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Spare Parts Classification – a Step for better Inventory Management

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ABSTRACT

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In this thesis spare parts classification models and their applicability to the case company providing after sales services in the marine industry are studied. The aim is to provide an outlook of what kind of classification models and criteria can be found in academic literature, and how these methods could be utilized in the case company. By classifying spare parts, a foundation for improved spare part recommendations can be made. Spare parts classification can also be seen as a first step for improving inventory management.

In the theory part, an outlook on the life cycle management, different classification criteria and the most common spare part classification models is carried out mainly from the after sales environment point of view. The empirical part of the study is carried out as a case study which utilizes a qualitative research approach. The empirical part also studies spare part sales within the case company and therefore it can be seen that the study also utilizes quantitative research methods at some extent.

A spare part classification model was created in the empirical part of the study. The applied model classifies spare parts based on their criticality on both machine and system levels. With the help of classification model, more detailed spare part recommendation lists can be provided for customers. The model can also be utilized when developing a centralized inventory for spare parts.

TIIVISTELMÄ

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Tässä diplomityössä tutkitaan varaosien luokittelua ja niiden soveltuvuutta laivateollisuudessa toimivalle huoltoratkaisuja tarjoavalle yritykselle. Tavoitteena on selvittää minkälaisia luokittelukriteereitä ja -menetelmiä on olemassa ja miten niitä voitaisiin hyödyntää case-yrityksen kohdalla. Varaosien luokittelua kehittämällä pystytään luomaan puitteet yksityiskohtaisempien varaosasuositusten tekoon sekä myöhemmälle varaston kehittämiselle.

Tutkimuksen teoriaosuudessa luodaan katsaus yleisimpiin luokittelumenetelmiin, luokittelukriteereihin sekä elinkaarihallintaan varaosaympäristön näkökulmasta. Tutkimus toteutettiin pääosin kvalitatiivisena case-tutkimuksena, vaikkakin työstä löytyy myös kvantitatiivinen tutkimusote varaosien myyntiä analysoitaessa.

Empiriaosuudessa luotiin varaosien luokittelumalli, joka huomioi varaosien kriittisyyden laite- ja systeemitasolla. Luodun mallin perusteella case-yritys pystyy luomaan yksityiskohtaisempia varaosalistoja asiakkaille. Varaosien luokittelumallia voidaan myös hyödyntää varaosavaraston kehittämisessä.

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1 Introduction

1.1 Background

Global competition and slowing economic growth have driven companies to find new sources to satisfying growing customer needs. In the industrial environment, the need for services may arise from the installation phase to a sudden system failure during the operation. Hence, many manufacturing companies are providing different after-market services such as installation, training, maintenance, repair services and spare parts (Goffin & Colin 2001, p. 275). Studies show that services and spare parts sales can be as much as 75% more profitable in some cases than the actual core business (Natarajan et al. 2012, p. 1).

The after-market business is essential for companies to achieve customer satisfaction and gain competitive advantage by providing services through the ownership period (Goffin & Colin 2001, p. 275). Services not only increase revenues but also create information on the product level by providing usage and performance data to support the after sales business (Ala-Risku 2009, p. 1). The potential of services and especially the spare parts business has been identified in the case company however, more advanced spare parts product support and long delivery times are having a negative impact on a customer satisfaction.

Improving spare part availability by classifying spare parts and the desire to meet growing customer needs was the main motivation for this thesis. Finding ways to identify and classify spare parts that should be stored either in local inventory or onboard were found necessary in order to improve the level of service. It has been found that customers are more interested in the availability and quick delivery times than price itself if there is an urgent need for spare parts. Short delivery times and good performance are also key factors when building stronger relationships with customers (Altay et al. 2011, p 7).

