Optimizing spare-parts management

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Abstract

**Purpose:** The purpose of the study is to develop a model that will facilitate the choice of maintenance strategy within the Swedish pulp and paper industry. Without compromising system availability, the model aims to reduce inventory holding costs.

**Methodology:** At first, a literary research was conducted to create a holistic view over the chosen topic, in time it developed into a literature framework. Secondly, a case study was conducted in order to obtain empirical data. The data were obtained through interviews and archival records. The literature framework and the empirical data were then cross-analyzed with each other.

**Findings:** In this thesis, a model has been developed based on previously applied and accepted methods. The methods have been identified and described in order to provide a strategy in which the inventory levels- and value could be lowered. The findings indicate that the organization must seek to assign ABC-classified and VED-analyzed components different maintenance actions in order to reduce the total cost.

**Theoretical contribution:** This thesis contributes to a methodology development regarding spare parts management. It aims to add knowledge to the existing gap regarding spare parts order point and batch size. The thesis provides a procedure in which systems including critical and expensive components are evaluated in order to assign them the appropriate maintenance.

**Practical relevance:** The model has only been exemplified by using a system position from Stora Enso Skutskär, the numerical values are examples. The model must be tested with real values and the risk analysis must be carried out with a group of employees with great insight regarding the selected component and system position.

**Limitations:** This thesis is delimited to spare parts management and inventory management. The study only involves one Swedish organization, whereas the organization and its spare parts management illustrates the complexity concerning spares. The model will not be verified as the focus is to highlight the research gap and to develop the model.

**Keywords:** Spare parts management, classification, risk-analysis, maintenance
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1 Introduction

*In this chapter an introduction to the subject of the thesis with purpose along with research question and limitations will be stated.*

The flow of products and information within an organization are the essentials of logistics and supply chain management builds upon this framework. Supply chain management intends to streamline the path between processes, entities, suppliers, customers and the organization (Christopher, 2011). By transparency and allowing organizations to share and spread information concerning demand, it is possible to reduce or eliminate inventory (ibid.). The most common SCM objectives are said to be; improvement in demand planning, lead time reduction, control, reliability, transport, production and acquisition costs (ibid.). Additionally, effective SCM will enhance the coordination of activities and reduce risks (Vlahakis, Apostolou & Kpanaki, 2018). By properly managing relationships within the supply chain, the organizations will gain superior financial performance (Christopher, 2011; Vlahakis et al., 2018).

The main objective of keeping inventory is to provide components and materials whenever demand arises (Williams & Tokar, 2008). Building a supply process and managing inventory therefore heavily depend on the demand process (ibid.). The process concerning demand is based on the assumptions that the demand rate is both known and constant, or that the demand rate is unknown and not constant (ibid.). Whereas the demand for spare parts are intermittent, as they occur infrequently and, at times, showing no demand at all (Turrini & Meissner, 2017). This makes the operational lifetimes exponentially distributed as events occur continuously and independent at a constant average rate (ibid.). From these assumptions, one has to set parameters concerning the optimum order quantity, order point and safety stock, which will determine the quantity kept in stock and its value (Braglia, Grassi & Montanari, 2004). When seeking to reduce the quantity of spare parts kept as inventory by setting low order points and safety stocks, one must ensure that the availability and accessibility of spare parts will not increase the downtime in case of failures. As each time unit of downtime is costly, unavailability must be avoided and thus, there is a challenging tradeoff between spare parts holding costs and the cost of unavailability. Even though the holding costs are high, organizations will suffer a greater financial loss due to the cost of downtime and therefore tend to keep a great number of components kept as inventory (Wong, Van Oudheusden & Cattrysse, 2007; Lin, Basten, Kranenburg & Van Houtum, 2017). Spare parts management heavily depends on the lifetime of the asset, which is affected by the environment surrounding it (Durán, Macchi & Roda, 2016). The failure rate and maintenance policies will influence the consumption rate of spares, in which management seek to establish inventory policies (ibid.). The failure rate of an asset is traditionally seen through the theory of the bathtub curve, whereas failures are decreasing, constant or increasing (ibid.). To deal with failing components, organizations repair, replace and maintain the components. System maintainability is the ability of a system to be maintained to prevent failures from occurring, and also to restore the system to a desired state when failures occur (Yasseri & Bahai, 2018). As maintenance also adds to the downtime of a system, organizations need to reduce maintenance activities and the overall downtime as it enables higher availability of the system, and an available system enables profitability (Loria, 2013). Due to the cost of downtime, organizations tend to have large quantities of spare parts to serve maintenance when failures occur, leading to high inventory holding cost (Gu, Zhang & Li, 2015).
The total cost of ownership can be one critical issue that organizations face when they make decisions regarding purchasing (Christopher, 2011). Aside from the visible acquisition cost, other costs such as, management-, operating-, maintenance-, inventory holding-, technical support-, obsolescence-, training- and disposal cost will incur (ibid.). The decision-making process must take these costs into consideration as they affect maintenance planning, operations strategies, spare parts/logistics support design, replacements and repairs (Durán et al., 2016). The total cost of ownership depends on many variables and it affects the overall financial performance of organizations as well as it causes optimization problems.

In order to reduce the number of components in stock and the total cost, organizations should aim towards higher system availability. Whereas availability of a system A(s) according to Hassine, Hamou-Lhadj and Alawnew (2018) describes to which extent a system or a component is operational and performing its required function. Which implies that A(s) = 90% requires more maintenance and spare parts than A(s) > 90%. Given the assumption that maintenance operations are designed in such a way that it supports and enables higher availability than current system availability. The total cost should be reduced as the number of spares kept in stock are determined based on maintenance operations, allowing the organization to minimize the total cost.

\[
\text{Minimize Total Cost } C = f(X1, X2, X3 \ldots Xn) \text{ Subject to } A(t) \geq A0
\]

1.1 Purpose
The purpose of the study is to develop a model that will facilitate the choice of maintenance strategy within the Swedish pulp and paper industry. Without compromising system availability, the model aims to reduce inventory holding costs.

1.2 Research Question
- How can order points and batch sizes be determined?

1.3 Scope of the research
The study is delimited to the development of a model, in which spare parts management and inventory will be treated. The study involves one Swedish paper mill which illustrates the issues concerning the management of spare parts. Whether it is possible to validate and verify the model remains as this study only develops and explains a conceptual model.

1.4 Thesis Disposal
**Chapter 2:** Methodology – presents the approaches and the methods that have been used when conducting the study. Each moment is described both theoretical and practical whereas the chapter ends with a critical review of the chosen methods.

**Chapter 3:** Literature review – consists of literature and theories that have been used during the study.

**Chapter 4:** Results – the empirical data that have been collected for the study is presented.

**Chapter 5:** Analysis – during this chapter the empirical data is analyzed in relation to the literature review and a model is proposed. The chapter will also answer the research question.

**Chapter 6:** Conclusion – the conclusion that have been reached through the study will be presented in this chapter. Both theoretical and practical contributions will be presented as well
as the purpose will be answered.

