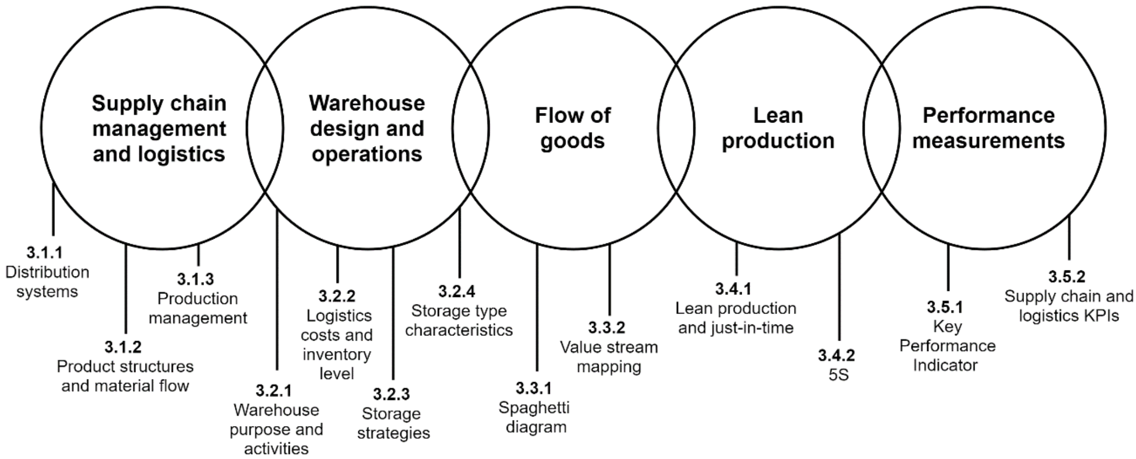



***Figure 3*** *Theoretical framework overview*

## 3.1 Supply chain management and logistics

Christopher (2011) defines supply chain management as the management of upstream and downstream relationships with suppliers and customers in order to deliver superior customer value at less cost to the supply chain as a whole. Although the term is called supply chain management, Christopher (2011) asks whether demand chain management would be a more suitable term to indicate that the fact that the market drives the chain.

As a link between suppliers and market, logistics management supports the planning and coordination of all activities necessary to obtain desired quality, service to low cost. Figure 4 illustrates the logistics management process and its span from raw-materials management to delivery of finished goods.

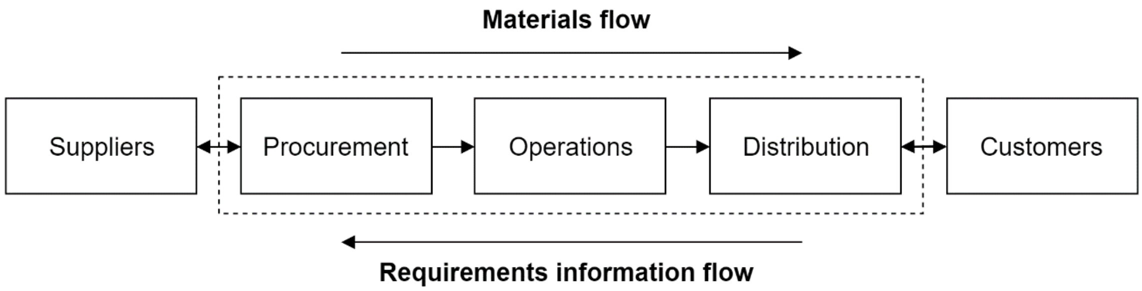



*Figure 4* Logistics management process (Christopher, 2011)

*Globalisation*

Currently, logistics management faces a challenge due to the strategic issue of globalisation. Christopher (2011) states that in the global business today, materials and components are sourced worldwide, products are manufactured offshore and sold in many different parts of the world. Due to this, companies such as Hewlett Packard, Philips and Caterpillar now sees the management of the logistics process as a central issue. (Christopher, 2011)

### 3.1.1 Distribution systems

Within supply chains, the term distribution includes the moving and storing of products from suppliers to customers. This is made in a distribution network, acting as a chain in which the products are moved and stored. (Chopra & Meindl, 2013)

*Direct distribution system*

Lumsden (2006) describes how a direct distribution system is built around direct transports between producers and customers (see Figure 5). This system is fast but at the same time very resource demanding.

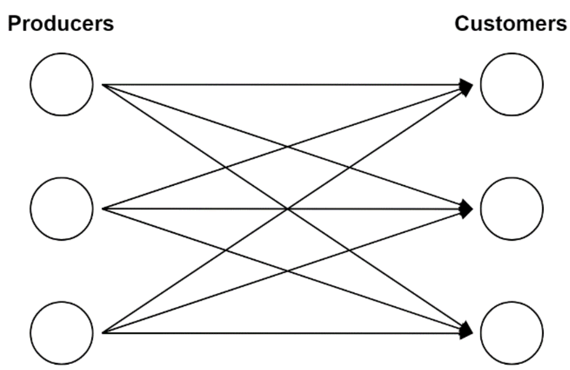



*Figure 5* Direct distribution system (Lumsden, 2006)

*Terminal system*

The number of direct relations in the distribution system can be reduced by introducing a terminal system. This means that product flow always pass a terminal between the producer and the consumer. When reducing the number of relations, the average amount of goods in each relation will increase which can improve the service level. At the same time, this means that the transportation distance will increase.

In some systems, products can be transported through multiple terminals (See Figure 6). The system means that a certain number of customers are connected with a specific terminal. As a consequence, the customers will always get deliveries from one and the same terminal. This approach can create a higher efficiency due that consolidation of products can take place in many different transportation relations.

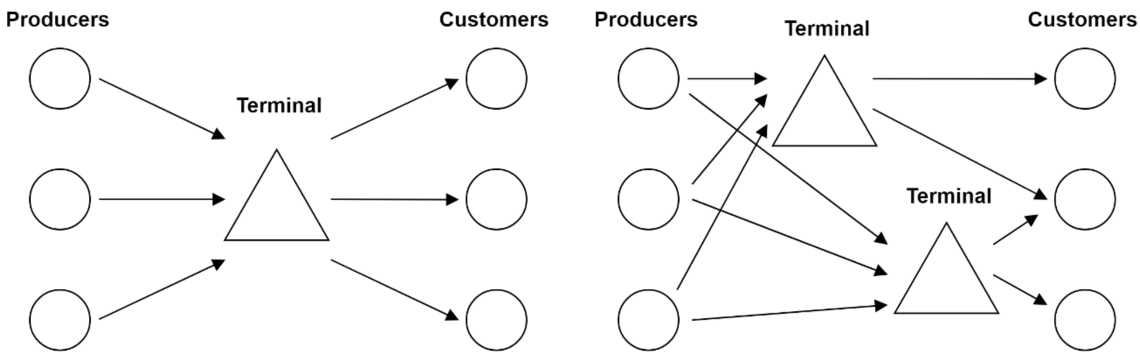



***Figure 6*** *Terminal distribution system (Lumsden, 2006)*

### 3.1.2 Product structures and material flow

In manufacturing companies, products are produced by processing of raw material and assembly of sourced components and semi-finished goods. The material content in such produced products can be defined by product structures which specifies how a product is built from raw material and sourced components through manufactured and semi-finished parts to the final production and assembly. (Jonsson & Mattsson, 2011) The product structure, and its complexity, can be visualized by a tree with a products structure levels (see Figure 7).

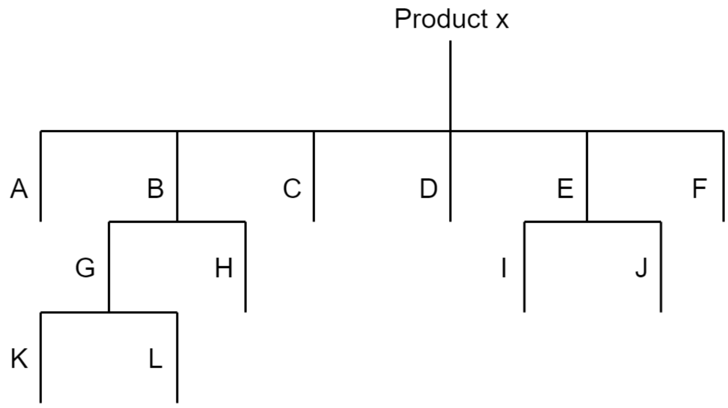



*Figure 7* *Product structure tree (Jonsson & Mattson, 2011)*

One major purpose with defining product structures is to support material planning activities which uses material requirements from forecasts on finished products.

*Product structures depth in relation to costs and complexity*

The product structure tree also reveals the depth and width of the structure which impacts the complexity, not the least from a logistics point of view. For instance, a large depth of a structure implies longer lead times. The depth of a structure also affects the administration of the products' material flow. Deep product structures emerge when sourcing of material, manufacturing and assembling are made in many steps in a process. (Jonsson & Mattsson, 2011)

### 3.1.3 Production management

Components in a manufacturing company can be divided in three categories; standard, customer order specific and customer specific. This is done due to the level of customer order management when producing the components, and the main difference between the categories is where the customer order point is located (see Figure 8).

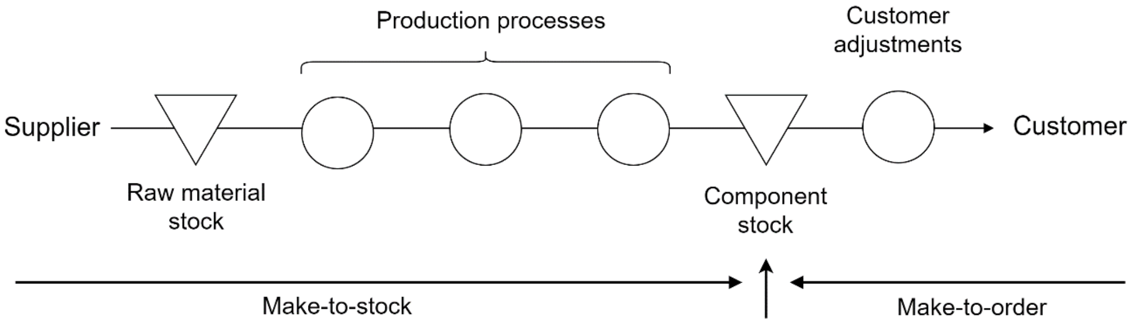



*Figure 8* *Customer order point (Jonsson & Mattson, 2011)*

The customer order point can be described as the point where the manufacturing and delivering of a product is managed by a customer order. Manufacturing of components before the customer order point is called make-to-stock (MTS) in contrast to make-to-order (MTO) after the customer order point.

## 3.2 Warehouse design and operations

### 3.2.1 Warehouse purpose and activities

Heragu et al. (2005) states that the two primary functions of a warehouse include temporary storage and protection of goods and provide value adding services such as fulfilment of customer orders, packaging, after sales services, repairs, testing, inspection and assembly. Gu et al. (2007) also highlights warehouses as an essential component of any supply chain with its major roles including consolidation, pricing, labeling and product customization. According to Bartholdi & Hackman (2017) storage locations implies several different costs generated by e.g. space renting, heating, air-conditioning and security. Even though outdoor storage is associated with some substantial costs, the costs are somewhat lower than indoor storage.

*Warehouse operations*

Within a warehouse, the five main activities are; receiving, put-away, storing, picking and packing/shipping. Ideally, an item should flow continuously through a warehouse and this sequence of processes. Each time an item is put down in this flow, it must be picked up again sometime later, called double-handling. When such double-handling is summed over all the many skus and pieces and/or cases in a warehouse, the costs can be quite considerable. De Koster et al. (2007) defines order-picking as the process of clustering and scheduling orders, assigning the stock on location to order lines, releasing orders to the floor, picking the articles from storage locations and disposing of the picked articles. Order-picking is described by Bartholdi & Hackman (2017) as the most labor intensive activity in most warehouses due to the associated traveling. This is also highlighted by Chackelson et al. (2013) who identifies order picking as a key activity in a warehouse. It is suggested by Bartholdi & Hackman (2017) that by carefully planning put-away activities, traveling can be reduced.

*Information systems*

Organizations and companies can use different IT-systems to collect, store, manage and interpret data from its business activities. Such a system is often called Enterprise Resource Planning (ERP) which can provide an integrated and continuously updated view of the business processes through common databases. Within an ERP system, different applications use data from across various departments such as manufacturing, purchasing, sales and accounting (Almajali, 2016).

As a stand-alone system or as a module of the ERP system, organizations can use a Warehouse Management System (WMS). A WMS is a software that manages inventory, storage locations and staff to increase the efficiency of the warehouse operations. (Bartholdi & Hackman, 2017) According to Hékis et. al. (2013) a WMS can help ensure the agility and quality in material flow, streamline and improve procedures of storage, such as receiving, inspecting, addressing, storing, picking, packing, loading, shipping, issuing of documents and inventory. Normally, a WMS keeps track of every item in a warehouse including its dimensions, how it is packed by the supplier, all the storage locations in the warehouse, their locations and dimensions. The aim is to use this information to govern the flow of people, machines and products through. (Bartholdi & Hackman, 2017)

### 3.2.2 Logistics costs and inventory level

*Logistics costs and tied up capital*

Jonsson & Mattsson (2011) states that logistics costs and tied up capital together with customer service have big impact on profitability. With high tied up capital the direct costs and financial demands increases in a company. Due to this, the logistics costs and tied up capital needs to be well balanced in accordance with other logistics targets. Since tied up capital is close connected with delivery service, it needs to be considered in order to measure logistics performance. The tied up capital expresses the amount of value tied in the material flow, but also in inventory, work in process (WIP), finished goods and transports. To measure and compare tied up capital in different inventory locations with other areas and warehouses, the inventory turnover could be used:

$$inventory\ turnover\ = \frac{annually\ demanded\ products}{average\ inventory\ level}$$

To calculate the inventory turnover, the annual demand of the inventory is divided by the average inventory level (see Figure 9). The inventory turnover shows how many times per year the average inventory is turned and expresses the value of the total material flow.

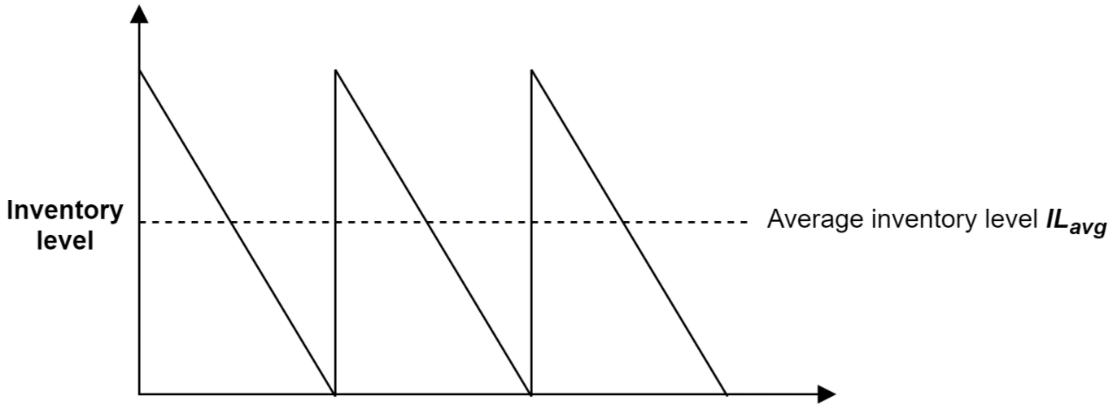



***Figure 9*** *Average inventory level over time*

*Order quantity and safety stock*

Normally, the uncertainties in demand can create difficulties in available supply in a warehouse. To avoid and manage the risk for stockout due to this, a safety stock level can be decided (see Figure 3.7). By never permitting the inventory level of an item to go beyond the safety stock, the ability to supply can increase significantly and the cost of lost sales would decrease accordingly. (Monk & Wagner, 2009) According to Hopp & Spearman (2008) the point when to place the order is called reorder point (*R*) at which a given order quantity (*Q*) is ordered, a so called (*R*,*Q*) policy. This strategy demands accurate forecasts that can handle dynamics and variations.