The spare part business environment differs in many ways from the normal consumable business. Demand patterns for spare parts are often sporadic meaning that the need for the spare part comes suddenly. This makes it difficult for the supplier to forecast the future demand and optimize inventory levels. Customers in industrial environment are not tolerant towards long lead times. From the supplier point of view holding too large inventories ties up money having a negative impact on a company’s financial performance. On the other hand, a lack of spare parts can mean down-time for operations and thus, loss of production. A lot of academic research can be found in the area of spare parts classification and spare parts controlling in both technical and economic ways but still there is a lack of common rules and understanding into how to manage these areas (Cavalieri et al. 2008, p 379-380). This sets the foundation for this study. The after sales department in the case company has neither an active spare parts inventory nor classification models for controlling spare parts.

1.2 Objectives

The objective of this study was to identify different ways spare parts can be classified in order to improve their availability by relying on existing literature and empirical findings. To answer to the main research problem, a few sub-questions need to be presented:

1. What kind of classification models can be found from academic literature?
2. What criteria should be taken into account when classifying spare parts?
3. How spare parts classification can improve availability?

This thesis focuses on mapping the best classification practices and applying a suitable model for the case company. As inventory management is a wide topic, this study will focus on developing a spare parts classification model, and any stocking strategies and other inventory management policies will not be developed in this study. However, the inventory policy subject will be examined slightly as it is linked strongly with spare parts classification. Setting up an inventory management policy would be the next step once there is a common understanding of how spare parts can be classified.

1.3 Research methods

Different research methods have evolved and researchers tend to prefer methods they have been using in their previous studies. Some researchers might favor experimental research approaches while others tend to use survey-type approaches. The research strategy like the research methods depend on the chosen research assignment or the problems of the study. For researchers it is important to choose research methods where the research problem can be pictured and analyzed in a detailed way, to provide the best possible outcome. (Hirsjärvi et al. 2008, p. 128)

The research strategy means the combination of the chosen research methods used to conduct the study. The research method can be separated from the research strategy and be seen as a smaller concept than the research strategy itself. This can be described by using a river crossing allegory presented by Robson in 1995. In this allegory, the river crossing is the main problem and can be seen as a basic principle for the study. Specific research problems are related to questions such as how many people want to cross the river, how often they want to do it and when they want to do it. The decision of how the river crossing is going to be done can be seen as the research strategy. Finally, once it has been decided whether the river will be crossed by using boat, plane or bridge, the research method which is related to the model of the bridge, plane or boat, can be chosen. (Hirsjärvi et al. 2008, p. 130)

Traditionally, research methods can be divided into quantitative and qualitative methods and further, into three different categories: experimental research, quantitative survey-research and case study. The two first mentioned methods have been popular in academic research while the latter has gained multiple different names as time has passed. In an experimental study, a sample from a larger group is picked, analyzed and influenced in systematic and controlled ways in order to find differences between variables. These differences will then be measured numerically and compared to the hypothesis. Survey studies are carried out by gathering information from groups of people in a harmonized way. Typically this is done by using questionnaires and structured interviews. The results and phenomena can then be explained by analyzing the gathered material (Hirsjärvi et al. 2008, p. 130). The case study is an empirical research method where a specific object is used as research material. The material can be based for example on company, customer, product, group or society. The focus in the case study can be directed into analyzing problems, processes or environmental factors. The case study utilizes different research methods and usually it is focused only on the available case material which can be related for example to pricing, inventory policies, net working capital or logistics aspects. The case study differs from the survey study in a way that the material is well defined unlike in survey studies.