2. Methodology

*In this chapter, the research process will be presented, including a description of the methods used to answer the purpose and the research question. A theoretical background will be given to create understanding of the chosen methods, which is followed by practical description of the approach. The chapter ends with a critical review, where validity and reliability are discussed.*

2.1 Scientific Method

**Positivism**

Based on natural science, positivism seek to explain correlations between properties without the influence of human behavior (Biggam, 2015). The positivistic view states that reality is objective and that the research is independent of the observer, whereas the measured and predicted results are reliable (ibid.). Aligning with Biggam (2015), Olsson and Sörensen (2011) argue that the research must be objective as the results should be possible to repeat, regardless of who conducts the research. Positivism contains elements of the deductive approach as the purpose of theory is to generate and test hypothesis in order to allow explanations (Bryman, 2016). At the same time, the positivistic view contains elements of the inductive approach as the gathering of facts builds knowledge (ibid.). As the positivistic view concerns quantification and numbers along a measurable dimension Bryman and Bell (2015) argue that to enable a quantitative analysis the collected data need to be converted into variables.

**Phenomenological**

A phenomenological approach states that there are several equally valid views on interpretations of reality as interpretations of reality are affected by the surrounding context and time (Biggam, 2015). According to Remenyi, Williams, Money and Swartz (1998) the phenomenological approach aims to create an understanding of a phenomenon within a certain context, and thus create understanding for different interpretations. The phenomenological approach contains little or no quantification as the qualitative methods are more common (Bryman & Bell, 2015). According to Yin (2013) qualitative methods enable a deeper understanding of the phenomena being studied.

**Choice of scientific approach**

This study has a phenomenological approach as it aims to create an understanding of a certain business context. Data has been collected through interviews and by accessing documents from the organization. As the study includes employee’s interpretations of the organization, the study cannot be positivistic as it might become subjective as it includes human interpretations. However, the study will be positivistic when practitioners aim to apply the model. In such case, a system and its measurable data will be further analyzed in order to increase the overall system availability.
2.2 Case-study
Within scientific studies, a well-known research strategy is to use case studies (Ejvegård, 2003; Yin, 2003). According to Yin (2003), case studies offer the opportunity to create a holistic view of particular events. When conducting a case study, the researcher is surrounded by complexity as the researcher strives to conduct a detailed and intensive analysis of a case (Bryman & Bell, 2015). Case studies are often associated with a workplace or organization, and it mainly focuses on one specific entity, whereas the description should give a picture of reality (ibid.). According to Cohen, Manion and Morrison (2011) case studies allows the researcher to penetrate situations that require more than a numerical analysis. For instance, case studies holds the opportunity to blend quantitative- and qualitative methods for data collection (Cohen et al., 2011). The availability of data required to answer the research questions are crucial when choosing case company (Yin, 2014).

Case Company
The organization Stora Enso are currently active on four continents, Asia, Europe, North- and South America whereas they employ 26.000 people (Stora Enso, 2018a). The organization are globally providing packaging solutions, biomaterial, wooden constructions, paper and during 2017 their sales were up to 10 billion EUR (Stora Enso, 2018b). The unit in Skutskär are active within the division for Biomaterials as they manufacture short, long fiber and fluff pulp, and their capacity during 2017 was 540 000 tons (Stora Enso, 2018b). The capacity will increase during 2018 with another 160 000 tons as the demand for Fluff keep rising (Stora Enso, 2018c).

Selection of case company
The choice to carry out the study at Stora Enso Skutskär is based on the author having access to interviewing staff and documents through employment. The author has not been guided by the company and have thus independently chosen to carry out the study in the area since there is a gap within the research concerning the subject.

2.3 Scientific approach
Explanatory
Explanatory case studies seek to provide explanations to why something occurs (Biggam, 2015). According to Yin (2012) the method involves quantitative analyzes as the design intends to explain relationships between dependent and independent variables, whereas the independent variable explains the phenomenon being studied. The method is applicable when researchers need to conduct comparison between experimental- and control groups (Bryman & Bell, 2013).

Descriptive
The most common kind of case studies are descriptive as the researcher intend to describe a real phenomenon (Yin, 2012). The descriptive design can be conducted without specialist knowledge as it does not require a large amount of analytical activity (ibid.). Though Yin (2012) argue that the descriptive design only reproduce a phenomenon and that it does not prioritize between the presented problems. According to Bryman and Bell (2015) most descriptive research is qualitative as the researcher reproduces a specific phenomenon, though it is pointed out that the descriptive design produce too much details.

Exploratory
Within this form of case study, research questions and methodologies are formed after data collection and field work (Yin, 2012). By observing a social phenomenon the researcher is
allowed to find a theory. However, the study may depart from the form of case study when research questions and methodology can be set (ibid.).

Choice of scientific approach

The study is designed according to the exploratory approach as the author has compiled and proposed a model after studying a real problem. By studying how the organization manages its inventory levels, the author has been allowed to create a model for how these can be reduced.

2.4 Reasoning Approaches

Deduction

Deductive reasoning refers to test premises, the quest for truth by investigating the interaction between statements and the real world (Blumberg, Cooper & Schindler, 2011). Existing knowledge within certain areas of related theories give the researcher one or more statements (hypotheses) to undergo an empirical review (Bryman & Bell, 2013). Based on general principles, theory and assumptions of reality deduction intends to draw conclusions about individual phenomena (Olsson & Sørensen, 2011). If the statements are true and if it is impossible for the conclusion to be false, Blumberg et al (2011) states that the deduction is valid.

Induction

Inductive reasoning does not possess the same strength between reasons and conclusions as deductive reasoning (Blumberg et al. 2011). Conclusions are to be drawn from one or more pieces of evidence or facts, whereas the facts are explained by the conclusion and the conclusion finds support through the facts (ibid.). Discoveries in reality combined with general theories allows the researcher to form new theory (Olsson & Sørensen, 2011).

Abduction

Combining inductive and deductive reasoning allows the researcher to observe certain events and ask why they occur (induction). By forming a hypothesis and testing the event (deduction) the researcher can explain the why the event occurs (Blumberg et al. 2011). This combination is called abduction, whereas inductive reasoning observes events and deductive reasoning provides explanations (Patel & Davidson, 2011).

Choice of reasoning approach

The study involves inductive reasoning as the author studied the behavior of an organization. By combining several known theories, the author has created a model in which system availability can be evaluated in order to assign maintenance strategies and to reduce the inventory cost.

2.5 Data-collection method

Interviews

Interviews are one common method within social life as it comes in various forms, including research (Bryman & Bell, 2015). Interviews enables the researcher to gain access to information regarding behavior, attitudes, norms, beliefs and values, while at the same time, the method is applicable for collecting both qualitative- and quantitative data (ibid.). Qualitative methods enables the researcher to understand problems and issues when aiming to analyze different phenomenon and its characteristics (Jakobsson 2011).

Structured Interview
When the interview follows a certain schedule, whereas the purpose is to interview all respondents under the same conditions and with the same questions, the interview is structured (Bryman & Bell, 2015). The questions are specific and leaves little or no room for interpretation as the answers are fixed, thereby giving the interviewer the opportunity to aggregate the respondents answers (ibid.). The structured interviews are commonly used within social survey research as fixed answers and coding enables a quantifiable analysis (Cohen et al., 2011).