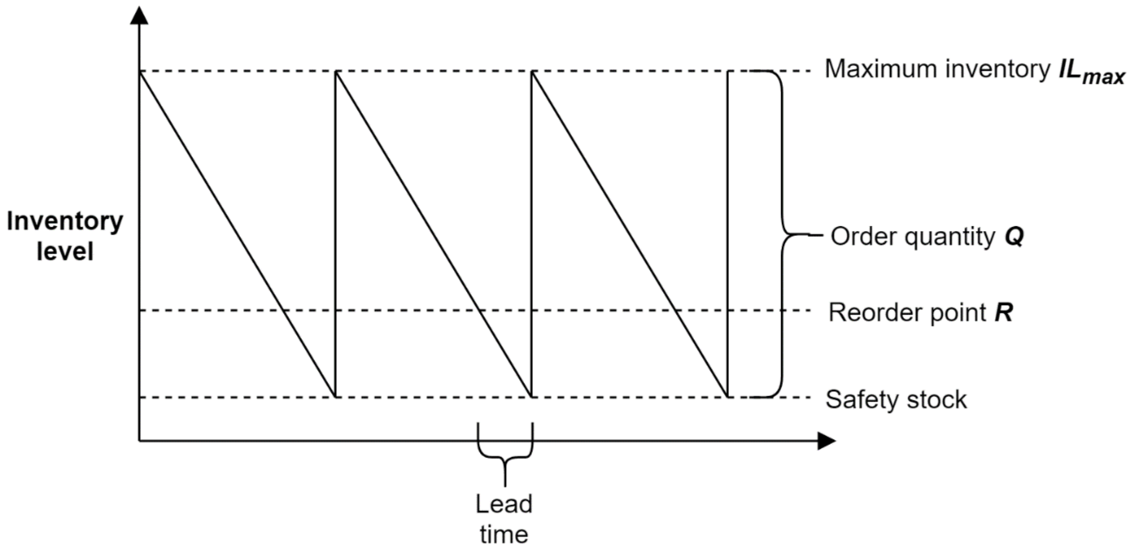



***Figure 10*** *A (RQ) policy inventory system with safety stock*

In Figure 10, it is apparent that the maximum inventory level $IL_{max}$ can be calculated as:

$$maximum\ inventory\ level\ =\ order\ quantity + safety\ stock$$

Through and ERP system and a Materials Requirements Planning (MRP) module such forecasts and parameters can be calculated. By using data from the ERP, the MRP system can help develop these forecasts to reduce the possibility of producing insufficient inventory while also reducing the amount of required safety stock. (Monk & Wagner, 2009)

### 3.2.3 Storage strategies

*Shared vs. dedicated storage*

Gu et al. (2007) and Bartholdi & Hackman (2017) states some basic storage strategies which include shared storage, dedicated storage and class-based storage. The strategy of dedicated storage implies that one specified location is reserved for a particular item. This enables more popular items to be stored in convenient and well known locations which eases the work for the staff who can more efficiently find storage locations when in put-away and picking. While this can increase e.g. picking speed and reduce errors, the strategy does not use storage space very efficiently since different replenishment cycles among the products will create both completely empty and completely full storage locations at times.

To improve the rather poor space utilization of dedicated storage, one can use a strategy of shared storage where a product is assigned to more than one storage location. This implies that when a location becomes empty, it becomes available for different items, which at that time needs a storage location. In general, this strategy enables a warehouse to have more storage locations and by that more items, than by using dedicated storage. There are however some disadvantages with shared storage, generated by having the items storage locations varying over time. In a put-away or a picking process, this will make it more difficult for the staff since they either need to learn or guess the locations or be directed by a warehouse management system (WMS). Usually, a strategy of shared storage is used in areas with bulk storage where most of the inventory is kept on pallets. The use of dedicated storage exists typically in very active picking areas, which are much smaller than the bulk storage. (Bartholdi & Hackman, 2017)

*Class-based storage*

The concept of class-based storage is expressed by Bartholdi & Hackman (2017) as increasing throughput by assigning the most frequently requested items to the most attractive and beneficial storage locations on the rack face. Frazelle (2002) implies that other used criteria besides popularity exists e.g. maximum inventory and cube-per-order index. However, the trade-off with this approach is that it uses a dedicated storage policy to ease the implementation. Thus, the advantages of having class-based storage and an efficient picking and put-away process also implies increased space requirements (Bartholdi & Hackman, 2017).

*FIFO*

When storing goods on pallets, space utilization may not be the only concern. In addition, the policy of which order to store the pallets can have a significant impact on the layout of a storage area. When items have e.g. an expiration date, it would make more sense to move them according to a First In First Out (FIFO) policy where the first item placed in the storage area is the first to leave (Bartholdi & Hackman, 2017). The FIFO policy not only helps keeping track of components but also on supplier's performance and enables faulty batches to be discovered earlier (Manohar & Appaiah, 2017). This policy enables staff to access a storage area from two sides, with put-away in one side and picking in the other. However, this obviously require more space due to the need of having both ends of the lane clear. For storing in pallet racks, special types of racks e.g. flow racks can support FIFO (Manohar & Appaiah, 2017), otherwise, floor storage can easily be organized in lanes accessible from two directions.

### 3.2.4 Storage type characteristics

*Floor storage*

The simplest way of storing palletized product is floor storage, which is typically arranged in lanes. The depth of a lane is the number of pallets stored back-to-back away from the pick aisle. The height of a lane is normally measured as the maximum number of pallets that can be stacked one on top of each other, which is determined by pallet weight, fragility, number of cartons per pallet, and so on. (Bartholdi & Hackman, 2017)

*Pallet rack*

As storage type in contrast to floor storage, pallet racks provides several benefits highlighted by Bartholdi & Hackman (2017). Since each level of the rack is independently supported, the accessibility to the products increases. Furthermore, it also may enable higher stack height than floor storage which can help increase the space utilization in a warehouse. If height space is unutilized, storing product high can be a cost-friendly alternative to gain storage capacity instead of having to expand. The pallet rack is also flexible to the extent that the height of the slots can be adjusted to the varying pallet loads. A different pallet rack, the double-deep rack enables pallets to be stored two deep which makes it requiring fewer aisles which in turn can increase the space utilization significantly. Bartholdi & Hackman (2017) suggests that to avoid double-handling each lane could be filled with the same product. While this eliminates the risk of double-handling, the pallet location will at times be empty and decrease the space utilization. There is also more work needed to pick and put-away the products which is another disadvantage with double-deep racks.

## 3.3 Flow of goods

### 3.3.1 Spaghetti diagram

A tool to graphically describe the movement of a product through a process is the spaghetti diagram. The strength of this diagram according to Gladysz (2017) is the possibility to visualise the movement of all kinds of objects, such as materials (and its current state e.g. raw material, semi-finished goods, finished goods), transportation assets, documents, people etc. Gladysz (2017) also mentions some drawbacks of this tools and states that it is static and time consuming. The American society of quality defines the tool as "A visual representation using a continuous flow line tracing the path of an item or activity through a process. The continuous flow line enables process teams to identify redundancies in the workflow and opportunities to expedite process flow". Allen (2006) suggests the process of drawing a spaghetti diagram as:

1. Obtain an existing or create a facility layout diagram (drawing)
2. Obtain an existing routing sheet or create one using typical object going through facility
3. Draw a continuous curve starting at the first location on the routing sheet to the remaining locations
4. Calculate total travel distance
5. Estimate travel time using travel speed
6. Study the spaghetti diagram and identify flows with high part's travel distances and areas in the facility that are rarely or never used
7. Move the processes closer together or rearrange to reduce total travel distance
8. Repeat steps 4–7 using new layouts and assumptions

### 3.3.2 Value stream mapping

Rother and Shook (1999) describe a method that covers the "door-to-door" production flow inside a plant, meaning all actions, both value adding and non-value adding required in the production flow to deliver a product from raw material to a customer.

They call it a value stream mapping (VSM); with the purpose to identify opportunities to streamline and improve work processes while reducing waste. A VSM follows the steps in Figure 11 below.

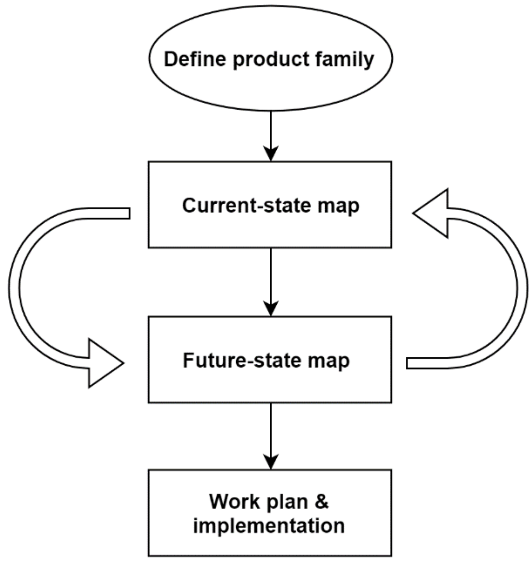



***Figure 11*** *The initial VSM process steps (Rother & Shook, 1999)*

The first step consists of choosing and defining a product family to map.

The second step is to draw a current-state map. The easiest way for researchers to do this is according to Rother and Shook (1999) to follow each products' "door-to-door" process through a site. Tyagi et al. (2014) states that a suitable method to do this is by "walking the gemba", and intends the Japanese word Gemba which and means "the actual place". A gemba walk is a very useful tool for understanding the daily activities in a company with the purpose of identifying problems through observations. During a gemba walk, researchers can with pen and paper easily denote actions and data indicators with different symbols. The purpose of the current state map is to highlight sources of waste, such as transportations, unnecessary touch points, and bottlenecks.

The third step is then to draw a future-state map where the identified waste is managed and removed.

When the future-state map is completed, the final step is to make an implementation plan on how to achieve the desired changes. This should preferably be on one sheet (Rother & Shook, 1999).

Tyagi et al. (2014) suggest different data indicators and symbols for the actions in a VSM:

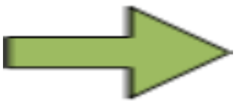
*Data indicators*

- **Cycle time**
  Time that elapses between one item coming off the process and the next one coming off (in seconds).
- **Changeover time**
  Time to switch from producing one type of product to another.
- **Number of people**
  Number of staff required to operate the process
- **Available time**
  Production time minus planned downtime

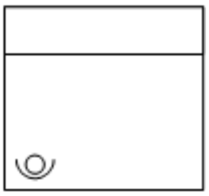
*Symbols*

**Inventory level**

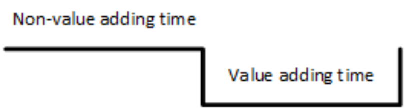
Current inventory divided by daily customer demand



**Transportation arrow**



**Process**




**Time line segment**

## 3.4 Lean production

### 3.4.1 Lean production and just-in-time

Hyer & Wemmerlov (2001) describes lean production as a more recent name for just-in-time (JIT), a methodology aimed primarily at reducing flow times within production and response times from suppliers and to customers (Ohno, 1988). Lean production became established in the 1990s, with the main objective of maximizing value for the customers through elimination of production waste (Womack & Jones, 2003). The starting point of lean production is value, described by Womack & Jones (2005) as the ability to provide products at the right time and to the appropriate price to satisfy customer needs. Three kinds of activities exists in a production plant; the ones that add value to the final product which should be maintained, the non-value adding but unavoidable which should be analysed and when possible reduced, and the non-value adding and avoidable, which should be eliminated. Womack & Jones (1996) describe five principles for reducing waste and creating a lean company;

1. Specify value by specific product
2. Identification of the product's value stream
    a. All specific actions required to develop and manufacture a product or deliver a service
3. Map the value flow without interruptions
4. Let the customer pull value from the producer
5. Pursue perfection - the process of reducing waste is never-ending

Thus, lean manufacturing is about reducing, or more preferably, eliminating waste. Dahlgaard & Dahlgaard-Park (2006) suggests a generic definition of waste as everything that increases cost without adding value for the customer. However, different kinds of waste can arise in an industry, Ohno (1998) describes the seven most common ones:

- **Defects or quality problems:** Usually related to lack of standard procedures, and quality control systems, or human failure.
- **Inventory** - Bottlenecks in production and unbalanced processes can lead to a surplus in inventory, creating a need for larger inventory areas and more handling operations
- **Motion** - Movement of staff that are non-value adding to the product e.g. when tools and components are placed in bad positions, from an ergonomic and distance perspective
- **Over processing** - Operations or processes that are non-value adding to the company and product

- **Over production** - Production of more items than required e.g. by the customer, meaning resources without any financial return such as stock, and warehouse space are used.
- **Transportation** - Unnecessary transportations within the plant, with the consequence of more handling operations and an increased lead time.
- **Waiting periods** - Time wasted waiting for people, materials or equipment.

A challenge with waste is that one will rarely have an overview of its size and impact, since it is usually never registered or measured as a whole within a company and its systems. Although some parts may be measured and reported, the most part is invisible, especially for managers who do not participate in the manufacturing processes. To be able to get a picture of how waste is managed, a company can compare processes and cost structures with other companies, an activity called benchmarking. (Dahlgaard & Dahlgaard-Park, 2006)

### 3.4.2 5S

*5S principles*

Hirano (1988) identifies the 5S methodology, originally developed in Japan, as enabling JIT manufacturing, and thus even lean production. It describes how to organize a work environment to obtain efficiency and effectiveness and Bamber et al. (2000) suggest that 5S could contribute to important strategic priorities such as; productivity, quality, cost, delivery, safety and morale. The 5S methodology consists of a list with five words, originally Japanese but adopted into English;

- **Sort**
  Removing surplus items from the work area which are not needed for the immediate continual operations (Hough, 2008).
- **Set in order**
  Store and put items and tools where they best support the function and purpose. (Agrahari et al., 2015).
- **Shine**
  Try to identify and eliminate the original cause of waste, dirt and damage while cleaning up the work area (Van Patten, 2006). Define cleaning standards with a cross functional team (Agrahari et al., 2015).
- **Standardise**
  Develop standardized routines and rules for maintaining the previous

activities and support continuous work with these steps (Agrahari et al., 2015).

- **Sustain**
  Ensure that the staff understands the importance of a safe, orderly and clean workplace and that they are willing to support that the standards are accommodated (Agrahari et al., 2015). Liu (2006) also stresses the importance of keeping the staff dedicated to follow the established routines.

According to (Gapp et al., 2008) an additional sixth S representing *safety*, has evolved and could well be included to the original 5S.

- **Safety**
  Support the reduction of work injuries by having 6S in an organization with an already mature way of working with 5S

*Effects and benefits of 5S*

- Powerful, visual and easily measured activities (Liu, 2006)
- Uncover otherwise hidden problems (Gapp et al., 2008)
- Increase efficiency and effectiveness through simplified processes that reduces workload and human errors (Osada, 1991)
- Enhance the level of morale to gain increased quality of work standards (Osada, 1991)
- Achieve conformity in the organization due to the staff sees value in working to one common measure (Van Patten, 2006).

## 3.5 Performance measurements

### 3.5.1 Key Performance Indicator

A company should always measure its performance, compare to others and plan to improve (Bartholdi & Hackman, 2010). However, according to Benita (1999) qualitative evaluations such as good, adequate or poor are vague and difficult to utilize. Bartholdi & Hackman (2010) suggests more quantifiable measures and states that performance should be measured as a ratio and not simply output e.g. pallets handled per person-hour. Such a Key Performance Indicator (KPI) have the benefit of being more easy to interpret and compare.

*Choosing KPI*

A KPI should be based on criteria that make it suitable for further analysis, which is supported by the SMART criteria. (Shahin & Mahbod, 2007)

- **Specific**
  Goals and measures should be detailed and as specific as possible to avoid broad or vague measures. This supports having compliance among staff in the organization
- **Measurable**
  Goals should be easy to measure, against a standard of performance and a standard of expectation
- **Attainable**
  Goals should not be out of reach but instead be reasonable and attainable. However, setting goals is a balance between the degree of attainability, challenge and aspiration
- **Realistic and result-oriented**
  Attainable measures still needs to be realistic in the particular working environment and result-oriented in an appropriate way
- **Time-sensitive**
  A measure should have a completion time frame to allow monitoring the progress.