This study is divided into two main parts, literature review and case-study. The literature part is written from the descriptive perspective and it focuses on presenting recent studies in the field of spare parts classification and inventory management. The main point of this part is to provide an overlook on the available spare parts classification models as well as presenting different classification criteria. Along with the classification models, basic principles of after-sales theory will be presented as well. The research literature used for review is gathered mainly from recent academic studies and publications, but some of the articles are older as the development of classification methods from the 1980s until today is also presented. The research strategy in this study can be seen as a case-study approach as it is focused on solving a case company’s problem related to the lack of spare parts classification models. The empirical part of this study has both qualitative and quantitative research methods as it includes both spare part sales analysis and semi-structured customer interviews. The figure 1 below shows the steps used in this study. Firstly, the research problem and research questions are defined. The theory will then be linked with the research problem and best practices will be adopted in order to apply the most suitable classification model for the case company's needs. Once the classification criteria and the classification model are chosen, the components can then be analyzed. Instead of performing simulation or other tests on the model, validation of the results will be carried out by presenting the classification model to the customer and gathering feedback from their side. Semi-structured interviews will be used when interviewing customers. Semi-structured interview can be positioned between structured interview and open interview. Typical features of semi-structured interviews are that the subject matter is known but the exact form and order of the questions are missing. Semi-structured interviews can be used for both qualitative and quantitative studies and it is seen as the most suitable approach for this study as the classification model needs to be presented and discussed before the presented questions can be answered. This is the reason why for example questionnaires would not provide as good feedback as semi-structured interviews (Hirsjärvi et al. 2008, p. 203).

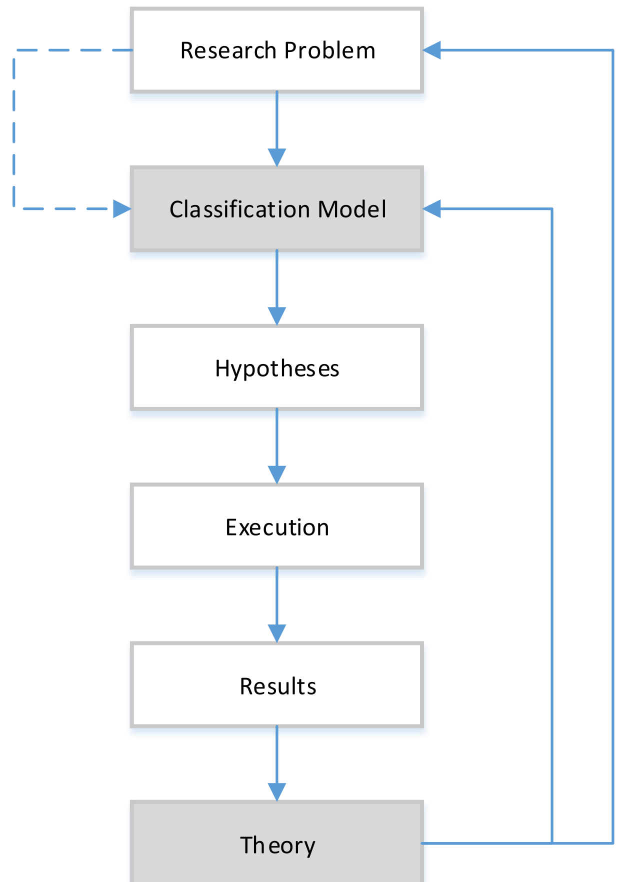


Figure 1. Linking research model and theory together (Hirsjärvi et al. 2008, p. 131), edited by K. Kansanoja

1.4 Structure of the study

This study is divided into eight main chapters. The first chapter is an introduction of the subject. In this chapter the background for the study is presented along with the research problem and research questions. Research methods will also be presented in this chapter.

Theory used in this study is presented in chapters two, three and four. These chapters provide an outlook on spare parts classification, spare parts demand, criticality and inventory management including life cycle management. Chapter two focuses on presenting the theory of spare parts analysis and it presents the most common and latest classification methods that can be found from academic literature. This chapter also covers the classification methods used in the past and also presents how the spare parts criticality definition has evolved over time. In addition to different criticality definitions, chapter two also presents different approaches to define the criticality of spare parts. In chapter three, industrial after sales services will be presented. A quick look will also be provided on the different maintenance types as these are seen to be one of the sources for spare parts demand and also a possibility for spare parts classification like Reliability-Centered Maintenance (RCM) as an example. The final theory chapter, chapter four, presents steps for the development of inventory management. This chapter is a short overview as the main focus in this study is still related primarily to spare parts classification. It is still seen important to illustrate in which phase the spare parts classification should be carried out and how it is linked together with inventory management.