Semi-Structured Interview

When an interview follows a series of questions which can be seen as a schedule, though the interviewer have the opportunity to vary the sequence in which the questions are asked, the interview is semi-structured (Bryman & Bell, 2015). As the questions are open ended, the respondent has the ability to talk freely concerning the given topic (Cohen et al., 2011).

Choice of interview method

The interviews have been designed according to the semi-structured method, the questions are open ended giving respondent the opportunity to talk freely about the topic (see appendix 1). Open ended questions according to Jakobsson (2011) enables greater understanding of the phenomenon of interest. The interviews have been conducted at the respondents’ respective offices and they have had the possibility to reject the interview itself and questions. Interviewing employees at the organization has contributed with an understanding to how the organizations spare parts management works. To get an overall perspective of Stora Enso Skutskärs spare parts management, two employees have been interviewed, one inventory manager and one maintenance engineer.

Archival Records

Documents that contain the organizations employee payroll, old product or service descriptions are kept on paper and within the business enterprise system (Remenyi et al., 1998). How valuable such information is varies from case to case and in general this information is associated with quantitative data (ibid.). Documents can build a solid ground for the research as the evidence can steer the research and shed some light upon current organizational issues (Blumberg et al., 2011).

By accessing the material sheet, the study has been given the opportunity to present how the order point and batch size are determined by the organization and its maintenance engineers. The study also includes two different components with corresponding quantities in balance. This has helped the study effectively to illustrate how the organization is currently working with their spare parts.

2.6 Critical Review of Methodology

Validity

Validity concerns if the research actually measures what it aims to measure is validity according to Olsson and Sörensen (2011). Validity can also be called credibility as the researcher must find evidence to strengthen the drawn conclusions. By gathering information from multiple sources, the researcher can compare the answers and if the pattern is the same, the internal
validity will be strengthen (Yin, 2014). Validity originates from the natural science field, whereas methods and variables must be defined in order to maintain objectivity. According to Justesen and Mik-Meyer (2011) the researcher must not interfere or compromise the variables, research methods and the object being investigated.

Due to the fact that the proposed model has not been verified, the validity of the study is rather weak. However, the model consists of previously applied and approved methods, which should strengthen the validity of the study. The validity of the study is also strengthen by the fact that the interviewed respondents have reviewed and approved the transcribed material, as well as the draft in order to ensure that there is no bias in the information.

Reliability

In order to obtain a high degree of reliability or trustworthiness, the results must be replicable. Reliability requires that the same results can be achieved with the same methods, whereas the methodology needs to be described in detail (Olsson & Sörensen, 2011). Reliability should indicate a consistent approach, whereas the approach is independent of the researcher performing the research (Creswell, 2014).

To strengthen the reliability of the study the methodology is described in detail. To reduce the occurrence of faults or bias, the information obtained through interviews have been double-checked. Both the respondents and the author have checked the obtained information for accuracy. In appendix 1, the interview questions are found, which should enable other researcher to conduct the same case study. However, the reliability is lowered since other researchers might not have the opportunity to access the same organization or employees.

Ethics

Within research there are ethical issues to take into consideration, ethical issues relates to the integrity of research and its disciplines (Bryman, 2016). When conducting research, one must anticipate and eliminate potential consequences that might harm participants (ibid.). Avoiding to expose participants to harm can be enabled by confidentiality of the records, meaning that identities of participants are protected (Bryman, 2016). To conduct research involving several participants there must be consent, meaning that participants must be given the right information regarding the research in order to make a decision whether they are willing to partake or not (Bryman, 2016). Even though there might be consent, the researcher must reassure that involved parties are fully informed of the research objective (ibid.). Furthermore, the researcher must not invade on the privacy of the participants. The privacy is highly depending on informed consent and thus, the researcher must raise understanding concerning what the involvement of the participant will result in (Bryman, 2016). This means that researcher must give participants the opportunity to refuse answering certain questions (ibid.). Last but not least the researcher must not deceive the participants, the intention of the research must be presented and accurate (Bryman, 2016). By presenting the objective of the research and not as something else, the researcher can avoid deception and thereby trust can be built and maintained amongst researchers and society (ibid.). The research must also try to rule out interview bias, which according to Jakobsson (2011) is the interviewers’ effect on the respondents’ answers. The respondent can be affected by the attributes, as behavior, sex, education or attitude (Jakobsson, 2011).
To ensure that the participants are not exposed to harm, their names are confidential within this study. The participants have also been given the opportunity to approve the results regarding the organizations work methodology prior to the submission of the report. The participants have been informed about the research objective and have had the opportunity to refrain from participating. It should be pointed out that the author is currently employed by the case study company, which is an ethical issue. It has resulted in difficulties in being objective. However, the author does not have any leverage or higher status than the respondents. The employment also constitute trust as the author is known by the respondents, which means that the interviews have been relaxed.
3. Theoretical Framework

The theoretical framework consists of literature from academic journals in relevance to the subjects; spare parts management, maintenance and availability, whereas the theory has been chosen due to its previous proven applicability. The academic journals are found in the databases Emerald and Science Direct. Keywords to find the suitable journals are e.g. inventory management, spare parts management, maintenance strategies and system availability.

3.1 ABC-classification

Inventory classification is of great importance for organizations as the number of items kept as inventory makes it difficult to implement a control system for every item. Instead of trying to control every single item, organizations seek to classify them into different groups, whereas the groups are assigned different policies (Mohammaditabar, Ghodsypour & O’Brien, 2012; Mattsson, 2003). The policies should include ordering and control parameters aligning with the importance of the groups (Sarmah & Moharana, 2015). Class A are items of high importance while low in numbers, items classified as C are large in quantities but are less important than A, the B class is located in between (Mattsson, 2003). The ABC classification standard work accordingly to one criterion, namely the annual cost usage (Torabi, Hatefi & Saleck Pay, 2012). Since the classification is limited to annual cost usage many crucial factors such as lead time, criticality, inventory cost, obsolescence, commonality, reparable, durability and so on are not taken into account (Sarmah & Moharana, 2015).

3.2 VED analysis

Based on consultation with maintenance experts, the qualitative VED classification can be built, and it enables organizations to classify components as vital (V), essential (E) and desirable (D) (Roda, Macchi, Fumagalli & Viveros, 2014). Vital components are those who cause great losses and downtime when failures occur, essential parts are those who cause moderate downtime and loss and desirable parts are those who cause minor disruptions when failures occur (Botter & Fortuin, 2000). Since the criticality of the component is central to a VED classification, subjective judgements are required (ibid.).

3.3 Times-series forecasting

In order to predict demand, organizations can use the quantitative method of times-series forecasting (Olhager, 2013). Time-series forecasting enables organizations to estimate future needs, based on historical demand the organization can obtain an average demand rate, in which order point, safety stocks and batch size can be established (Olhager, 2013).