### 3.5.2 Supply chain and logistics KPIs

According to Benita (1999), the process of choosing appropriate supply chain performance measures can be rather difficult due to the often complex environments. The dominant performance measures used by supply chain models have been; cost, and cost combined with customer responsiveness. Costs may include e.g. inventory or operating costs while customer responsiveness measures can include lead time, stockout probability and fill rate. Benita (1999) have identified a set of measures based on essential components in supply chain success (see Table 4).

***Table 4*** *Performance measures in supply chains*

| Performance measure | Description |
|---|---|
| Distribution cost | Transporting and handling costs |
| Manufacturing cost | Labour, maintenance and re-work costs |
| Inventory cost | Inventory investment, obsolescence and WIP costs |
| Manufacturing lead time | Time required to produce an item or batch |

## 3.6 Summary

The theoretical framework is summarised in Figure 12. The figure shows how the areas of the framework will contribute to the research process and affect the structure of the report.

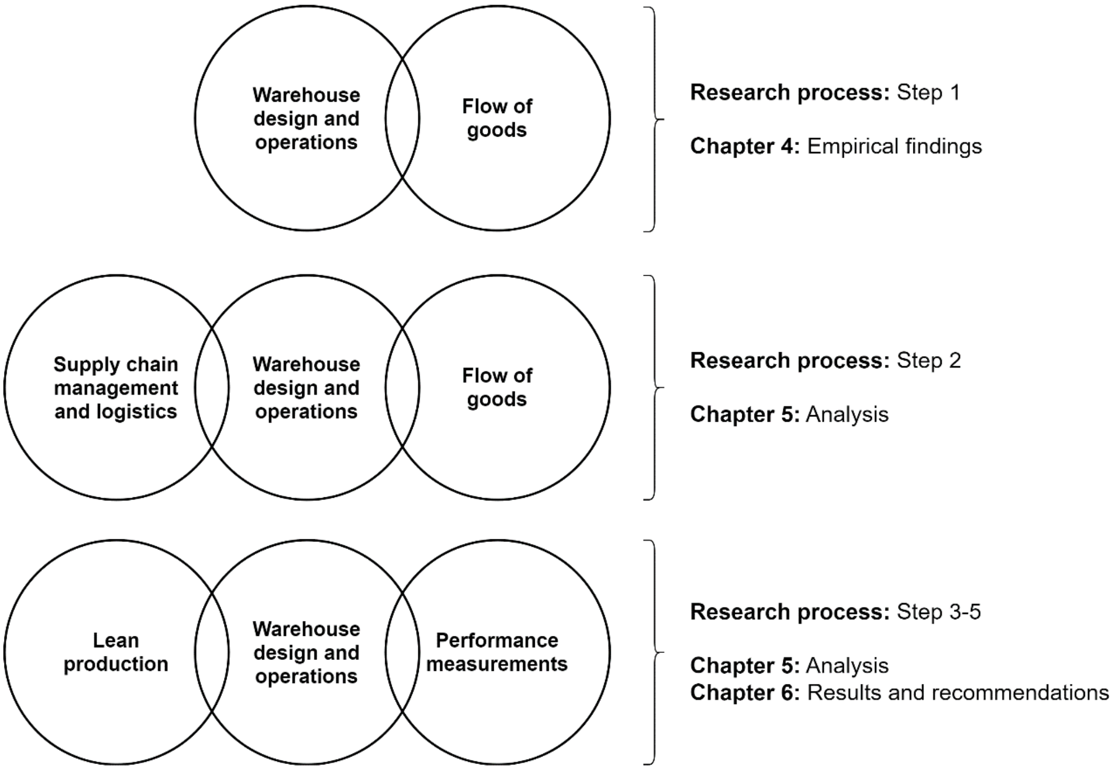



***Figure 12*** *Item categories and items associated with a stone crusher*

# 4 Empirical findings

*This section covers step 1 in the research process where the current situation is reviewed. It reveals gathered and collected data containing products, processes, activities and routines. The data collection result of storage and flows is illustrated and presented.*

## 4.1 Sandvik products and supply chain

### 4.1.3 The cone crusher and its components

Within the production unit in Svedala, Sandvik manufactures both cone crushers and jaw crushers. However, it was found that the cone crusher is the most frequently produced product and thus a major part of the flows and processing activities is connected to it. The cone crusher represents the largest product segment in the business unit Stationary Crushing & Screening and are divided in two product categories CH and CS (hydro and spider) with slightly different capabilities and usage areas. In total, there are 17 different models of the cone crusher.

Components in the cone crushers are divided into four different item categories; major components, key components, wear parts and spare parts. Within these item categories several different items exist (see Figure 13).

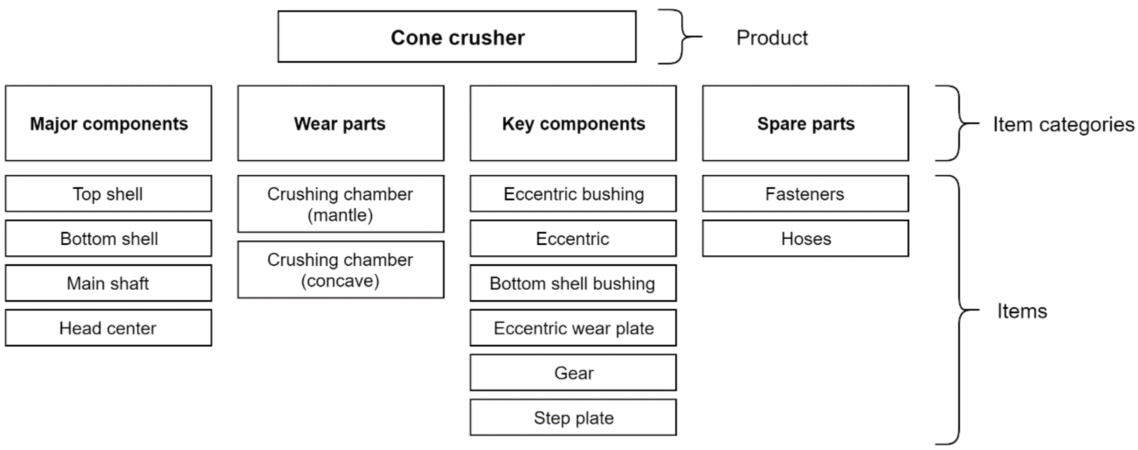



***Figure 13*** *Item categories and items associated with a stone crusher*

*Product structures*

When further examining and collecting data of the four item categories (major components, wear parts, key components and spare parts), their product structures could be obtained (see Figure 14).

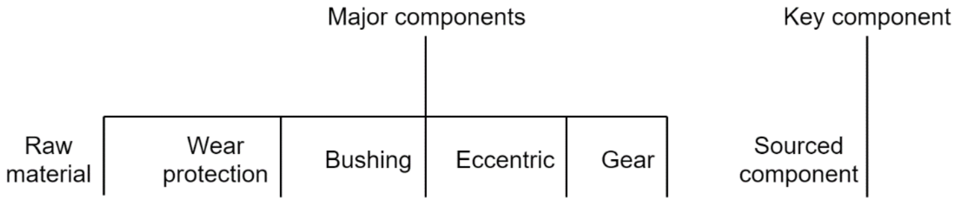



***Figure 14*** *Product structures of major components and key components*

As shown in Figure 14, the major components product structure depth was larger than for key components, but also larger than wear parts and spare parts (product structures are not illustrated).

*Processing activities*

By making several observations, it was discovered that two of the item categories; major components and wear parts, was in need of extensive processing in facilities spread over the site. Most of the items belonging to key components and spare parts was sourced and most often in no need of processing.

*Items' characteristics*

Through the ERP system, item characteristics such as weight and dimensions was obtained (see Table 5). By examining and reviewing the items, it was found that the major components and wear parts were significantly larger and heavier than the other item categories.

***Table 5*** *Item categories characteristics*

| Item category | Items | Weight (kg) |
|---|---|---|
| Major components | Top shell, bottom shell, main shaft, head center | 400 - 23 000 |
| Key components | Eccentric bushing, eccentric, bottom shell bushing, eccentric wear plate, gear, step plate | 1 - 6000 |
| Wear parts | Crushing chamber (mantle), crushing chamber (concave) | 500 - 5000 |
| Spare parts | Fasteners, hoses | 0.5 - 430 |

### 4.1.1 Chosen focus items

To narrow the scope of the thesis project, it was decided to focus on the item categories with the highest impact on Sandviks logistics processes. This decision was based on the three factors previously mentioned; product structure, processing activities and weight, which all affects the goods flow, warehouse operations, and storage and equipment requirements. The factors was listed and summarized (see Table 6).

***Table 6*** *Comparison of factors impacting the logistics processes*

| Item category | Product structure depth | Processing activities | Weight (kg) |
|---|---|---|---|
| Major components | Extensive | Extensive | Extensive |
| Wear parts | Modest | Extensive | Moderate |
| Key components | Non-existent | Moderate | Moderate |
| Spare parts | Non-existent | Moderate | Modest |

After evaluation of the impacting factors, the chosen focus items was decided; major components and wear parts. These item categories represents six items; top shell, bottom shell, main shaft, head center, crushing chamber (mantle) and crushing chamber (concave) (see Figure 15).

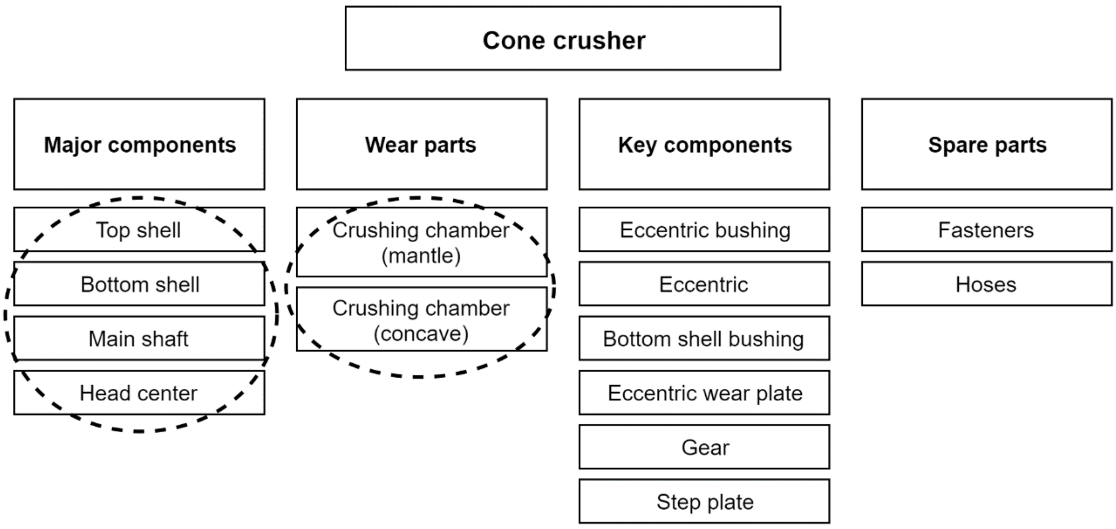



***Figure 15*** *Chosen focus items*

These items were considered as focus items, on which most of the research effort was directed. The items and their place within the cone crusher is illustrated in Figure 16 below.

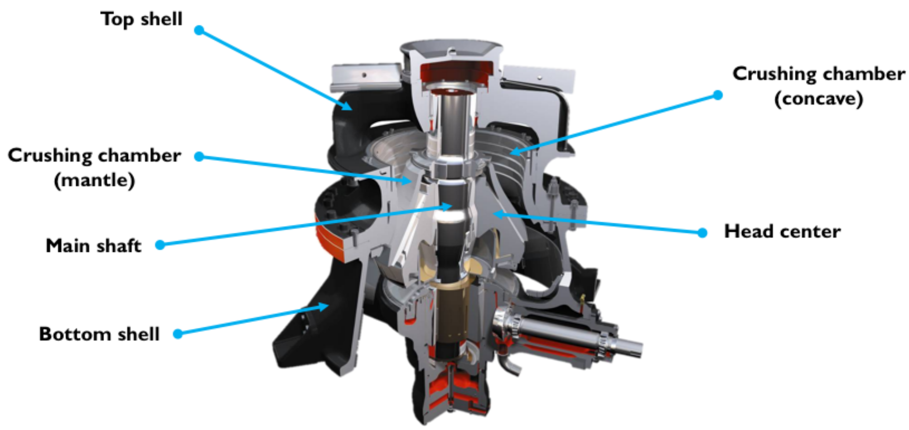



*Figure 16* *Focus items illustrated within a cone crusher*

### 4.1.2 Site overview

The production unit's different storage and processing locations were identified during the gemba walks. A description of these locations follows, and all locations involved in the flow are highlighted in Figure 17 below. An enlargement of this map can be viewed in Appendix A.

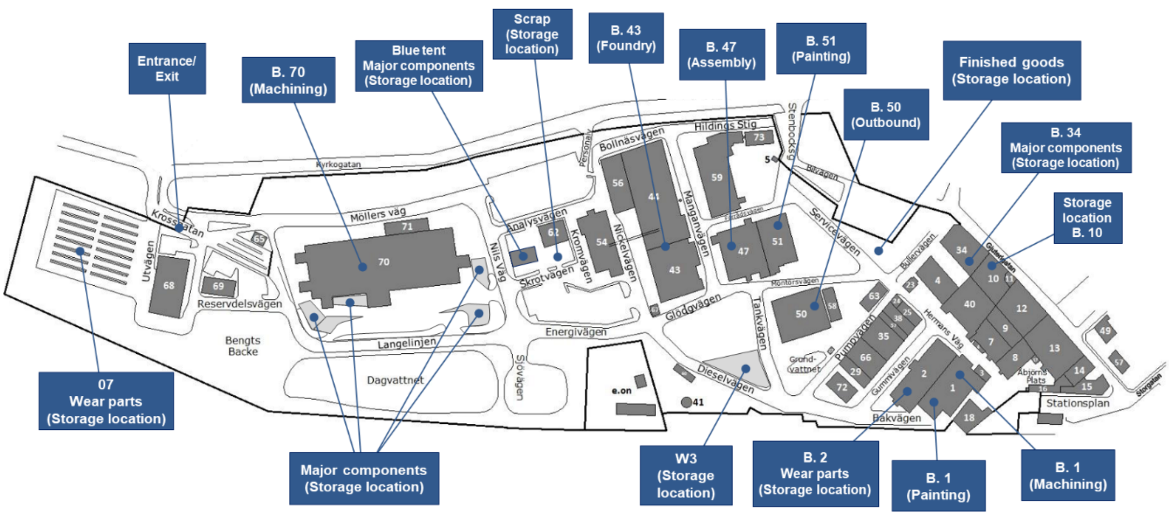



*Figure 17* *Site map of the production unit in Svedala*

A description of the facilities and units is presented below:

- Building 47 (Assembly) - This is the point where the flow of major components and crushing chambers for EQ converge and the items are assembled.
- Building 1 (Machining, painting) - Processing of the wear parts

- Building 2 (Drying area) - Drying of wear parts
- W3 (Storage) - Storage location for finished crushing chambers for EQ
- Building 34 (Storage) - Storage location for machined major components
- Building 10 (Storage) - Storage location for machined major components
- Building 70 (Machining) - Machining of major components
- Building 51 (Painting) - Painting of items
- Building 50 (Outbound) – Outgoing goods is prepared
- 07 (Storage) - Storage location for finished wear parts for AM
- Building 43 (Foundry) - Casting of new crushing chambers
- Blue tent (Storage location) – Storage of machined major components

### 4.1.4 Supply chain set-up

The supply chain set-up within Crushing & Screening is shown in Figure 18 below. Assembly centers in China and India and the production unit in Svedala are together with external suppliers providing all global warehouses with parts and components. Two of these warehouses, 07 and C1, are located in Svedala and Eindhoven respectively, where the latter currently is run by a 3PL.