Chapter five is the first chapter of the empirical part of this study. In this chapter the case company and department are presented. Based on interviews and email-interviews, the current status of the spare parts classification methods within the case company are presented. The theory presented in chapters two and three will work as a primary source for the developed classification model presented in chapter five. Both included and excluded criteria will be presented and discussed in a detailed way to provide answers as to why some criteria have been included and some not in the developed classification model. The sixth chapter presents the key findings which resulted from the spare parts classification model and also evaluates the results.

Second last chapter includes discussion and final conclusions. The purpose of this study, research questions and achieved results will be shortly discussed. Also evaluation of the results, references and research methods will be carried out in this chapter. Finally, the conclusions will be summarized and recommendations for the next steps will be given. In the last chapter, chapter eight, a short summary of the study will be drawn.

2 Spare Parts Analysis

2.1 Spare parts classification

The objective of this chapter is to provide a thorough understanding of the spare parts analysis and classification models. Spare parts are widely used within industrial environments for both maintenance and as normal consumables. Basic inventory management principles are difficult to apply as commonly, the rate of demand is sporadic and historic demand data can very be limited (Cavalieri 2008, p. 382). Spare parts can be divided into repairable- and non-repairable parts. Repairable spare parts can be further divided into three sub-categories: non-interchangeable, one-of-a-kind and rotatable parts. If non-interchangeable part fails and cause stoppages in the production line or in the system, a part from less critical equipment cannot be swapped as it does not share the same technical specifications. Therefore, special attention is needed when storing such parts in order to avoid any production losses. Non-repairable parts are also called disposables or consumables and usually thrown away when defective. Rotatable parts are interchangeable and can be swapped with similar product. Rotatable parts can be used in a way where one, for example circuit breaker, is taken into the service shop for refurbishment purposes and once it is ready, it can be brought back to the production line and the next circuit breaker can be taken for refurbishment. (Fortuin et al. 1999, p. 950)

Usually spare parts and parts meant for assembly are manufactured in the same factory. As the demand for spare parts is often lower, these are manufactured with lower priority if more capacity is needed for assembly parts. To cover this, companies may keep spare parts in the stock, but for many inventory managers it is difficult to estimate the correct stock levels. Where the forecasting techniques meant for components needed in production lines keep failing when analyzing spare parts demand, experience based estimations tend to end up with too high stock levels causing extra costs (Fortuin and Martin 1999, p. 953). Classification of spare parts would be one possibility to control high amounts of different spare parts with low and fluctuating rates of demand (Molenaers et al. 2011, p 570). Another aspect that is necessary to take into account is the product lifecycle. The lifecycle for production products is often shorter than for service products. Fortuin and Martin distinguish three lifecycle phases for service parts. (Fortuin and Martin 1999, p. 951)

1. *The initial phase:* the phase where the equipment and systems are just introduced to the markets. As the components used in the system are new, no historical demand data is available.
2. *The normal phase:* the phase where the equipment has reached the stable status and a little bit information of the demand and other technical issues are gathered.
3. *The final phase:* in the final phase the production has stopped but the services can be continued. During this phase maintenance responsible persons are usually placing final orders for spare parts.

As the spare parts business is seen to be beneficial for companies, it is important to classify and review spare parts for being able to manage inventory levels efficiently. A lot of academic studies can be found regarding different classification models in production environments but not as much in spare parts environments (Bacchetti et al. 2011, p 722). The following sub-chapters provide an outlook on the recent classification models suggested in academic literature mainly from the spare parts point of view. Classification models can be divided into quantitative (for example ABC and FSN), qualitative (for example VED) or their combination such as analytic hierarchy process (AHP) (Cavalieri et al. 2008, 383). Further, these models are based on either mathematical models or classification approaches. Mathematical models are built based on linear programming, dynamic programming or simulation and they are meant for optimizing inventory turnover in terms of order quantities and safety stocks. The downside of these models is either the complexity or intangibility for use in real life spare parts management. Classification approach based tools are widely used in companies operating in the industrial sector. Usually companies have built their classification based tools around the ABC-analysis model because of its ease of implementation and user friendliness. This approach enables companies to optimize their inventory levels to avoid over-sized stocks and respectively also stock-out situations. The downside of many classification models is that they do not take other features such as life cycle, number of suppliers, or commonality into account. (Braglia et al. 2004, p. 55-56)