3.4 Availability

Availability refers to the degree to which a system or component is accessible and operational, when use is required (ITEM Software, 2007). By accessing the systems operating time and downtime it is possible to estimate the availability of the system. The availability, A(t) is the probability that a system or component is operating during the time t, given the assumption that it was operating at time zero (ibid.). By looking at the maintenance log for a given period of time, one can estimate mean time between repair (MTBR) and mean time to repair (MTTR), giving the function: A= MTBR/(MTBR+MTTR) (ibid.). Having low availability will most certainly generate great loss in revenue as well as it indicates that actions are required (IBM, 2008).
3.5 Order point
An order point system is described by Olhager (2013) as a common tool in material planning for components with independent needs. An order in the form of a purchase order is initiated when the stock level reaches the set order point. If an order is released, it should be included in the stock level. The sum of physical balance and outbound orders is called the stock position. This is necessary if the order quantity is less than the consumption during the lead time. The order point is determined based on the sum of security stocks and expected demand during lead time. (Olhager, 2013).

3.6 Safety Stock
According to Olhager (2013), uncertainty in forecasts contributes to the need for a safety stock. Demand is assumed at the planning stage to be deterministic even though demand is in fact stochastic. A safety stock is being held to reduce the emergence of crisis situations, if demand increases spontaneously. The main purpose with a safety stock is to cover random variation in demand during the lead time. (Olhager, 2013).

3.7 Batch size
Inventory management shall provide information on how large quantities are to be purchased each time a demand arises, as described by Olhager (2013). Determining the batch size is tedious as there is a balance between the orderly cost and the holding cost. A low batch size leads to lower holding costs, but higher order costs as orders occur more frequently. A large batch size leads to lower commission costs, but to higher holding costs since it will take time before using the components. (Olhager, 2013).

3.8 Fault tree analysis
When evaluating systems, it is important that all possible failure modes are mapped (Vishnu & Regikumar, 2016). The failure modes can be broken down by conducting a fault tree analysis (FTA) which according to Gharahasanlou, Mokhtarei, Khodayarei and Ataei (2014), is a systematic safety analysis tool that enables the organization to identify the root cause of failures. Based on the severity level, a top event is chosen and events that are related to the top event will be drawn below the top event forming a tree. At each branch the analysis will continue until basic explanations to the occurrence are reached (Gharahasanlou et al., 2014). When an event is broken down to the most basic explanation, a circle is drawn and if there are not a sufficient amount of data concerning the failure, a diamond will be drawn which represents the state of one undeveloped event (ibid.).

3.8 Failure modes and effects analysis
According to Paciarotti, Mazzuto and D’Ettorre (2014) failure modes and effects analysis (FMEA) is a bottom-up approach, and its main objective is to critically assess the severity level of failures in products, processes or systems. FMEA holds the opportunity to prioritize between different failure modes by assigning them a risk priority number (RPN) (Sharma & Sharma, 2010). Using this approach requires a collection of statistical data which relates to components failure frequency and its detectability (ibid.). RPN includes three different factors; occurrence, detection, and severity, which should be evaluated by using a ten-point numerical scale (1=Best and 10=Worst) by an expert and later on multiplied giving RPN= (Severity of failure) x (Likelihood to detect failure) x (Occurrence frequency) (Kyungmee & Ming, 2018; Ningcong, Hong-Zhong, Yanfeng, Liping and Tongdan, 2011). Before analyzing critical components, one has to set an RPN value and all components whose value exceeds the acceptable criteria will be
classified as critical components (Aouati, Chaib, Cozminca & Verzea, 2017). The occurrence factor represents the chance that a failure mode occurs sometime during a given time in the lifecycle of a system. This enables the organization to compare different failure modes and their occurrence value which makes it possible to reduce the risk by preventive controls (ibid.). The detection factor represents the chance that failures that occur are undetected by current detection controls. The severity factor represents the chance that failures that occur are undetected by current detection controls. The occurrence factor is established based on the consequence if failures do occur, and having established the severity value, the organization can compare all the severity values and find the most critical failure mode (Kyungmee & Ming, 2018).

3.9 Prognostics and health management
The length from the current time to the end of the useful life is one definition of Remaining Useful Life (RUL), meaning the expected time that an asset or component are to be usable to fulfil its function (Si, Wang, Hu & Zhou, 2011). Estimating RUL is crucial in condition based maintenance and prognostics and health management, while components are in use organizations need to assess RUL as it affects maintenance, inventory, operational performance and the overall profitability (Jardine, Lin & Banjeric, 2006). When aiming to estimate RUL, there are generally two types of data, namely event data and condition monitoring data. Event data refers to previous failure data, whereas the information from the component undergoing investigation needs to be stored and acquired for statistical estimations (Si et al., 2011). Condition monitoring data such as environmental information and degradation are acquired in cases when components are not allowed to fail (ibid.).

3.10 Maintenance
Operations within maintenance are divided into three different groups: corrective maintenance, preventive maintenance and improvement maintenance. The overall aim is to carry out certain actions during the lifetime of a component in order to maintain or restore the component to the desired state whereas it can perform the required function (Komonen, 2002). By combining and applying the different maintenance strategies the organization can obtain the advantages of all the strategies, namely to maximize equipment reliability and minimize lifecycle costs (Vishnu & Regikumar, 2016).

Corrective maintenance
Corrective- or failure based maintenance (CM) is performed when unforeseen or unplanned failure occur, whereas the component does not fulfill its purpose (Poppe, Basten, Boute and Lambrecht, 2017; Chena, Cowlinga, Polacka, Remdea and Mourdjis, 2017). The main advantage of this maintenance policy is that the components are fully used, meaning that there is no RUL of the component. Applying corrective maintenance enables the organization to use the minimal number of spare parts and maintenance actions to restore the process. Even though the minimum amount of parts and actions are taken within this strategy there are possible setbacks as well. When a failure occurs within a process, the resources needed to restore the process have not been scheduled and thus the cost for downtime is high. Working according to this strategy also makes it hard to predict the demand as the demand for components is determined by the current behavior of the asset (Poppe et al., 2017).
Periodic maintenance

Periodic maintenance (PM) is preventive as it aims to repair or replace components before they fail, and since it is impossible to exactly determine when components fail, the strategy is a combination of deterministic demand and random demand (Carnero and Gomez, 2017). When applying this strategy, the organization seek to plan and schedule all operations concerning maintenance in order to prevent failures. The maintenance can be based on a certain calendar time or after a given number of hours that a machine operates. In comparison to CM, the main advantage of PM is that it enables the organization to anticipate the resource planning whereas the overall cost is lower than in CM (Poppe et al., 2017). Previous analysis of the maintenance cost shows a great reduction in cost when performing PM, in comparison to CM. In fact, the cost for CM is on average three times higher (Mjirda, Benmansour, Allaoui & Goncalves, 2016). When working accordingly to the PM strategy, one should be aware that the components are not being fully utilized as they are functioning when they are replaced and therefore there is a tradeoff (Cipollini, Oneto, Coraddu, Murphy and Anguita, 2018). If organizations working with PM seek to increase the utilization of the components, they can extend the interval between the PM operations. Although, extending the interval between maintenance will most certainly result in more failures before the scheduled maintenance, leading to CM. Scheduled maintenance can be based previous experience or numerical estimations, which enables the organization to forecast the demand for some time in advance as the demand for a spare part is announced before the consumption (Poppe et al., 2017).