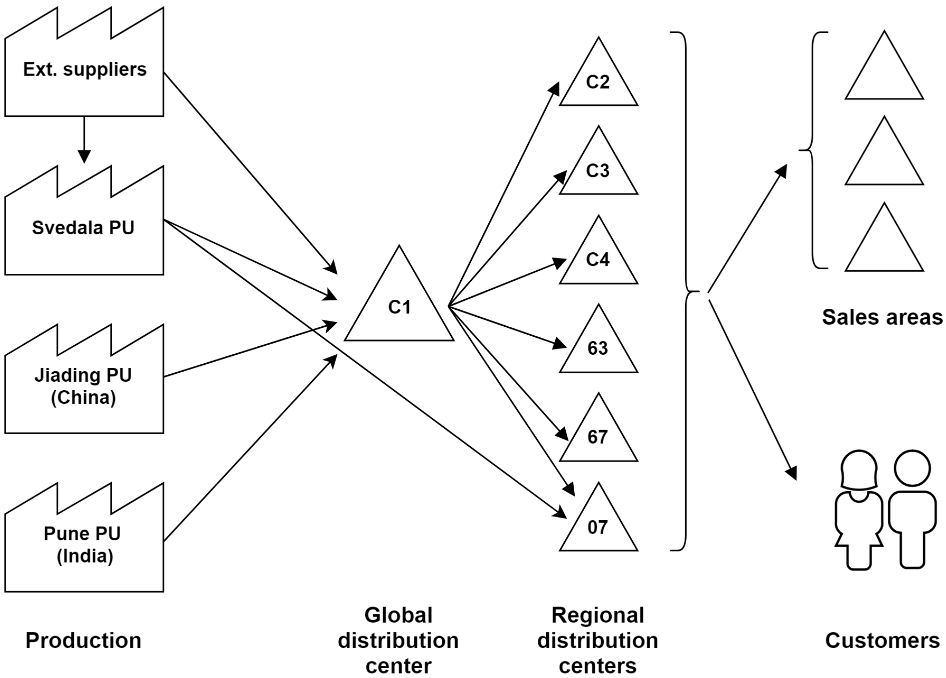



***Figure 18*** *Sandvik Crushing & Screening supply chain set-up*

Today, these global warehouses are providing smaller regional warehouses around the world with aftermarket goods. The cooperation with C1 is about to end and a new global warehouse in Venlo is to be launched, which will affect Sandvik in following ways; the goods previously delivered from external suppliers to C1 will instead go through the production site in Svedala, which will result in overall increased stock.

## 4.2 Production activities

### 4.2.1 Processing of items

Within the production site, the major components and wear parts are machined and processed in different stages, with different article numbers assigned to the items depending on the current processing stage. All major components are purchased as casted (raw) components ready for machining. The wear parts are casted and produced by the foundry on the site, using scrapped crushing chambers as raw material. However, a substantial part of the wear parts is additionally bought from external suppliers in e.g. China. These crushing chambers are delivered to Sandvik completely machined, painted and finished i.e. are only received and stored within the production site, why it is not part of the scope in this project.

The outbound flow of the major components and wear parts can be divided in two segments, equipment (EQ) and aftermarket (AM). EQ includes the assembled and ready to use products while the AM segment provide customers with components and parts for already existing stone crushers. It was found that a notable part of Sandviks business comes from AM, representing a large part of the goods delivered from the entire site. Internally, this affects the goods flow and the items require different activities within the site depending on the end purpose (see Figure 19 and 20).

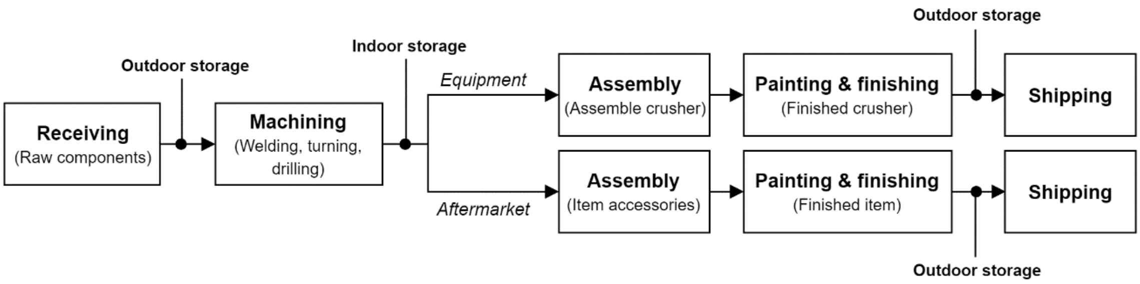



*Figure 19* *Major components: EQ and AM flow*

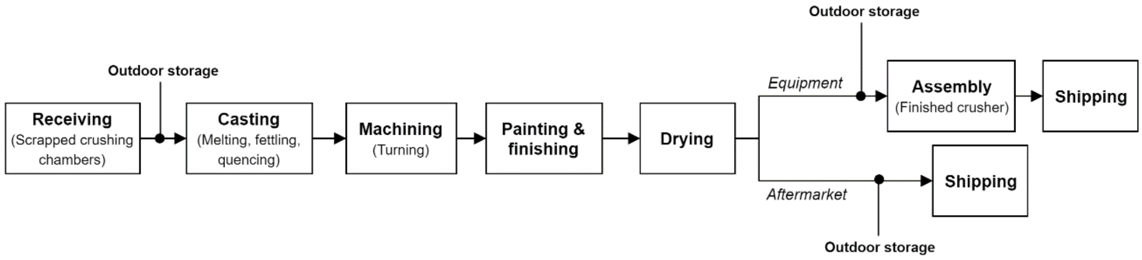



***Figure 20*** *Wear parts: EQ and AM flow*

*Processing level impact on storage demand*

In Figure 19 and Figure 20 above, it can be seen that machined items, not yet assembled or painted, need indoor storage. This is to avoid rusting and impact from the outer environment which can damage the machined surfaces. Thus, an item requires different storage types depending on its processing stage.

## 4.3 Warehouse operations

### 4.3.1 Information system

Sandvik use the M3 ERP system for managing their business and different processes within their supply chain. M3 provides an overview of the storage locations and stock levels with detailed information of all items. However, M3 do not reveal the available space at each storage location, thus, when put-away of an item, warehouse staff manually finds a suitable location, puts the item down and then entering the chosen location in the system. The new location of the item is now available in the system and can be located by the warehouse staff.

Since a safety stock inventory is kept for the major components, a MRP system is used to plan, forecast and manage the inventory levels. Data from the ERP system is used to calculate appropriate reorder points and order quantities.

### 4.3.1 Storage locations and storage capacity

The research showed that each storage location was dedicated to hold only major components or wear parts, i.e. these items was never mixed in the storage locations. However, in each storage location, single or multiple types of items could be stored. This is analysed further in coming sections.

*Storing of major components*

Observations and interviews showed that all major components were stored on the floor in different storage locations, thus no sorts of pallet rack is used (see Table 7 and 8).

*Table 7* *Indoor storage capacity for major components*

| Storage location | Description | Item(s) | Area (m2) |
|---|---|---|---|
| A1V01 | Building 34 | Top shell, bottom shell, main shaft | 402 |
| A1X01 | Building 10 | Head center, main shaft | 144 |
| A6C01 | Blue tent | Top shell, bottom shell | 170 |
| **Total** | | | **992** |

*Table 8* *Outdoor storage capacity for major components*

| Storage location | Description | Items | Area (m2) |
|---|---|---|---|
| P7A02 | Dieselvägen | Top shell / bottom shell | 240 |
| P7B01 | West | Bottom shell | 270 |
| P5A01 | West | Top shell | 600 |
| P6A01 | West | Main shaft | 330 |
| P5B01 | West | Head center | 570 |
| A7A01 | Outside Märta | Finished goods | 375 |
| **Total** | | | **3185** |

### *Warehouse layout in building 10*

As previously mentioned, the storage location in building 10 contained of head centers and main shafts. The storage location layout can be seen in Figure 21 below.

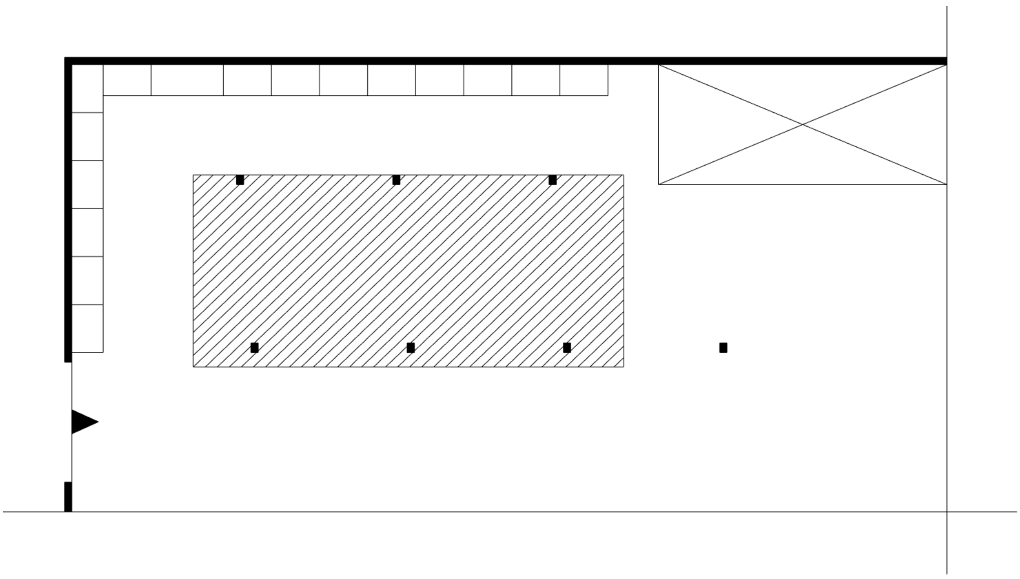


***Figure 21*** *Warehouse layout building 10*

*Storing of wear parts*

It was notable that actual storing of wear parts, both physically and in M3, only exists after they are finished and ready for EQ or AM. Thus, only outdoor storage locations exists for the crushing chambers. This is due to that the wear parts are casted, machined, painted and finished in one single sequence of activities. This can be compared with the major components, which are stored in different storage locations after e.g. machining (prior to assembly). All AM wear parts were stored in pallet racks at 07 (see Table 9) while EQ items were stored on the floor at W3 (see Table 10). Each section of the pallet racks at 07 contains three levels with a capacity of 3000 kg per level. Since the largest crushing chambers, with a weight over 3000 kg, could be placed on the first level (ground floor) the pallet racks can keep all models of the crushing chambers.

However, depending on the utilization in machining, casted crushing chambers may not be able to be processed instantly, why buffer spaces are used to hold the crushing chambers until there is free capacity in machining (see Table 11).

***Table 9*** *Pallet racks storage capacity for wear parts*

| Storage location | Description | Items | Pallet positions |
|---|---|---|---|
| 07 | 07 | Crushing chamber | 2000 |
| **Total** | | | **2000** |

***Table 10*** *Outdoor storage capacity for wear parts*

| Storage location | Description | Items | Area (m2) |
|---|---|---|---|
| W3 | W3 | Crushing chamber | 800 |
| **Total** | | | **800** |

***Table 11*** *Buffer capacity*

| Storage location | Description | Items | Area (m2) |
|---|---|---|---|
| Buffer zone | Building 2 | Crushing chamber | 240 |
| Buffer zone | Building 1 and 2 | Crushing chamber | 400 |

| | | | |
|---|---|---|---|
| Buffer zone | Building 40 | Crushing chamber | 84 |
| **Total** | | | **724** |

*Shared vs dedicated storage*

In all cases, the storage locations were used to hold only one specific item category, i.e. major components and wear parts were never mixed in the storage locations. Thus, the storage locations contained only a certain item, e.g. top shells, or it contained many different items from the same item category e.g. top shells and main shafts. It was established that a certain specific item was never stored solely in the storage locations. Figure 22 and Figure 23 below illustrate the storage routines found.

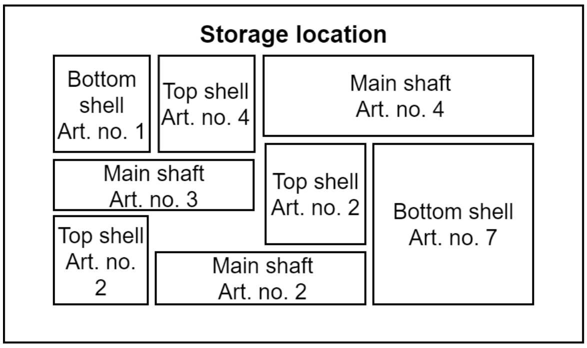



***Figure 22*** *Shared storage locations within the item category*

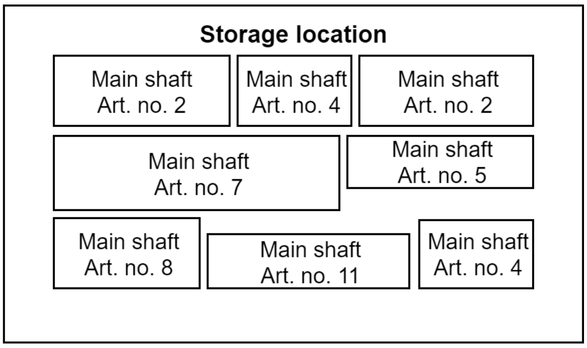



***Figure 23*** *Dedicated storage locations within item categories*

*MTS strategy towards aftermarket sales*

Recently, Sandvik have decided on a new MTS strategy towards AM items due to that the sales within this area lately have increased. The strategy aims at building up a stock of machined and finished major components to be able to deliver AM products with a shorter lead time.

### 4.3.2 Item characteristics and inventory levels

By analysing data extracts from M3, characteristics and properties regarding the items could be obtained. To calculate the inventory levels, extractions of the MRP system was evaluated and through item article number the order quantity and safety stock could be identified. It was decided to use the maximum inventory level ($IL^{max}$) and the average inventory level ($IL_{avg}$). The maximum inventory level was calculated as:

$$maximum\ inventory\ level\ =\ order\ quantity\ +\ safety\ stock$$

Since it was desired to calculate how the inventory could be stored in alternative ways, e.g. pallet racks, the average inventory level $IL_{avg}$ was used. In Table 12 and 13 the outdoor and indoor inventory levels are shown. The average inventory level was calculated as:

$$average\ inventory\ level\ =\ \frac{order\ quantity}{2}\ +\ safety\ stock$$

***Table 12*** *Major components indoor inventory levels*

| **Item** | $IL_{max}$ | $IL_{avg}$ |
|---|---|---|
| Top shell | 35 | 22 |
| Bottom shell | 26 | 16 |
| Main shaft | 48 | 30 |
| Head center | 40 | 24 |

***Table 13*** *Major components outdoor inventory levels*

| **Item** | $IL_{max}$ | $IL_{avg}$ |
|---|---|---|
| Top shell | 50 | 27 |
| Bottom shell | 33 | 19 |
| Main shaft | 105 | 53 |
| Head center | 50 | 25 |

*Main shafts and head centers detailed characteristics*

Since items weight and dimensions affects the possibility to use pallet racks, it was essential to obtain these values. However, since it was clear that top shells and bottom shells was to large and heavy to be placed in any sorts of pallet racks, only main shafts (see Table 14) and head centers (see Table 15) was analysed.