Risk-based maintenance

Risk-based maintenance (RBM) purpose is to reduce or eliminate the risk that may cause failures of operating facilities. The strategy consists of two phases; risk assessment and maintenance planning based on risk (Arunraj & Maiti, 2007). RBM seeks to prioritize between risks that are caused due to component failure, which means that components with greater risk are maintained more frequent. As maintenance operations will be carried out based on risk assessment, the risk assessment is crucial (ibid.).

Condition-based maintenance

Condition-based maintenance (CBM) includes the level of degradation of components, the condition is measured and when the level of degradation reaches a certain level the component is replaced (Poppe et al., 2017). Within CBM, organizations work with components critical degradation levels at which the component fails. The aim is to detect an abnormal situation by a set of sensors that register given parameters in an operational machine, such as temperature and vibrations (Carnero & Gomez, 2017). The degradation levels operates with a threshold value and it should indicate when an organization need to take action before a failure occur. If a component fails before the scheduled CBM, CM is performed. Bear in mind, working with CBM requires the organization to establish degradation thresholds which often are set close to the actual failure level of components, making the strategy similar to CM (Poppe et al., 2017).

3.11 Long-term storage degradation

Storage reliability refers to components kept as inventory and in case of failure, the organization need to assume that the component stored for a certain period is fully functional, given the assumption that the component had a reliability of 100% when put into storage (Zhang, Zhao, Zhang, Wang & Zhang, 2017; Zhang, Sun & Zhao, 2017; Zhao & Fu, 2015). According to Zhao
and Fu (2015), statistical data indicates that components kept in stock for 10 years have a higher failure rate than components kept in stock for 5 years. In other words, long term storage affects the operational reliability due to degradation, aging, corrosion or thermal fatigue (Zhang et al., 2017; Cheng & Elsayed, 2018).

3.12 Just in time
By short lead times where materials have a short turnover rate, Just in time (JIT) effectively reduces the costs as the material is purchased, delivered and consumed upon the actual demand. Whereas the main purpose of JIT is to reduce the cost of keeping inventory (Oskarsson, Aronsson & Ekdahl, 2013). JIT requires transparency and a fully operational planning process as the material is to be delivered at the exact time, it is suitable when there is variation in demand (ibid.). To apply JIT, the conditions regarding short setup times, small batch sizes and short lead times are required (Olhager, 2013).

3.13 Conceptual model
The model proposed in this thesis concerns spare parts inventory management, whereas the model has been evolved throughout the literature review. The model is built based on the concept of prioritizing spare parts corresponding to their annual cost usage and criticality. What can be found in the literature are the different maintenance strategies, risk assessment- and classification methods used to enhance system availability. However, maintenance and inventory management have previously been treated separately. To the best of the authors’ knowledge there is no conceptual model that seeks to combine the different maintenance strategies and inventory management to reduce the spare parts inventory holding cost. Therefore, the proposed model aims to connect the maintenance- and inventory department to establish lower order points and batch sizes, allowing the inventory holding cost to be reduced.
4. Stora Enso

This chapter is based on interviews and archival records that have been conducted at Stora Enso Skutskär. The results are based on the conducted case study.

4.1 Stora Enso the organization
Since the merger between the Finnish organization Enso Oyj and the Swedish organization Stora Kopparbergs Bergslags Aktiebolag, Stora Enso have been active since 1998 (Stora Enso, 2018a). The organization is active worldwide and employs people through North- and south America, Asia and Europe, whereas most of the manufacturing and sales occur in Europe. Stora Enso employs 26,000 people in over 30 countries with the ambition to be a leading provider of renewable solutions in paper, packaging, biomaterials, and wooden constructions (ibid.). During 2017 Stora Enso earned 1 billion EUR before interest and taxes, which compared to the operational results during 2016 is a 2,5 percent increase (ibid.). Stora Enso have great manufacturing capabilities, whereas their annual capacity accounts for 5.9 million tonnes of chemical pulp, 5.4 million tonnes of paper, 4.7 million tonnes of board, 1.4 billion square metres of corrugated packaging and 5.6 million cubic metres of sawn wood products (ibid.).

4.2 Stora Enso Skutskär
The construction of the plant in Skutskär began in 1893 and two years later in 1895 the production started, the plant belongs to the biomaterial division as it manufactures short, long fiber and fluff pulp (Stora Enso, 2018b). The plant manufactures three different types of products, Stora Enso Supreme, Select and Care, whereas the overall production capacity is 540,000 tonnes a year (ibid.). The Supreme and Select fabrics are produced and sold for further processing, whereas it is used to manufacture, print and writing paper, graphic paper, packaging solutions and cardboard. The latter product Care, is used to manufacture absorbent hygiene products (ibid.). Due to a growing population around the world, Stora Enso are experiencing increasing demand for fluff pulp (Care) (Stora Enso, 2018c). As the demand for fluff pulp keeps increasing, Stora Enso Skutskär seek to expand their production capabilities to increase their revenue (Stora Enso, 2018b).

4.3 Inventory Management
The inventory units’ primary purpose is to provide components for a variety of processes and operations when needed, hence the number of stored components and inventory management has remained unchanged. Due to the great number of components kept as inventory, the cost is high and it affects the financial performance of the organization. The financial performance suffers due to inventory holding costs, obsolescence (outdated and or no further usage), and administration costs that occur due to stocktaking and costs for maintaining all components kept in stock. Delivery precision and availability are considered to be of high value, however, it has contributed to high capital tied up. Furthermore, the components kept in stock contributes to lack of storage space. In order to maintain high operational reliability, spare parts and components need to be available to maintenance personnel to avoid unnecessary delays and costs. Due to this Stora Enso Skutskär are currently holding 15 317 different kinds of components accessible at their inventory unit. However, it should be pointed out that some of the components have a quantity of zero and that they are linked to the fixed asset register, whereas they need to be ordered and purchased prior to the demand. The total quantity currently consists of 100 934 pieces of components, though the quantity varies due to current demand and usage.
4.2 Order point and safety stock

The material requirement planning (MRP) and inventory control process at Stora Enso Skutskär is software based and assessed using the enterprise resource system SAP. The intention of planning the requirement of material is to ensure accessibility concerning components and spare parts in case of failures within the plant. The plant needs to control the types and quantities of materials they purchase to meet the irregular demand for spare parts to assist their maintenance personnel, which in this case are referred to as customers. Planning the requirement for spare parts is complex as failures are irregular. However, it should assess a couple of questions if possible, what item is required, how many are required and when are they required. To cope with these kind of questions, Stora Enso Skutskärs maintenance engineers are responsible for the material planning, as they are the ones with technical knowledge. A material sheet (see image 1) is filled out by a maintenance engineer and handed in to the inventory unit as they are responsible that the component is placed in the business enterprise system. The demand, criticality, lead time from supplier and the number of parts lists for one component should be taken into account by maintenance engineers when determining the order point and safety stock. However, there are some issues concerning those factors as the inventory management is suffering due to high costs. It is pointed out that the maintenance engineers do not have too much logistical knowledge, also the material that is purchased will only affect the inventory units budget as each unit will carry the cost of material once they intend to obtain and use the material. Due to the fact that the stockholding does not affect the different departments’ budgets, there is convenience among staff to keep large quantities of different components to ensure their own needs in the future. A component will later on appear in the ERP system as seen in the material info sheet (see image 3 and 4). The material info sheet enables employees to see previous demand, order point, safety stock, quantity and at which position the component is used.