***Table 14*** *Main shaft characteristics*

| **Item** | **Weight (kg)** | **Dimensions (cm)** |
|---|---|---|
| Main shaft CH420 | 461 | 100x100 |
| Main shaft CH430 | 747 | 100x100 |
| Main shaft CH440 | 1270 | 120x120 |
| Main shaft CH540 | 867 | 120x120 |
| Main shaft CH550 | 1604 | 140x140 |
| Main shaft CH660 | 2002 | 120x80 |
| Main shaft CH860 / CH865 | 2930 | 130x130 |
| Main shaft CH870 | 3851 | 160x160 |
| Main shaft CH880 | 6068 | 150x150 |
| Main shaft CH890 / CH895 | 6465 | 150x150 |
| Main shaft CS420 | 580 | 70x70 |
| Main shaft CS430 | 956 | 120x120 |
| Main shaft CS440 | 1688 | 100x100 |
| Main shaft CS550 | 2142 | 120x80 |
| Main shaft CS660 | 2605 | 120x120 |

***Table 15*** *Head center characteristics*

| **Item** | **Weight (kg)** | **Dimensions (cm)** |
|---|---|---|
| Head center CH420 | 448 | 100x100 |
| Head center CH430 | 815 | 100x100 |
| Head center CH440 | 1400 | 120x120 |
| Head center CH540 | 1680 | 120x120 |
| Head center CH550 | 2040 | 140x140 |
| Head center CH660 | 780 | 120x80 |

| | | |
|---|---|---|
| Head center CH860 / CH865 | 3195 | 130x130 |
| Head center CH870 | 4850 | 160x160 |
| Head center CH880 | 7815 | 150x150 |
| Head center CH890 / CH895 | 6984 | 150x150 |
| Head center CS420 | 700 | 70x70 |
| Head center CS430 | 977 | 120x120 |
| Head center CS440 | 1750 | 100x100 |
| Head center CS550 | 1983 | 120x80 |
| Head center CS660 | 2700 | 120x120 |

### 4.3.2 Inventory levels and storage demand

The aim was to evaluate the required storage space for all research items. Since all major components used floor storage, the storage demand was measured as area ($m^2$). By using the specific area for each item together with the inventory level, total required storage space could be calculated (see Table 16 and Table 17). To make a secure and solid approximation of how well the current storage capacity was, it was decided to use the maximum inventory level. Due to difficulties in handling the items and to be able to have some extra space between the items, 0.2 m was added to each side om the items.

***Table 16*** *Total indoor inventory space (for maximum inventory levels)*

| **Item** | **Area ($m^2$)** |
|---|---|
| Top shell | 107 |
| Bottom shell | 77 |
| Main shaft | 97 |
| Head center | 83 |
| **Total** | **365** |

***Table 17*** *Total outdoor inventory space (for maximum inventory levels)*

| **Item** | **Area ($m^2$)** |
|---|---|
| Top shell | 176 |

| | |
|---|---|
| Bottom shell | 112 |
| Main shaft | 222 |
| Head center | 96 |
| **Total** | **1117** |

By comparing the above calculated storage requirements to the current storage capacity, a valuable analysis could be made.

### 4.3.4 Obsolete and slow moving items (OSMI)

It was found that the wear parts produced by Sandvik are viewed as obsolete and slow moving items (OSMI) after a period of two years. This means that the crushing chamber value is written-off and thus have no remaining value. OSMI in forms of wear parts i.e. crushing chambers are then scrapped and used as raw material to cast new crushing chambers. By reviewing data from Sandvik, it was found that 53 finished crushing chambers was scrapped due to OSMI during one year.

## 4.4 Flow of goods

### 4.4.1 Which flows to analyse?

The result of the first observations was that the major components have almost identical flows through the site, which enables the number of flows to be reduced. Since VSM is a very time consuming tool, all flows could not be value stream mapped due to time limitations. Due to this, certain areas were identified as more in need of investigation and therefore chosen to be value stream mapped. The flows of the other research items were analysed and evaluated by doing gemba walks and interviews.

In total, four flows were mapped;

- **AM flow: Top shell, bottom shell, main shaft, head center**
  (Since the flows of the items were almost identical, one flow was used to represent the movement of the items)
- **EQ flow: Top shell, bottom shell, main shaft, head center**
  (Since the flows of the items were almost identical, one flow was used to represent the movement of the items)
- **AM flow: Crushing chamber**
- **EQ flow: Crushing chamber**

The four different flows were mapped by gemba walks and interviews, the result of these mapping are illustrated in the spaghetti diagrams (see Figure 24 – 27) below. The black dots represent where the items are put down / picked, so called touch points. Other findings except from the items routes are also explained below.

One specific flow was chosen where a VSM was made;

- **AM/EQ flow: Crushing chamber**
  From building 44 (Foundry) to building 47 (Assembly) / 07 (Storing)

### 4.4.2 Current-state map: Major components for EQ

*Findings*

- During gemba walks and interviews, it was found that a large amount of items were queued before being painted in building 51. The waiting items did also obstruct goods to move within the facility and thus, this activity was considered a bottleneck.
- A lot of movement was made right outside the Märtha office where movement from employees is high.
- The overall route is not optimal, with items going back and forth along the assembly, painting and storing processes.
- The storage locations in building 34 and 10 are shared among the items, creating unorganized storage space without FIFO and easy access. Maximum utilization of space.

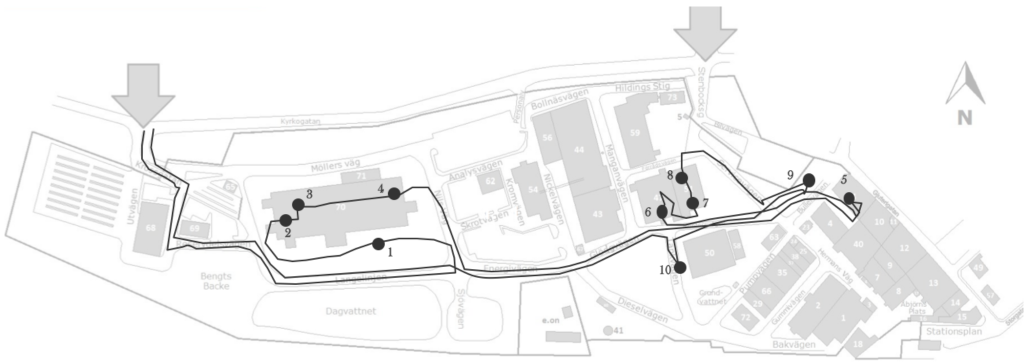


***Figure 24*** *Major components for EQ*

In Table 18 below, the activities within the flow are described.

***Table 18*** *major components flow activities for EQ*

| No. | Action |
|---|---|
| 1 | Delivery of raw component to storage location outside building 70 |

| | |
|---|---|
| 2 | The item is placed inside building 70 to obtain room temperature |
| 3 | Machining of the item |
| 4 | The item is moved and waiting to be picked up |
| 5 | The item is stored in building 34 or 10 |
| 6 | The item is assembled with a finished crusher in building 47 |
| 7 | The finished goods is moved to building 51 for painting and finishing |
| 8 | The stone crusher is placed to dry |
| 9 | The stone crusher is stored at the finished goods storage location (A7A01) |
| 10 | The stone crusher is picked and moved to the outbound area and shipped to customers |

### 4.4.3 Current-state map: Major components for AM

- The transportation process was streamlined
- The storage location "the blue tent" was unorganized and full, no FIFO

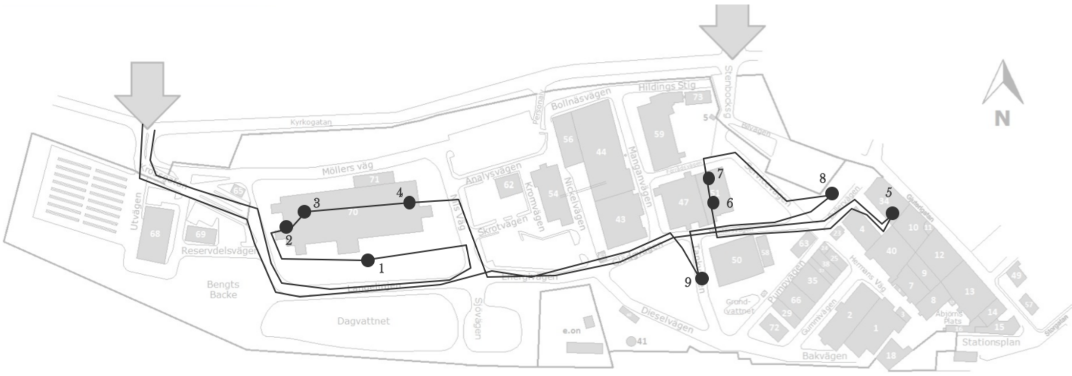



***Figure 25** Major components for AM*

In Table 19 below, the activities within the flow are described.

***Table 19** AM major components flow activities*

| No. | Action |
|---|---|
| 1 | Delivery of raw component to storage location outside building 70 |
| 2 | The item is placed inside building 70 to obtain room temperature |
| 3 | Machining of the item |
| 4 | The item is moved and waiting to be picked up |

| | |
|---|---|
| 5 | The item is stored in building 34 or 10 |
| 6 | The item is moved to building 51 for painting |
| 7 | The item placed to drying |
| 8 | The item is stored at the finished goods storage location (A7A01) |
| 9 | The item is picked and moved to the outbound area and shipped to customers |

Exceptions:

Main shafts are not painted why they are moved directly to outbound where they are shipped. The largest top shells and bottom shells are stored in the blue tent instead of building 34 and 10

### 4.4.4 Current-state map: Wear parts for EQ

*Findings*

- The items were transported and stored more than once before some processes
- No FIFO in building 2
  - Truck driver spends 30 minutes each day on moving blocking items
- Unorganized buffer zones outside building 1
- Poor storage location on W3 due to no hard floor surface (muddy and frozen ground, makes the trucks either shaky or getting stuck)

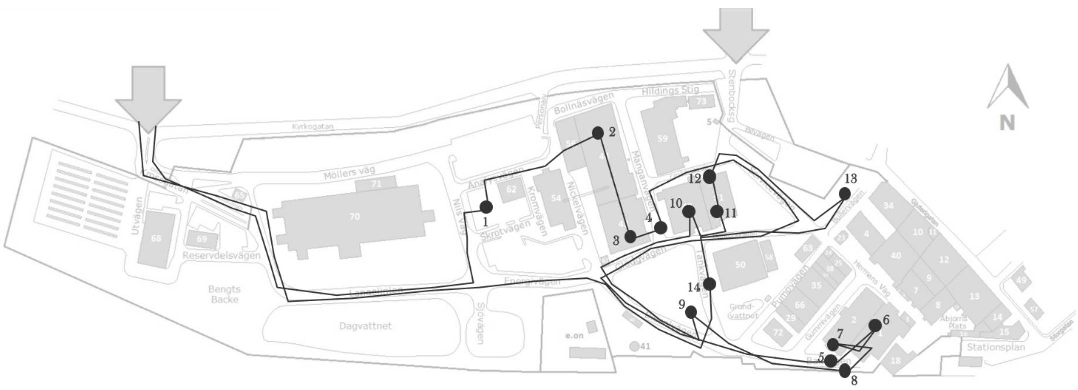



***Figure 26*** *Wear parts for EQ*

In Table 20 below, the activities within the flow are described.

*Table 20* *EQ wear parts flow activities*

| No. | Activity |
|---|---|
| 1 | Delivery of scrapped crushing chambers from supplier |
| 2 | The scrap is moved to and casted in building 44 (Foundry) |
| 3 | The casted wear parts are placed to cool down |
| 4 | The item is loaded on a truck |
| 5 | The item is stored outside building 1 |
| 6 | The item is waiting to get processed in building 1 |
| 7 | The processed item is waiting to get picked up |
| 8 | The is loaded on a truck |
| 9 | The item is stored on W3 |
| 10 | The item is moved to building 47 (Assembly) and assembled in a crusher |
| 11 | The crusher is moved to building 51 (Painting) where it is painted |
| 12 | The crusher is moved and placed to dry |
| 13 | The finished crusher is stored outside the Märtha office |
| 14 | The crusher has been moved to building 50 (Outbound) where it is shipped |

### 4.4.5 Current-state map: Wear parts for AM

*Findings*

- Around 50 finished items become obsolete every year
- The items were transported and stored more than once before some processes
- No FIFO in building 2
    - Truck driver spends 30 minutes each day on moving blocking items
- Unorganized buffer zones outside building 1

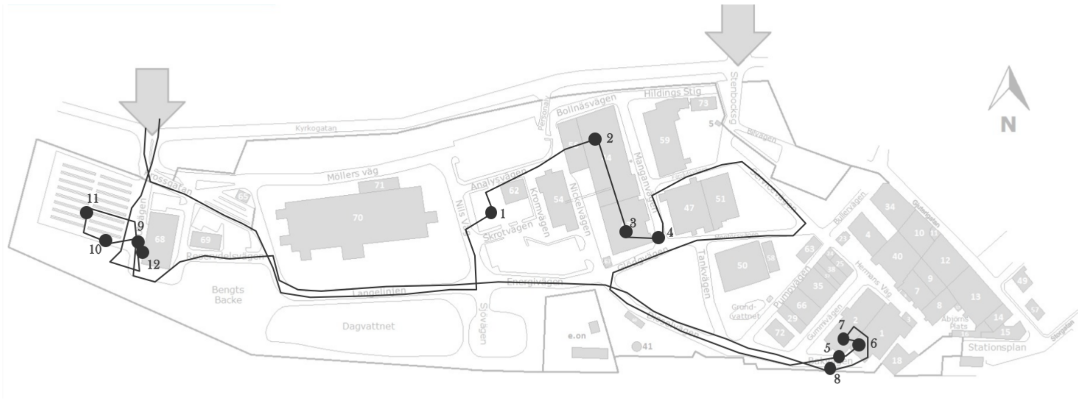



***Figure 27*** *Crushing chambers for AM (Step 1-7 equal for AM and EQ)*

In Table 21 below, the activities within the flow are described.

***Table 21*** *AM wear parts flow activities (step 1-7 are equal to EQ flow)*

| No. | Action |
|---|---|
| 1 | The supplier has delivered the scrap |
| 2 | The scrap has been taken to building 44 |
| 3 | The scrap has been casted |
| 4 | The item has been put on a truck |
| 5 | The item is stored outside building 1 |
| 6 | The item is waiting to get processed in building 1 |
| 7 | The finished item is waiting to get picked up |
| 8 | The item has been put on a truck |
| 9 | The item has been transported by truck to 07 |
| 10 | The item has been offloaded beside the outside storage |
| 11 | The item has been stored in the outside storage |
| 12 | The item is secured and fastened on a pallet |
| 13 | The item is loaded on a truck and shipped |

### 4.4.6 Current-state map: Summary

The collected data for the four analysed flows is presented in table 22 below.

***Table 22*** *Flow analysis measurements*

| Flow | Distance (m) | Touch points |
|---|---|---|
| Major components for EQ | 2990 | 10 |
| Major components for AM | 2600 | 6 |
| Crushing chambers for EQ | 3000 | 10 |
| Crushing chamber for AM | 2490 | 13 |

## 4.5 Value Stream Map

### 4.5.1 Current-state map: Wear parts for AM and EQ

As mentioned previously, it was decided to make a VSM only for one certain item and flow; crushing chambers after being casted, moving from building 43 (Foundry) to building 47 (Assembly) and 07 (AM). The reasons this area was picked were, mainly because it has not been investigated by Sandvik in a while, but also because the throughput of it was high and therefore has a large impact if it would be improved. The flows are shown in Figure 28 below.

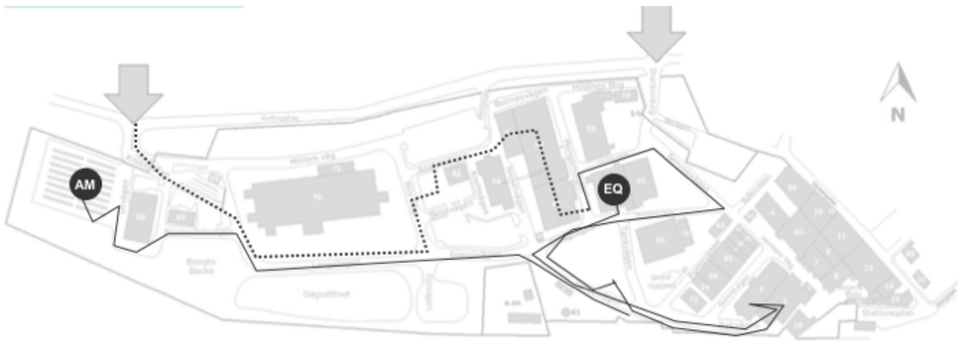



***Figure 28*** *The chosen flows for the VSM*

The VSM was made in order to get detailed insight in the activities within these routes and to identify the non-value adding actions (waste), in order to eliminate them. The most part of these flow consist of building 1 and 2, where also the most important processes are, since the items are machined and painted there. The focus of the VSM lies therefore within these buildings and its processes. As mentioned in the theoretical framework, data such as inventory level, demand and different process data was necessary to perform the VSM. The processes and these necessary data are described below.