![Material sheet](Image 1: Material sheet)
**Material info sheet**

<table>
<thead>
<tr>
<th>Materialnummer:</th>
<th>375908</th>
</tr>
</thead>
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<tr>
<td>Materialbeteckning:</td>
<td>PNEUM.AI CYL 166-10-1000 166/100 SLAG=100</td>
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<td>TILLVERKARE: AVENTICS</td>
</tr>
<tr>
<td>Materialmärke:</td>
<td></td>
</tr>
<tr>
<td>Tillverkare:</td>
<td>AVENTICS (REXROTH)</td>
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</table>

<table>
<thead>
<tr>
<th>Materialtyp:</th>
<th>Z06 Underhåll, repar. o drift</th>
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<td>062801 PNEUMATISK CYLINDER</td>
</tr>
<tr>
<td>Inköpare:</td>
<td>211 Förståd Skutskår</td>
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<tr>
<td>Materialplanerare:</td>
<td>003 SCHYMBO</td>
</tr>
<tr>
<td>MRP-typ:</td>
<td>Z1 Man. best. punkt m. ext. behov</td>
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<tr>
<td>Partinform.nyckel:</td>
<td>FX Fast partistorleksberäkning</td>
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<tr>
<td>Fatt partistorlek:</td>
<td>2,000</td>
</tr>
<tr>
<td>Best. punkt:</td>
<td>2,000</td>
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<td>Säkerhetslager:</td>
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<tr>
<td>Basmängd enhet:</td>
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| Tillgängl.kvt.: | 4,000 |
| (lager förutom REPD/REPR) |

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| Förbrukning i år: | 0,000 |
| Förbrukning första året: | 0,000 |
| Förbrukning s-första året: | 0,000 |

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<td>------------</td>
</tr>
<tr>
<td>03.11.2016</td>
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<tr>
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<td>20.10.2016</td>
</tr>
<tr>
<td>20.10.2015</td>
</tr>
<tr>
<td>08.07.2015</td>
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</table>

Stora Enso ProductionMaterial info sheetDatum 24.04.2018HelsinkiSida 2

Standort / Systemposition / Utrustning

| SV-650G176 SV-028459 | Massabastyrning efter tork |
| SV-650.627 SV-024506 | Dragvals f.utskottsuppsåser=bock |
If the components are non-repairable, Stora Enso establishes order points and batch sizes as seen in image 2, to ensure that the spare parts are available in case of failure. The order point and batch size are determined based on how many systems the component is included in. As for the component seen in image 2, the order point and batch size corresponds to the number of systems the component is included in. In image 2, it can also be seen that the available quantity of the component is four. This is because the material at an earlier phase has been reserved, and due to the reservation, the inventory balance has fallen below the order point, which has created an order against the supplier. The reserved material has since been returned to the inventory unit when the need for the component has disappeared, so the inventory balance has doubled to the number of system positions in which the component is included, allowing the inventory
holding cost to increase. Repairable components differ from the non-repairable components as they are not given an order point or batch size, instead they have a safety stock as can be seen in image 3. When the repairable components are no longer profitable to repair, an order is placed at the supplier based on demand. However, in some cases Stora Enso will not store the component as seen in image 4. In such cases the component does not have order point, batch size or safety stock as it will be purchased upon demand, allowing the organization to reduce the inventory holding cost.

Image 4: Material info sheet
4.3 Maintenance

As the overall goal is to produce 1500 tons a day, manufacturing processes and its machines have a high utilization. Due to utilization there is wear and tear affecting machines and components. In order to facilitate the manufacturing processes, Stora Enso seek to prevent breakdowns and malfunctions by scheduled maintenance. Once a year, during a period of ten days, scheduled maintenance is performed on all production entities, whereas the manufacturing process stops completely. Asides from the annual maintenance shutdown during ten days, minor maintenance operations are conducted on individual production entities. During the scheduled maintenance, orders and reservations are critical as they indicate what operation is needed and who will perform the task. The order should also state at which date the operation is needed and by a reservation, components and spares will be allocated. The reservation of material also enable the inventory unit to purchase the right material at the right quantity and time without affecting the inventory holding cost. Stora Enso supplements all the scheduled maintenance operations with corrective maintenance, whereas components are either repaired or replaced in case of unforeseen breakdowns.

When maintenance operations are being planned, the maintenance engineers use the facility register to locate the system position in need of maintenance. Having found the system position with its underlying structure, as seen in the example (image 5), the maintenance engineers can obtain information regarding what kind of functions and components that are included in the specific system.

![Image 5: System position](image-url)
Having the system position overview as shown in image 5, employees gain access to previous and upcoming maintenance operations concerning the chosen system position.

Image 6: List of maintenance operations

In this case, a system position (fiber sedimentation) with its 16 underlying structures is shown. During a two year period, 33 maintenance operations have occurred in between 2016-05-28 to 2018-07-23, whereas three underlying structures have undergone maintenance.

<table>
<thead>
<tr>
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<th>Previous maintenance</th>
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<tbody>
<tr>
<td>SV-180.001</td>
<td>25</td>
</tr>
<tr>
<td>SV-180.106</td>
<td>6</td>
</tr>
<tr>
<td>SV-180.107</td>
<td>2</td>
</tr>
<tr>
<td>In Total</td>
<td>33</td>
</tr>
</tbody>
</table>
5. Analysis

This chapter will analyze the case company and its spare parts management. As the case company face problems due to their high inventory value and large quantities, a model is developed to address their spare parts management.

Looking at the case company's approach in establishing order points, batch sizes and safety stocks, it becomes clear that maintenance engineers set these with regard to the number of system positions in which the component is included. Looking at image 2, we see that the order point has been set to the value two, which also corresponds to the number system positions in which the component is located. Note that batch formulation is set to two, which means that each time the quantity in stock becomes two, an order is placed on two new components. This means that the organization after the current lead time has four of these components stocked. Looking at image 3, we see that the safety stock has been set to value one and this corresponds to the number of system positions on which the component is located. The safety stock is set to one to cope with the variance in demand during lead time, but this, as opposed to the first example, contributes to lower inventory levels and costs. Due to the batch formulation which is set to zero, the purchase quantity is determined when the order of the component is created and based on current demand. In order to determine how ordering points and safety stocks are established, one can clearly state that there is a routine, such as a maintenance engineer completing a form. However, there is no overall strategy for how the maintenance engineer will act upon completion of the form, hence the stock levels will be higher as the maintenance engineer wants to ensure the availability of the component when demand arises. This indicates that as long as the inventory unit is capable of delivering components upon demand, the result is satisfactory. However, this approach has contributed to high inventory levels and keeping inventory is expensive, whereupon a new routine for determining order points, safety stocks and batch size is needed.