The production processes within building 1 consists of machining, painting and drying. Each crushing chamber is machined in two phases; tempo 1 and tempo 2. In some cases, one machine can perform these phases in one sequence, in most cases however, the crushing chamber needed to be moved to another machine before tempo 2 could be initialized. It appeared early during the gemba walk that the wear parts processing time varied a lot. This was due to that the waiting time between the processes could vary from 2 hours to 5 days, while other wear parts was prioritized.

This complicated the gemba walk, since the items were difficult to follow in real-time, why a new approach was chosen. The average waiting time between the processes (machining tempo 1, machining tempo 2, painting, drying) was calculated as:

$$average\ waiting\ time\ = \frac{average\ number\ of\ waiting\ items}{throughput}$$

**Processes**

1. **Machining tempo 1**
    a. Automatic machining process with 1 operator
    b. Cycle time: 62 min
    c. Change over time: 15 minutes
    d. Average observed inventory: 62

2. **Machining tempo 2**
    a. Automatic machining process with 1 operator
    b. Cycle time: 63 min
    c. Change over time: 14 minutes
    (On the other hand, processing step 1 and 2 spends about 30 hours a week additionally when switching from processing one kind of manganese to another, in change over time).
    d. Average observed inventory: 40

(The machining time varied a lot depending on the size of the crushing chambers. The average machining time for the crushing chambers for two months was collected and analysed in order to make the result more accurate)

3. **Painting and finishing**

a. Two Processes with 1 operator
    i. Automatic painting
    ii. Manual finishing
b. Cycle time: 16
c. Change over time: 30 seconds
d. Average observed inventory: 65

**4. Drying**
a. The item needs to dry inside for 16 hours
b. No operator needed
c. Average observed inventory: 33

Other information necessary, such as inventory, demand and throughput are shown in Table 23 - 25 below.

***Table 23*** *Other observed inventory*

| Location | Average inventory |
|---|---|
| Outside building 1 | 250 |
| 07 | 4000 |
| W3 | 35 |

***Table 24*** *Crushing chambers demand*

| Market | Demand (per week) |
|---|---|
| Crushing chambers for AM | 200 |
| Crushing chambers for EQ | 6 |

***Table 25*** *Throughput and transports of crushing chambers*

| Transport | Amount (per week) |
|---|---|
| Total transports (throughput) from building 2 | 250 |
| Transports to W3 (EQ item) | 6 |
| Transports to 07 (AM item) | 244 |

The VSM drawing for the crushing chambers is presented in Figure 29 below. An enlarged copy can be viewed in Appendix B.

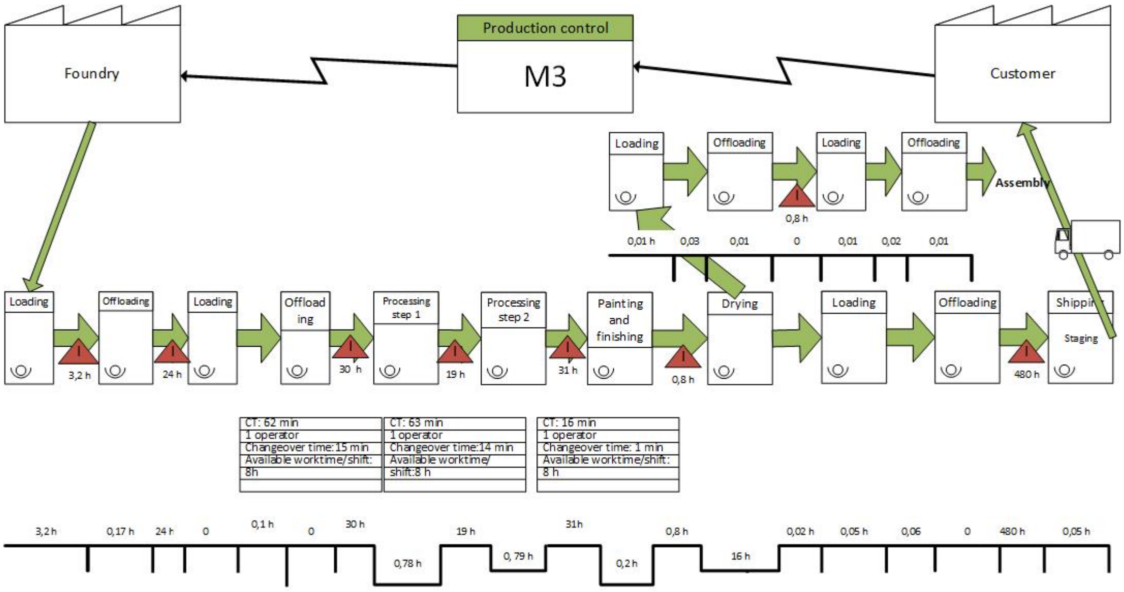



***Figure 29*** *Value stream map of the crushing chambers*

***Table 26*** *Value adding time for crushing chambers (EQ and AM)*

| **Action** | **Time (h)** |
|---|---|
| Average processing time tempo 1 | 0.81 |
| Average processing time tempo 2 | 0.83 |
| Painting | 0.27 |
| Pallet securing | 0.02 |
| Drying | 16 |
| **Total** | **17.93** |

***Table 27*** *Non-value adding time for crushing chambers (AM)*

| **Action** | **Time (h)** |
|---|---|
| Waiting to get transported from foundry to building 1 | 3,2 |
| Transportation and offloading at building 1 | 0,17 |
| Stored outside building 1 | 120 |
| Loading/offloading and transportation into building 1 | 0,05 |
| Waiting for processing step 1 | 30 |
| Waiting for processing step 2 | 19 |
| Waiting to get painted | 31 |
| Waiting to get picked after drying | 0,8 |
| Loading/offloading and transportation to 07 | 0,13 |
| Waiting to get shipped | 480 |
| **Total** | **684** |

***Table 28*** *Non-value adding time for crushing chambers (EQ)*

| **Action** | **Time (h)** |
|---|---|
| Waiting to get transported from foundry to building 1 | 3.2 |
| Transportation and offloading at building 1 | 0.17 |
| Stored outside building 1 | 120 |
| Loading/offloading and transportation into building 1 | 0.05 |
| Waiting for processing step 1 | 30 |
| Waiting for processing step 2 | 19 |
| Waiting to get painted | 31 |
| Loading/offloading and transportation to W3 | 0.05 |
| Stored at W3 | 120 |
| Transportation to building 47 | 0.02 |
| **Total** | **323** |

# 5 Analysis

*This section addresses steps 2-5 in the research process where the empirical findings and current-state map are analysed for further improvement and optimization. The research questions will be answered by the help of the empirics and suggested and implemented actions will be described and evaluated.*

## 5.1 Flow analysis: Future-state map

The sources of waste and problem areas were identified through the spaghetti diagrams and gemba walks. By further analysis of the results, the researchers could provide suggestions of how to eliminate the waste and make improvements. The spaghetti diagrams below illustrate the future-state map of each affected flow (See Figure 30 and Figure 31).

### 5.1.1 Analysis: Head center and main shaft travelling through the site separately while they could be travelled as a package

*Current situation and problem*

Main shafts and head centers are always assembled into a main shaft package before going to EQ and AM. Today, the main shafts and head centers are transported through the site as separate parts, from building 70 (Machining) to building 34 (Storage) to building 47 (Assembly), where they are assembled together.

Current data for AM main shaft and head center before assembled (sum of both flows)

- Annual demand: 222
- Item travel distance: 6000 m
- Picked: 6 times
- Put down: 6 times

Current data for EQ main shaft and head center before assembled (sum of both flows)

- Annual demand: 312
- Travel distance: 6000 m
- Picked: 4 times
- Put down: 4 times

**Solution: Merge the flow of main shafts and head centers through prior assembly**

Could these items be assembled earlier in this flow, and thereby reduce the handling and storage requirements? By make the assembly into a main shaft package right after machining (building 70), the two flows could be merged into one.

After the assembly in building 70, items flow could then be managed according to whether it is a AM or EQ item. Main shaft packages for AM could be stored in the blue tent, and then shipped from 07. The main shaft packages going to EQ should still be stored in building 34 (Storage).

*Impact*

The prior merging of head centers and main shafts enables the EQ and AM flows to be redesigned. For EQ main shaft packages, the flow and handling activities from building 70 (Machining) to building 47 (Assembly) will be reduced by half. For AM main shaft packages, transportation would never be necessary back and forth through the site, and the travel distance would decrease significantly. The total number of touch points for the AM main shafts and head centers would also be reduced, while travelling as a package. Furthermore, implementing this solution would also unburden the assembly in building 47 which would be able to focus on assembling finished crushers. The spaghetti diagram below illustrates the new route of main shaft packages going to AM. Table 29 below shows the waste that could be eliminated with this solution.

**Data if they are assembled as a package (AM)**

- Annual demand: 111
- Travel distance 1500
- Picked: 3 times
- Put down: 3 times

**Data if they are assembled as a package (EQ)**

- Annual demand: 111
- Picked: 2 times
- Put down: 2 times

***Table 29*** *Waste eliminated with prior assembly of head center and main shaft*

| Waste eliminated | Minutes (per day) |
|---|---|
| Picking AM (3 minutes, 3 times á 222 items divided by 250) | 8 |
| Put down AM(1 minute, 3 times á 222 items divided by 250) | 2.5 |
| Picking EQ (3 minutes, 2 times á 312 items divided by 250) | 3.7 |
| Put down EQ (1 minute, 2 times á 312 items divided by 250) | 2.5 |

| | |
|---|---|
| Travel (4500 á 10 km/h 222 times divided by 250) | 40 |
| **Total waste eliminated** | **56.7** |

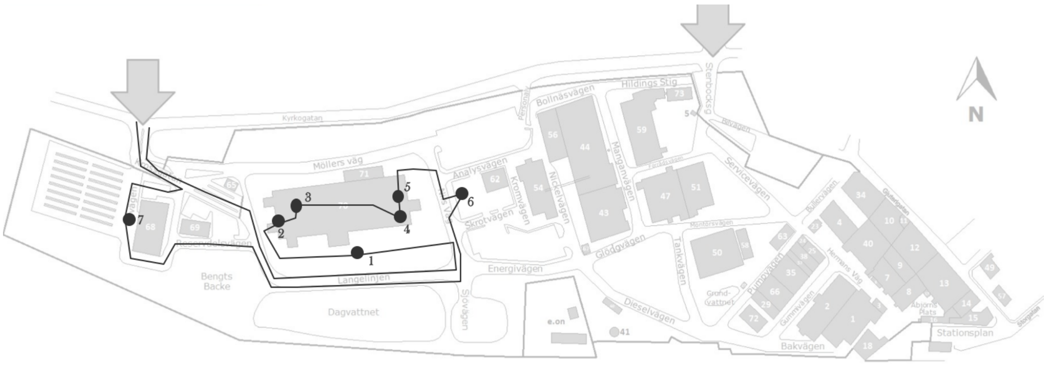



*Figure 30* *Future-state map: main shaft packages for AM*

In Table 30 below, the activities within the flow are described.

***Table 30*** *AM main shaft packages flow activities*

| No. | Action |
|---|---|
| 1 | The supplier has delivered the items outside building 1 |
| 2 | The item has been put inside building 1 to get the right temperature |
| 3 | The item has been taken in for machining |
| 4 | The machined item is assembled |
| 5 | The item is waiting to get picked up |
| 6 | The item has been stored in the red tent |
| 7 | The item has been taken to outbound where it is shipped to the customers |

## 5.2 Flow of goods analysis: VSM

The result of the VSM in section 4 showed that the average time elapsed between casting of a crushing chamber to it is shipped to a customer (AM) or moved to assembly (EQ) is 702 hours and 341 hours respectively. The value adding time for both of these flows is 17.9 hours, representing 3 % and 8 %, which implicates that a lot of non-value adding time exists. During most of this non-value adding time the items are waiting to be machined or stored. This due to the high amount of WIP within a lot of steps in the flow. The non-value adding time increases the WIP costs for Sandvik while it does not add value to the customer, something Dahlgaard & Dahlgaard-Park (2006) defines as waste. In following sections, the identified waste, solutions of how it can be reduced and its impact is described.

### 5.2.1 Analysis: Unnecessary double handling and limited accessibility

*Current situation and problem*

When analysing the flow of the crushing chambers going to EQ, it was found that some of the touch points and double handling could be reduced. Especially in the flow between drying in building 2 (Drying) and building 47 (Assembly). The activities within this flow were; transportation, drying, transportation, storing, transportation, assembly. This can be seen in the VSM drawing (see Appendix B). A transportation to storing is necessary to have in the flow and is according to Womack & Jones (2005) unavoidable waste. However, when looking at the VSM drawing, but when there are two transportations/storing before a process it is probably an avoidable waste, which according to Womack & Jones (2005) should be eliminated.

By analysing data from interviews and observations shown in the VSM, it was found that the truck driver spends 30 minutes per moving around recently painted crushing chambers to be able to access crushing chambers dried for 16 hours or more. This is due to that the drying area (floor storage) do not have the capacity of having FIFO lanes and neither pallet racks that allow immediate access to any crushing chamber.

**Solution: Combined drying and storing of wear parts in pallet racks**

To eliminate the identified waste, a storage location could be created in building 2 (Drying) combine the drying and storing of the crushing crushing chambers in the same space. To allow for a picker to access the dried and finished crushing chambers without having to move recently painted crushing chambers, pallet racks could be installed.

*Impact*

The throughput in the processing of crushing chambers is shown in Table 4.16 below. Since a truck can only transport one crushing chamber at a time, the total number of transports from building 2 (Drying) is equal to this amount. However, the destination and route of the crushing chambers going from building 2 (Drying) depends on whether the item is going to AM or EQ.

The truck driver can only transport one crushing chamber at a time to W3, which means 6 transports to W3, and 6 transports from W3 to building 47 a week (12 transports in total).

Then they can be moved directly from building 2 to the assembly and omit the handling and transport to w3. With this solution there would only be 6 transports a week. It would not affect the transportation distance of the manganese, but the transportation route for the truck driver from an arbitrary point to W3 6 times a week would be eliminated. The time the truck driver spends on moving items blocking each other would also be eliminated by installing the pallet racks. The put down time for every transport from building 1 to W3, and the pick time for every transport from W3 to building 47 would also be eliminated. The waste eliminated per day is shown in Table 31 below.

***Table 31*** *Waste eliminated by putting up pallet rackets in building 2*

| **Waste** | **Minutes (per day)** |
|---|---|
| Moving blocking items | 30 |
| Picking (3 minutes of picking time á 1.2 picks per day) | 3.6 |
| Put down (1 minute of putting down time á 1.2 put downs per day) | 1.2 |
| **Total waste eliminated** | **34.8** |

(The time for the truck driver to drive from an arbitrary point at the site, to W3 was included in the picking and put down time).

This solution could therefore decrease manufacturing costs which is one of the performance measurements Benita (1999) suggests. This, due to the 35 minute decrease in working time for the truck driver.

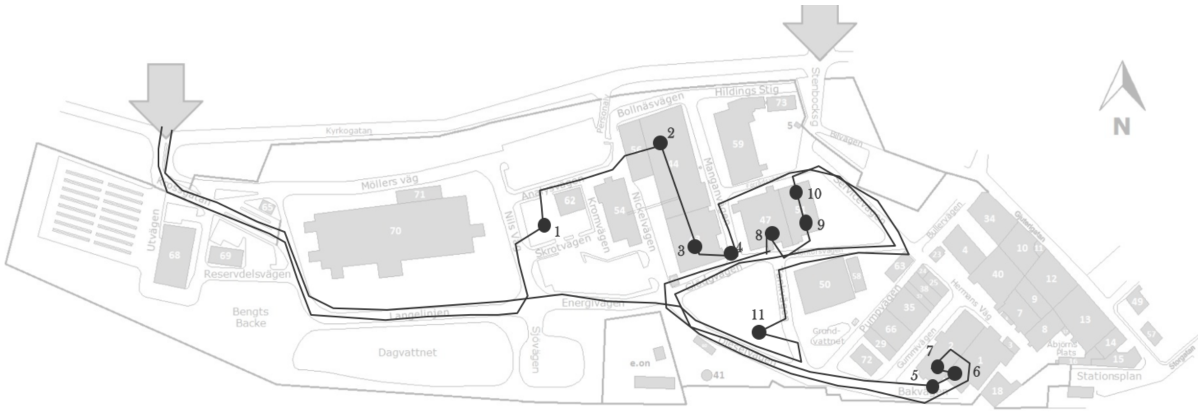



*__Figure 31__ Future-state map: Crushing chambers for EQ*

In Table 32 below, the activities within the flow are described.

*Table 32* EQ wear parts flow activities

| No. | Action |
|---|---|
| 1 | The supplier has delivered the scrap |
| 2 | The scrap has been taken to building 44 |
| 3 | The scrap has been casted |
| 4 | The item has been put on a truck |
| 5 | The item is stored outside building 1 |
| 6 | The item is waiting to get processed in building 1 |
| 7 | The finished item is waiting to get picked up |
| 8 | The item has been taken to building 47 where it is assembled |
| 9 | The item has been taken to building 51 where it is painted |
| 10 | The item is drying |
| 11 | The item is stored on W3 where it is shipped to the customers |

### 5.2.2 Analysis: High tied up capital, obsolete costs and poor accessibility

*Current situation and problem*

The casted (raw) crushing chambers does not have a given storage location before they are processed and finished. Thus, before machining, the items are stored randomly outside and around building 1 and 2 in buffer zones without a specified location in the M3. Thus, when the logistics staff are unavailable or off duty, the machining staff are sometimes forced to retrieve the crushing chambers on their own, often struggling to find and locate them.

When resources such as time and processing effort have been put down on an item, the tied up capital increases. A crushing chamber e.g. increases in value by 20 % when it has been processed. It is therefore desirable to have the item unprocessed and raw as long as possible before shipping to the customer, while not increasing the lead time. Today Sandvik manufactures finished crushing chambers according to a make-to-stock strategy, without a customer order point. As shown in the empirics, 4000 finished crushing chambers are stored at 07 today, while the weekly demand only is 200. This could indicate that the inventory is to high containing finished and rather valuable items, which instead could be stored as unprocessed and raw crushing chambers. Another indication of a too high inventory of finished crushing chambers, is the yearly amount of OSMIs. The cost of these OSMIs was possible to calculate by analysing the data collected in the VSM.

**Data:**

- OSMI per year: 53
- Processing time per item: 2 hours and 20 minutes
- Total OSMI processing time per year: 125 hours
- Processing cost per hour: 1150 SEK
- Costs wasted related to OSMI: 140 000 SEK (125x1150)
- Average finished goods inventory (AM): 4000
- Tied up capital in finished goods (AM): 4 000 000 SEK per year (Assumed that crushing chamber value is 1000 SEK)

**Solution: MTS strategy for raw crushing chambers and MTO strategy for finished crushing chambers through changed customer order point**

Create storage locations to hold unprocessed (raw) crushing chambers while reducing the stock of finished crushing chambers. This would both decrease the tied up capital and prevent finished items from becoming obsolete. In other words, move the customer order point and adopt a MTS strategy for raw crushing chambers and a MTO strategy for finished crushing chambers. This might imply an increase in lead time, but on the other hand, there would be focus on processing the specific customer ordered items instead of items that might not be shipped and become obsolete. Due to this, the lead time might not be affected.

The buffer space currently holding raw crushing chambers outside building 1 and 2 could be redesigned as storage locations. Since the crushing chambers have appropriate dimensions and size, pallet racks could be used as storage. By adding and defining these storage locations in M3, the exact storage location and quantity of each crushing chamber would be visible.

*Impact*

- Eliminating OSMIs of finished crushing chambers: 140 000 SEK savings per year
- Lower tied up capital costs:
  - Reduction of average inventory of finished crushing chambers (AM) by 40 % to 2400.
  - Savings in tied up capital: 1600 x 1000 x 0.2 = 320 000 SEK per year. (Assumed that crushing chamber value is 1000 SEK)
- Time reduced in locating and searching of crushing chambers
  - Savings in labor cost

These changes also affected the travel distances and number of touch points, which are listed in Table 33.

### 5.2.3 Future state map: Summary of improvements

The new data for the four analysed flows is presented in Table 33 below.

***Table 33*** *Flow analysis measurements improvement*

| Flow | Reduced distance (m) | Reduced touch points |
|---|---|---|
| Major components - EQ | 0 | 8 |
| Major components - AM | 1100 | 6 |
| Crushing chambers - EQ | 0 | 2 |
| Crushing chamber - AM | 0 | 0 |

## 5.3 Warehouse operations

### 5.3.1 Analysis: No need of a WMS for major components

As mentioned, the M3 ERP system and the integrated MRP module provide a wide range of services that manages inventory levels, storage locations, forecasts and planning. However, through M3 it is not possible for Sandvik to view available storage capacity on each storage location which implies two main issues; warehouse staff are forced to manually locate a storage location when put-away of an item, and the logistics staff are not able to measure and evaluate the available storage capacity.

By integrating a WMS, these issues could be managed and eliminated, but is an investment that needs to be properly motivated. The data collected in this research do actually not show a high demand of having a WMS. This is based on careful analysis and evaluation of data with following motivation:

- **The research focus items have few different storage locations;** rather easy for warehouse staff to manually find and keep track of the storage locations without guidance from a WMS
- **High storage capacity;** increases the chance to be able to find free storage space for the items
- **Rather low turnover and picking/put-away frequency;** if any extra time when put-away, the overall impact is rather low

- **Very large items with variable shapes;** can create difficulties for a WMS to calculate available space

### 5.3.2 Analysis: Indoor and outdoor storage requirements are met

*Current situation and problem*

From the data gathered and analysed, it could be determined that Sandvik has sufficient storage space, both indoor and outdoor. The required indoor space (365 $m^2$) is well met by the available space (992 $m^2$) and the required outdoor space (1117 $m^2$) is satisfied by the current available space (3185 $m^2$). As mentioned, this is based on measuring the floor area, since the major components was not stored in pallet racks. Since the floor areas are not specific for only one item article, but for many different items, it is rather difficult to have an accurate measure of the exact capacity. However, since the indoor and outdoor space is only occupied with 37 % and 35 % respectively, it is at least reliable to state that the storage capacity is sufficient today.

**Solution: Monitoring and measuring of storage capacity**

As mentioned above, Sandvik have no ability to measure and keep track of the available space in their storage locations due to the lack of a WMS. To increase the visibility and make the evaluation of storage space more accurate, an approach and a simulation model is proposed.

- **Approach: Measure required/available storage capacity in terms of indoor and outdoor space**
  By letting the items article number indicate whether it needs indoor or outdoor storage, the required storage space can be calculated once all dimensions and inventory levels are collected.
- **Simulation model: Use demand data as input to evaluate required storage space**
  The suggested simulation model will then evaluate if the required space can be met.

### 5.3.3 Analysis: Increased space utilization to reduce costs

*Current situation and problem*

Since all machined items not yet assembled and finished for EQ or AM, need indoor storage, the efficiency of the assembly and painting processes have a high impact on the required amount of indoor storage. Thus, a long processing time in painting and assembly implies a larger demand of indoor storage. Since the indoor storage is both expensive (Bartholdi & Hackman, 2017) but also limited on the site, it needs to be thoroughly managed and evaluated. The new make-to-stock strategy of AM items is also demanding more indoor storage space due to the current limitations in painting and assembly.

The new MTS strategy have increased the load on the painting and assembly processes which now handle the previous EQ items but now also a higher number of AM items. At the time this research was carried out, the rather new strategy and corresponding bottleneck in painting and assembly created several backlogs in the production processes.

The empirics showed that all machined head centers, in need of indoor storage, was located in building 10 and 34. All head centers and main shafts was stored on the floor, and due to the different shapes and sizes, a lot of unutilized space was found between the items. Furthermore, the design of the storage locations did not allow easy access to the items. Due to this, Sandvik faces the risk of not discover faulty batches in time (Manohar & Appaiah, 2017). Thus, improving the utilization of this storage space and making the items more accessible was desirable. It was further concluded that FIFO storage was not necessary due to the long shelf life of the items.

- Current storage space: 144 $m^2$
- Amount of head centers stored:
  - $IL_{avg}$: 29 head centers = 56 $m^2$
  - Capacity in 144 $m^2$: ~87 head centers (56 $m^2$ x 3 = 168 ≈ 144)

**Solution: Improve storage utilization in building 10 through redesigned layout**

By evaluating the average inventory level and the weights of the items, it was found that 85% of the head centers (average inventory) had a weight below 3000 kg. Thus, pallet racks could be installed to hold the 85 % of the items on shelves while 15 % if the items (with a weight over 3000 kg) could be placed on the floor level. The pallet racks characteristics can be viewed in Appendix C.

- Number of installed pallet racks (Type P90+): 27
- Levels per section: 4
- Total pallet positions: 108

*Impact*

- ~25 % increased storage capacity
- Full accessibility of items: Increased picking
- Faulty batches discovered in time

The new warehouse layout is shown in Figure 32 below.

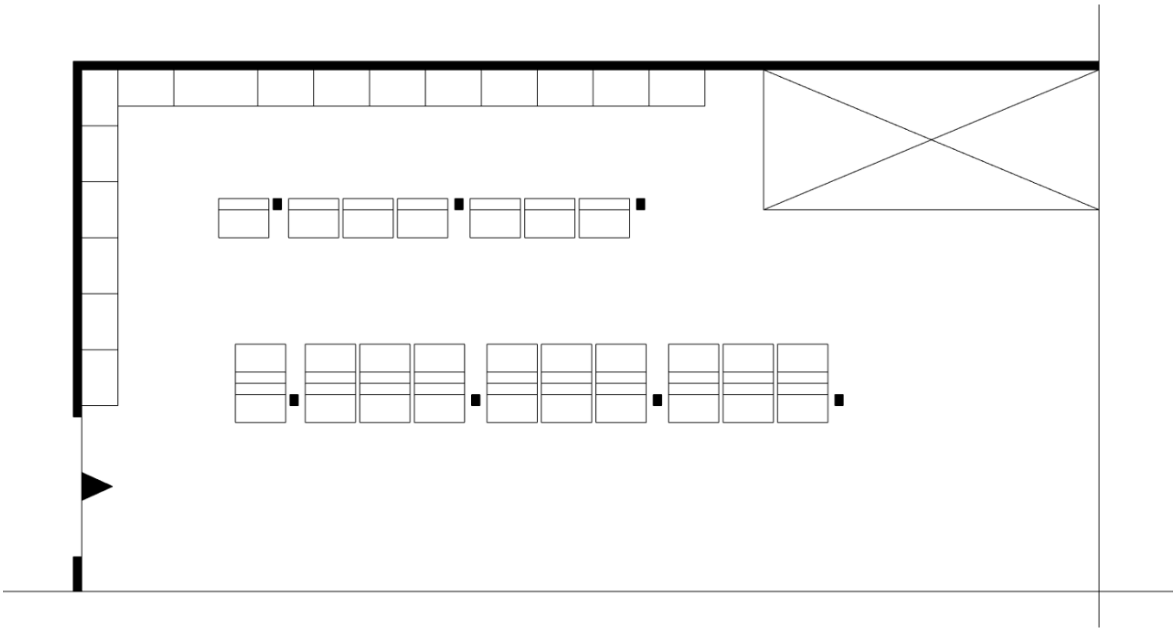


***Figure 32*** *New warehouse layout building 10*

## 5.3.4 Shared vs dedicated storage

Sandvik does not use a dedicated storage policy for any of the research items focused on in this report. Off course, warehouse staff may spend some time searching for the right item when picking, however, as shown by the empirics there is a rather low inventory turnover of the items which means that the extra searching time only have a limited impact on the total warehouse operations. This approach is supported by the literature which suggests that dedicated storage mainly should be used in rather small and very frequently visited storage locations. In the same way, no class-based storage policy was used since this demands a dedicated storage policy to ease the implementation. According to Bartholdi & Hackman (2017) space utilization is more efficient when using a shared storage policy, which is another reason for Sandvik to use this policy for major components.

## 5.3.5 Make-to-stock for machined crushing chambers

To support the increasing demand for AM parts, especially manganese, Sandvik could benefit from having a

- Easy to find and locate machined crushing chambers, Visibility of machined items in M3;
- Scrapping OSMI items without value added activities
- Reducing storage of finished crushing chambers, lower capital costs

# 6 Result and recommendations

*In this section, the analysis made are summarized, followed by recommendations of parts to implement. Also, presented in this chapter are recommendations for potential future projects for Sandvik and a discussion of the different solutions.*

## 6.1 Analysis summary

As previously described, several operations, routines and areas within Sandvik was identified as in need of improvement. By using proven methods and theories from the thesis framework, this was the main activities during step 2 in the research process described in section 2.3. The result of this analysis is summarised in Table 34 below, where the main insights are presented and also connected to the research focus items.

***Table 34*** *Analysis summary in connection to focus items*

| Items | Analysis |
|---|---|
| Wear parts | Unnecessary double handling and poor item accessibility |
| Wear parts | High tied up capital, obsolete costs and poor item accessibility |
| Major components | Head centers and main shafts travel through the site separately increasing touch points and travel distance |
| Major components | No need of a WMS for major components |
| Major components | Indoor and outdoor storage requirements are met |

## 6.2 Recommendations for implementation

Since costs and decisions related to the recommendations require time from management and stakeholders, the recommendations are yet to be implemented. The mapping of flows and collected data regarding Sandviks storage locations and warehouse operations has been provided to involved managers and staff. This information and data could be obtained due to the action research approach of the researchers being present in and close to operations and activities. From the analysis that was made, different solutions of how the internal logistics could be improved was generated. The result of these solutions are composed into the recommended actions in Table 35 below.

***Table 35** Recommended actions for implementation and their impact*

| No. | Recommended action | Impact |
|---|---|---|
| 1 | Combined drying and storing of wear parts in pallet racks, permanent storage location for EQ crushing chambers | Waste eliminated 34,8 min per day |
| 2 | MTS strategy for raw crushing chambers and MTO strategy for finished crushing chambers through changed customer order point | Reduced tied up capital: 320 000 SEK per year, reduced OSMI costs: 144 000 SEK per year, reduction in search of items |
| 3 | Measure storage capacity in terms of indoor and outdoor space / pallet positions. Use support from provided model. | Increased visibility of storage capacity |
| 4 | Merge main shaft and head center flows through prior assembly | Waste eliminated: 56 min per day |

## 6.3 Discussion

The solutions generated from the analysis resulted in a decrease in waste and streamlined flows. These improvements do not generate immediate capital savings, but can be translated to reduction in labour costs and tied up capital, lower lead time and increased customer satisfaction. However, it is very important to remember that these solutions require investments, which the researchers were not authorized to drive. Due to this, the actual costs of the solutions have not been taken into account in this research. Instead, focus have been to provide Sandvik with the potential savings and improvements, to enable the management to evaluate costs and savings prior to implementation decisions.

## 6.4 Future projects for Sandvik

Following analysis and solutions are provided as recommendations to future projects and investigations.

### 6.4.1 Further analysis: Should Sandvik absorb a 6th S?

*Current situation and problem*

The 5S methodology is used today within the crushing chamber machining, with schedules and lists containing work tasks and routines. When observing workplaces and storage locations, tools was always hanged and placed on the walls with markers or notes attached. The storage locations for the research items was never filled with other items, and was clean.