5.1 Strategy proposal

Stora Enso currently have 15 317 different components stocked, which indicates that each individual component cannot be assigned control systems as it according to Mohammaditabar et al (2012) would be too expensive. Instead, the organization needs to classify the components by applying the ABC classification technique, whereas the three different groups can be assigned different policies (ibid.). However, the ABC classification is limited, according to Sarmah and Moharana (2015) it does not account for lead time, criticality, and inventory cost to mention a few. Sarmah and Moharana (2015) opinions about ABC classification is supported by Mattsson (2003) who also emphasizes its shortcomings. However, Mattsson (2003) argues that the principle of the classification is to separate the important components from the less important once, allowing the organization to channel the majority of resources to those more important components. In order to allow for effective implementation of the classification, Stora Enso should assemble a group of employees who can define the different criteria for each class. Once the criteria of the three classes has been established, inventory personnel can easily categorize all components. Which aligns with Mattsson (2003) who argues that there must be criteria assigned to each class, in order for the classification to be valuable. To complement the shortcomings of the ABC classification, a VED analysis can be conducted. In this way, annual cost usage is supplemented with a qualitative statement from a maintenance engineer concerning the components criticality (Roda et al., 2014). However, the VED analysis requires subjective judgements according to Botter and Fortuin (2000). This should not be of any
concern as maintenance engineers are considered to possess sufficient knowledge regarding components and their function.

If the acquisition cost is considered as low and or if the component is frequently used it should be classified as B or C. Regardless of the outcome of the VED analysis, the organization should purchase and store the components as the inventory holding cost will be low. In order to determine the order point, safety stock and batch size, the organization can conduct time-series forecasting. The forecasting method enables the organization to effectively obtain the mean demand per time period according to Olhager (2013), in which batch size, order point and safety stocks can be established. If the demand for a component is low and that there is uncertainty in the lead time, the organization should establish a safety stock and store component (Olhager, 2013). Given the assumption that the acquisition cost for the component is high, it should be classified as A, which according to Torabi et al., (2012) concerns items of great importance and lower quantities. However, components classified as A and whose failures only cause minor disruptions, can also be purchased and stored based on time-series forecasting. The classification enables the organization to, already in the enterprise resource planning (ERP) system to delimit its search against components classified according to A, B or C. This allows the organization to easily compile records of all A-components with associated system position and historical demand as shown in image 2,3 and 4.

Components that are considered vital or essential and which are classified as A should be further analyzed, as these components in case of failure invoke long and expensive downtime. Such components can be analyzed using the model (see appendix 2: example application of the model) to assess the availability of the system in which the component is included. Availability estimations allows the organization to prioritize between different systems and select systems with low availability, which according to IBM (2008), are those who bear the highest costs in terms of downtime and maintenance. Given the assumption that it is a system with unsatisfying availability, the next step is to conduct a risk analysis. The risk analysis consists of a mixed approach, whereas the FTA will serve as a guide to the FMEA. Vishnu and Regikumar (2016) argues that employees with great insight into the chosen system position must be willing to participate when conducting a risk analysis as they have the knowledge and capabilities to map all potential failure modes and what causes them. In real life, this will most certainly be an issue as this requires several employees, and the time needed interferes with their everyday tasks at work. Given the assumption that the organization are willing to provide the required resources and that the employees are willing to partake, an FTA will be conducted. Furthermore, the FTA will be time-consuming and difficult according to Sharma and Sharma (2010) who argue that complex systems makes it difficult to obtain minimal cut sets. In order to simplify the implementation of FTA in this model, the analysis will only consist of a qualitative statement, which will help to illustrate different failure modes and what triggers them. To complement the results from the FTA an FMEA will be carried out. In general, the FMEA starts with defining failure modes (Kyungmee & Ming, 2018). In the proposed model the FMEA will assess the failures defined through the FTA. The reason for FMEA to only examine failures found in the FTA depends on the assumption that it will be more cost effective and time-compressed. As one can assume that more failure modes would occur if one intends to use both methods separately as they start from different ends, which ultimately changes direction away from the most critical parts. To make the model easier and more applicable the RPN scale in the proposed model will be non-linear in the range (1, 3, and 9), the values are defined as 1= low, 3=medium and 9=high. Using this range will according to Paciarotti et al. (2014) make the decision process
more user-friendly at the same time as it accounts for the widespread of opinions between team members. By modifying the range enables leaner and faster use of the tool with powerful outcomes, whereas it will not be as time consuming as the ten-point numerical scale (Paciarotti et al., 2014). To fit the scale, detectability will be read as non-detectability. Once the chosen system has been critically assessed and evaluated, the organization should apply a combination of the maintenance strategies as this according to Vishnu and Regikumar (2016) will maximize equipment reliability and minimize lifecycle costs.

5.2 Situational maintenance
Risk-based maintenance will be applied on the systems evaluated in the model. The model enables the organization to conduct maintenance work on components with a higher risk, which according to Arunraj and Maiti (2007) is the main purpose of risk-based maintenance as a component with higher risk should be maintained more frequent in order to reduce or eliminate the risk. As maintenance operations within risk-based maintenance is applied to prevent and reduce risks it is very similar to periodic maintenance, which according to Carnero and Gomez (2017) aims to repair or replace components before they fail. Risk-based maintenance and periodic maintenance should fit Stora Enso Skutskär well as they already work with scheduled maintenance, which means that the organization has experience and resources to expand the planned maintenance work. If the organization succeeds in expanding the planned maintenance, they also develop their resource planning as the demand is known (Poppe et al., 2017), meaning that the organization holds the opportunity to purchase and consume components without storing them. Asides from known demand, Mjirda et al. (2016) argues that the cost of periodic maintenance is three times lower than the cost of corrective maintenance. However, it should be pointed out that periodic maintenance does not fully utilize the components according to Cipollini et al. (2018) who argues that the components are still functioning when being replaced.

Since it is impossible to determine exactly when components will fail (Carnero & Gomes, 2017) argue that risk-based maintenance and periodic maintenance needs to be supplemented by corrective maintenance. As unforeseen failures and corrective maintenance contributes to variation, Stora Enso Skutskär need to have safety stocks which according to Oyhager (2013) will cover random variation in demand and reduce the emergence of crisis situations. However, if the preventive maintenance is successful, corrective maintenance should only be applied to components that are not considered to be of major importance to system function and performance. Using corrective maintenance on the components whose failures are easy to detect enables the organization to use the minimal number of spare parts and maintenance to restore the process according to Chena et al. (2017). Reasonably, corrective maintenance should be conducted on those components that have low inventory holding costs. This strategy enables Stora Enso to fully utilize the use of the components as they according to Poppe et al. (2017) and Chena et al. (2017) are replaced upon failure, meaning that there is no remaining life of the component.

Components that have a high acquisition cost, inventory holding cost and whose function is a critical part of a system may be a case for condition based maintenance. Working with condition based maintenance requires that the organization assesses the components remaining useful life as it affects maintenance, operational performance and profitability according to Jardine et al. (2006). Accessing previous failure data and condition data enables the organization to estimate the expected time that an asset or component can fulfill its purpose (Si et al., 2011). If done properly, the organization can set and monitor degradation thresholds at which the component
is replaced (Carnero & Gomes, 2017). However, Poppe et al. (2017) argues that organizations tend to set the degradation threshold close to the actual failure level of components, which results in the component being broken before the scheduled maintenance, and thus the strategy becomes very similar to corrective maintenance.