As an exception, the storage location W3 was not covered with asphalt or concrete. Instead W3 is simply a storage location on soil, which was wet and muddy during rainy days, and hard and bumpy during cold days. Thus, truck drivers either could be stuck in the mud or experience bumpy driving on the frozen surface, which do not fulfill the *shine* or *safety* of 5S.

Today, the finished goods for AM and EQ is stored at A701, very close to the Märtha office, which results in trucks going back and forth while a lot of staff is in movement due to the office.

**Solution: Move storage location of finished goods to W3**

By implementing the recommended action no. 1 described in section 6.2, the storage location W3 would be completely unused and free. Instead, this space could now be used for storing of the finished goods currently stored at A701.

By creating a hard surface on W3, Sandvik could benefit from having a more safe and easily managed area without the need of cleaning and maintaining, towards a lean production environment.

*Impact*

Since W3 is much closer to building 50 (Outbound), this solution would not only reduce the travel distance, but also reduce the traffic outside the Märtha office, which is beneficial for safety reasons. Since Gapp et al. (2008) suggests a 6th S for safety highlighting its importance for reducing waste and supporting lean production, Sandvik could benefit from considering this approach.

The time saved by reducing the travel distance is negligible but due to safety, a highly prioritised area within Sandvik, this could be a good solution. The spaghetti diagram below illustrates the new route (see Figure 33).

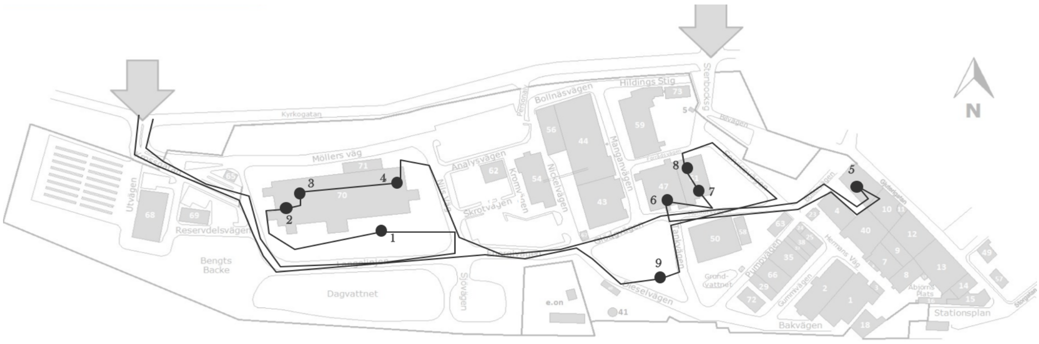



***Figure 33*** *Future-state map:  Major components to Equipment*

The activities for the new route is described in Table 36 below.

***Table 36*** *EQ major components flow activities*

| No. | Action |
|---|---|
| 1 | The supplier has delivered the item outside building 1 |
| 2 | The item has been put inside building 1 to get the right temperature |
| 3 | The item has been taken in for machining |
| 4 | The machined item is waiting to get picked up |
| 5 | The item is stored in building 34/10 |
| 6 | The item has been taken to building 47 in order to get assembled |
| 7 | The item has been taken to building 51 in order to get painted |
| 8 | The item is drying and is waiting to get picked up |
| 9 | The item has been taken to W3 where it is shipped to the customers |

### 6.4.2 Further analysis: Can handling and transportation of casted crushing chambers be reduced through new stacking routines?

*Current situation and problem*

Today, the casted crushing chambers going out from the foundry are placed one by one on pallets, before moved to building 1 (Machining). There are six transports from foundry to machining each day. It was discovered in interviews that stacking of these items is possible due to the raw surfaces not taking damage. Furthermore, it was found that the machining staff uses overhead cranes to lift the crushing chamber into the machines. During weekends and evenings, the logistics staff is unavailable which sometimes forces machining staff to by themselves retrieve crushing chambers for machining.

**Solution: Double stack crushing chambers before transport to machining.**

When the crushing chambers have been casted and are put on pallets for the transport to storage / machining, they should be stacked in pairs. This would not be an issue for machining staff since overhead cranes is used to lift the crushing chambers.

*Impact*

- 50 % reduction of number of transports from foundry to crushing chamber storage location
- 50 % reduction of transports from crushing storage location to machining
- 50 % reduction of space requirements for casted crushing chambers
- 50 % reduction of space requirements for crushing chambers not yet machined inside building 2
- Reduced need for machining staff to retrieve crushing chambers for machining: increased time available for machining

# 7 Conclusions

*Initially in this section, a conclusion of how the action research helped answering the research questions is presented. This is followed by a discussion of how the research can contribute to further studies in the field of logistics and finally a comment on the credibility in the research.*

## 7.1 Revisit research questions

Regarding **RQ 1** (Can Sandviks future storage requirements be met by the current storage capacity?) the evaluation of current storage capacity crossed against future requirements turned out to be more than sufficient. However, this point of view was not always shared among warehousing staff. This could be an effect of not having the possibility to have an overview of storage capacity in a structured manner. This is due to lack of a system support e.g. a WMS. However, the research showed that a WMS it might be superfluous and it requires a big investment, why the data file obtained by the researchers would be sufficient.

Addressing **RQ 2** (How can the current storage capacity be better utilized and improved?) it was early apparent in the data collection process that Sandvik had poor space utilization in many of their storage locations. This due to not seeking alternative solutions in storing of goods, but also an effect of handling large, heavy and bulky items. It would be beneficial for Sandvik to categorize and keep track of detailed characteristics of their items, such as weight, dimensions, storage requirements etc. in order to evaluate and investigate other storage possibilities. This kind of track keeping was something Sandvik lacked today. For Sandvik to be able to develop and improve their storage requirements it is a prerequisite to understand the importance of documenting this information about the the items.

As to **RQ 3** (How can the flow of goods be optimized?), the spaghetti diagrams was a useful tool in order to understand and get an overview of the transportations of the items and their touch points through the site. The VSM resulted in identifying waste, which was its purpose. Even though the collection of primary data during the gemba walk was hard to obtain in some aspects since there could be a complete variance from one item and also one interviewee to another. This led to a hard effort in collecting credible data, but this gave the researcher a better insight in the different flows. In the end the spaghetti diagram and VSM complemented each other, which resulted in finding potential solutions to make the flows more efficient by improving routes, reducing waste and touch points.

## 7.2 Contribution

### 7.2.1 Power of spaghetti diagrams and VSM

In situations where evaluation and improving of internal logistic flows are needed, this research confirmed that the spaghetti diagram and VSM are very good tools. The researchers discovered that the VSM approach presented by Rother and Shooks (1999), turned out to be very useful in order to identify waste. The spaghetti diagram is not just a simple tool suitable for analysing and improving a flow, but also a tangible support for both operational staff and top management to get an overview of operations and connections between different processes and activities. Providing staff with a holistic picture of a flow could decrease silo thinking and a more collaborative approach between the different departments could be achieved.

*Hints to future researchers*

During this action research, collecting data to a current-state map where the purpose is to follow an item from one point to another, turned out to be a complicated task with misguiding results in this particular case. This due to the static result a VSM generates, it is not well coupled with high variance between process and waiting time. Therefore, it is critical to be aware of these processing and waiting time variances before initializing a VSM process. Otherwise, researchers may face the a risk of getting the misleading results, recently mentioned. In those cases it could be better to use historical data to collect processing and waiting times in order to make the result of the mapping more accurate.

### 7.2.2 Heavy and bulky goods may be overlooked

The literature review provided several valuable methods and approaches to understand, analyse and improve warehouse operations. The researchers however often found that material handling concepts and theories towards very large and bulky items was rather limited. This characteristics of goods seemed to be connected with rather low inventory turnover and slow moving goods. If there is a connection, it could be the explanation to why the researchers struggled to find solutions for such situations. Environments where e.g. concepts as class-based storage or WMS was suggested was usually characterized by very active and frequently visited picking areas.

## 7.3 Credibility in this research

Since databases and information systems could not always provide necessary data e.g. detailed item characteristics, measurements and specifications, such information was collected manually. By comparing and merging manually collected (primary) data and database information (secondary data), the researchers could easily evaluate the reliability of the data. This also applies to the data collected when mapping the current situation, which mainly was manually collected by the researchers. In general, the qualitative and hands-on approach of an action research, can provide rather high reliability to a research. However, some database information (secondary data) such as demand and forecasts was sometimes difficult to control and evaluate. Since this information was obtained from on single source, one can assume that the reliability was sufficient, but it is very important to assess the validity of the data and question if it really is the actual information needed in the specific situation and environment.

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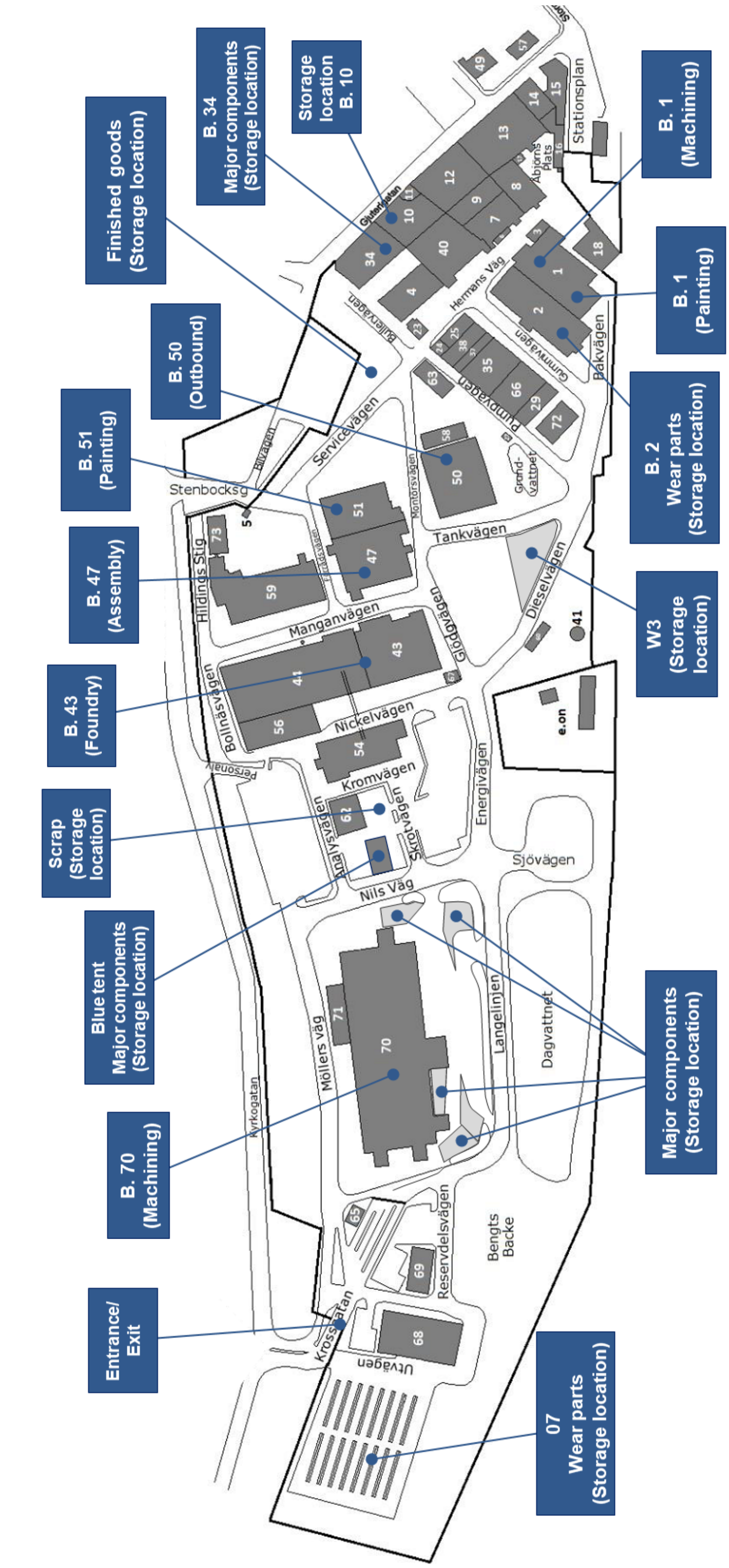
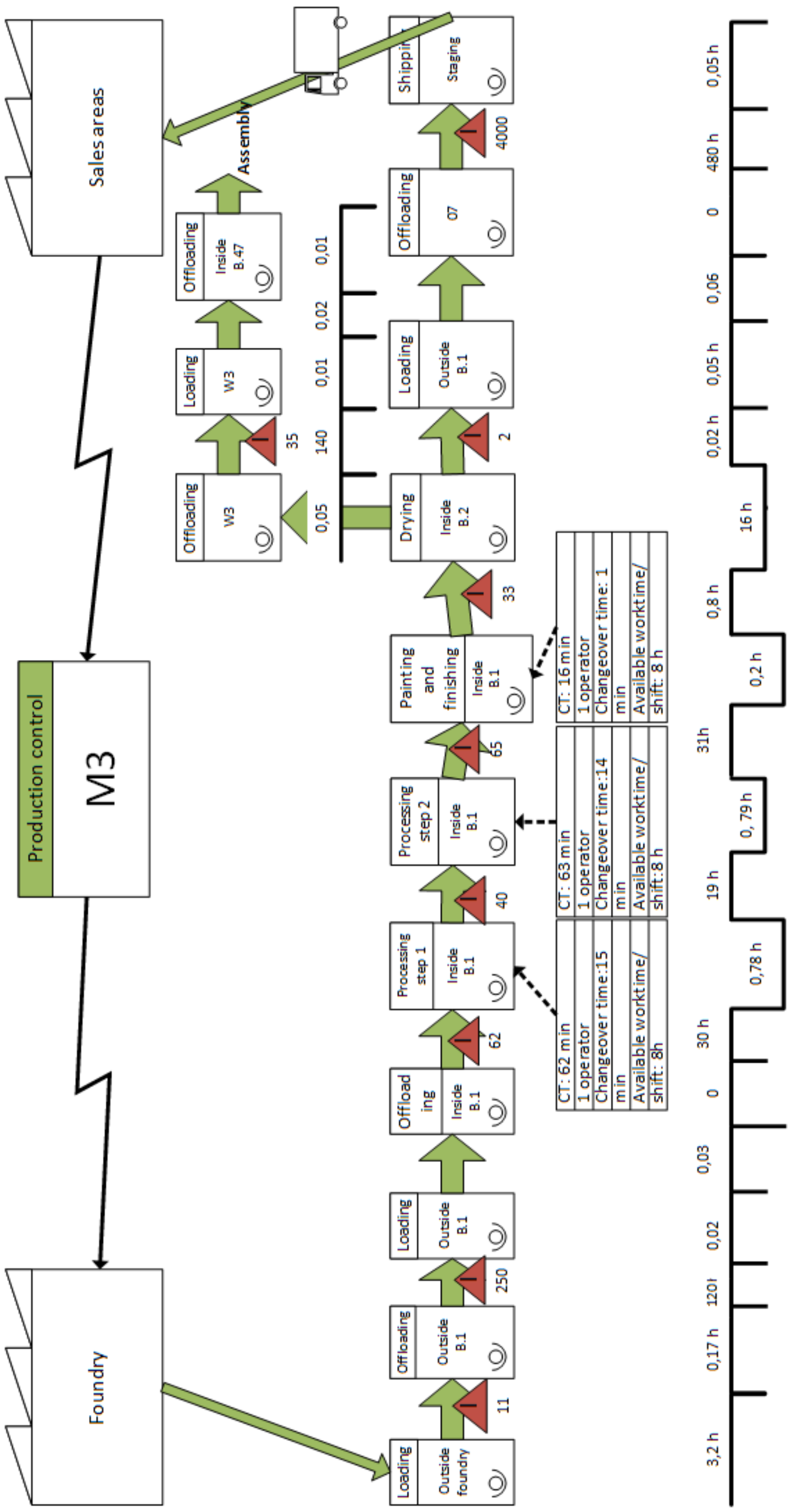
# Appendix A: Site map



# Appendix B: VSM drawing



# Appendix C: P90+ pallet racks