5.3 Reduced inventory holding cost

By evaluating different systems and its components, Stora Enso will be able to add resources to reduce as well as eliminate the emergence of failures by working accordingly to the risk-based maintenance strategy. If the probability of failures is reduced or eliminated, even the likelihood of downtime should be reduced and system availability should therefore increase according to Arunraj and Maiti, (2007). Increasing system availability indicates that the need for spare parts decrease, whereas order points and batch size can be reduced. Based on scheduled maintenance operations, the organization can anticipate its resource planning according to Poppe et al, (2017). Meaning that the organization can purchase and consume spare parts upon demand, which is the scheduled maintenance, and thus reducing the inventory holding cost. As Scheduled maintenance intends to replace components at a certain time, regardless of its current condition, the inventory unit will no longer experience the problems that arise when maintenance personnel returns components. If components are extracted from the inventory and the quantity falls below the order point, an order for new components is placed. If maintenance personnel return previously required components, the inventory balance is higher than necessary, leading to higher inventory holding costs.

Working with risk-based maintenance and periodic maintenance enables Stora Enso to apply the just-in-time principle in their spare parts management. However, just-in-time requires short lead times and a transparent flow of information according to Oskarsson, Aronsson and Ekdahl, (2013) and Olhager, (2013). The just-in-time principle is likely to apply only to those components whose function is not a critical part of a system. Purchasing spare parts based on demand will also reduce the risk of obsolescence, due to the fact that long term storage reduces the operational reliability by, degradation, aging, corrosion or thermal fatigue (Zhang, Zhao, Wang & Zhang, 2017; Zhang, Sun & Zhao, 2017; Zhao & Fu, 2015; Cheng & Elsayed, 2018).

5.4 Applicability of the model at Stora Enso Skutskär

Stora Enso has achieved very good results in 2016-2017 and thus has a strong economy, while at the same time the market opportunities are growing (Stora Enso, 2018c). In order to meet market demand, Stora Enso are expanding their manufacturing capabilities. Since the profit margins are better than ever, Stora Enso should seek to improve and expand their planned maintenance operations, in order to reduce the occurrence of corrective maintenance. However, one can assume that applying the model presented in this dissertation will be resource-intensive. The model requires that staff with great knowledge regarding the selected system position and its previous maintenance are involved. The staff involved in working with the model must be willing to put in a lot of working hours due to the amount of data needed to evaluate the system. In order to make the staff susceptible to the model and its work, top management must be the party communicating that they wish to develop the maintenance. Provided management and staff take on the model, it can be applied to a system, reasonably a smaller system will be chosen. A smaller system with a low number of components included will most certainly be
suitable when evaluating the model. Once the model has been applied, changes might be required.

6. Conclusion

This chapter will present the main conclusions of the research. Theoretical and practical contributions will be described, and the purpose of the study will be answered. Finally, the chapter ends with a proposal for further research.

The purpose of the study is to develop a model that will facilitate the choice of maintenance strategy in order to reduce inventory costs.

In this thesis, a model (Image 1) has been developed based on literature related to system availability, maintenance and inventory management. The outcome of the analysis is a model in which the inventory levels are to be reduced. By ABC-classification and VED analysis it becomes possible to evaluate the most expensive and critical components. The order point and batch size for components classified as B or C should be determined by time-series forecasting, regardless of the outcome in the VED analysis. Systems that include vital or essential and expensive A-classed components should undergo risk analysis. Depending on the results from the risk analysis, the different maintenance strategies should be applied to improve system availability. Vital or essential, A-classified components should be assigned scheduled maintenance, in which order point and batch size will be determined based on maintenance demand. As the maintenance should seek to increase system availability, the total cost should be reduced.

\[
\text{Minimize Total Cost } C = f(X_1, X_2, X_3 \ldots X_n) \text{ Subject to } A(t) \geq A_0
\]

The model has not been validated or verified, it has only been exemplified. Whether the model is applicable and contributes to lower costs is currently not possible to determine.

Theoretical contributions

This thesis contributes to a methodology development regarding spare parts management. It aims to add knowledge to the existing gap regarding spare parts order point and batch size. The thesis provides a procedure in which systems including critical and expensive components are evaluated in order to assign them the appropriate maintenance.

Practical relevance

The model has only been exemplified by using a system position from Stora Enso Skutskär, the numerical values are examples. The model must be tested with real values and the risk analysis must be carried out with a group of employees with great insight regarding the selected component and system position.

Future research

There is a scope for future research as the model remains to be tested on several systems in order to verify it. This can be done by gaining access to maintenance records, equipment availability and human resources from maintenance. The model needs to be further developed whereas the identified gap concerning spare parts management and total cost needs additional research.
References


[http://www.lagerstyrningsakademin.se/Artiklar/LSD17.pdf](http://www.lagerstyrningsakademin.se/Artiklar/LSD17.pdf)


Appendix

Appendix 1: Interview questions
Intervjufrågor till lagerchef på Stora Enso Skutskär

Hur ser nuvarande lagerstyrning ut?
- Hur är nuvarande lagerstyrning tillfredställande?
- Finns det förbättringsområden inom i nuvarande lagerstyrning?
- Hur stort antal komponenter klassade som reservdelar finns för närvarande lagerförda?
- Hur stor är nuvarande lagervolym?
- Finns det brister i att ha den lagervolym ni har?

Intervjufrågor till underhållsingenjör på Stora Enso Skitskär

Hur ser nuvarande underhållsarbete ut?
- Vilka typer av underhåll genomförs?
- Vad krävs för att underhållsarbetet ska fungera?
- Är nuvarande lagerstyrning tillfredställande?
Appendix 2: Example application of the model

<table>
<thead>
<tr>
<th>Underlying structure</th>
<th>Previous/planned maintenance</th>
</tr>
</thead>
<tbody>
<tr>
<td>SV-180.001</td>
<td>25</td>
</tr>
<tr>
<td>SV-180.106</td>
<td>6</td>
</tr>
<tr>
<td>SV-180.107</td>
<td>2</td>
</tr>
<tr>
<td>In Total</td>
<td>33</td>
</tr>
</tbody>
</table>

A total period of 17520 hours (2 years) has been taken for analysis

No. Of failures = 33
Total uptime = 16992
Total downtime = 528
Mean time to repair (MTTR) = 528/33 = 16
Mean time between repair (MTBR) = 16992/34 = 499,76
Availability = 499,76/(499,76+16) * 100 = 96,89

**Fault tree analysis**
Components and systems whose RPN value exceeds the previously stated criticality value will undergo RBM, whereas components are to be exchanged or assigned control parameters to be monitored. Based on the control parameters, a maintenance schedule will be proposed.

**Proposed maintenance schedule**

Assuming that the organization can establish control parameters that are monitored and followed up, MTTR should reasonably be shortened as the time for troubleshooting is eliminated. In order to easily show how availability is improved, the assumption is MTTR reduced to 8 hours. Maintenance will be performed quarterly to prevent the three events found in the FTA from occurring, meaning that scheduled maintenance will occur 12 times a year. During a two-year period, maintenance will be performed a total of 24 times.

17520 hours

Total uptime: 17520 – (8*24) = 17328

Total downtime: 24*8=192

MTTR: 192/24= 8

MTBR: 17328/25=693,12

Availability = 693,12/(693,12+8) *100= 98,85