2.1.1 ABC-analysis

The most common way to classify spare parts is the so called quantitative annual-dollar-usage ranking method (ABC-analysis). It was first invented by General Electric during the 1950s (Guvenir and Erel 1998, p. 29). The original ABC-analysis use only one criterion to separate parts from each other. In ABC-analysis, three groups can be created based either on annual dollar usage, annual demand, or unit price.

Parts which tie 10 % of the inventory but bring 70 % of the total revenue belong to group A. Parts which tie 20 % of the inventory but bring 20 % of the total revenue belong to group B. The weakest performing parts which form 70 % of the inventory but create only 10 % of the revenue belong to group C. The figure 2 and 3 below illustrate the grouping process based on ABC-analysis. (Chen et al. 2008, p. 35-36)

CLASS	% OF TOTAL ITEMS PURCHASED	% OF TOTAL PURCHASE ($)
A ITEMS	10	70
B ITEMS	20	20
C ITEMS	70	10

Figure 2. ABC analysis (Chen et al. 2008, p. 36)

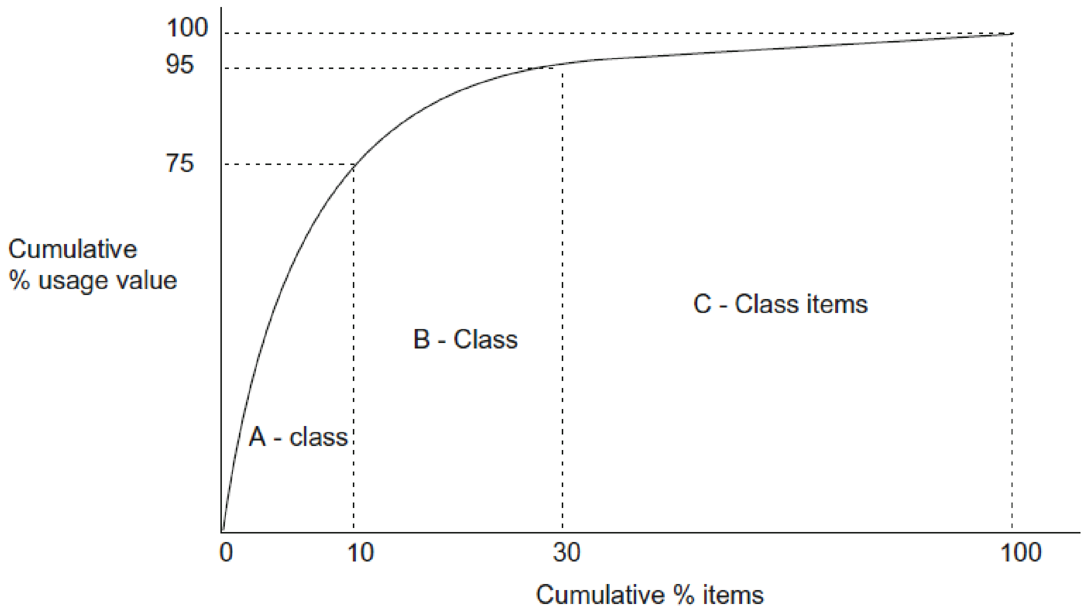


Figure 3. ABC-analysis presented in graphical form (Vrat, 2014, p. 41)

ABC-analysis can be applied to classify homogenous spare parts in large inventories. Spare parts can be grouped based on the parts usage value as shown in the figure 3 above. For example group B parts can be defined to be 20 % of the total demand. ABC-analysis is simple and straightforward and therefore has retained its popularity through the years. However, ABC-analysis can be problematic if the group of spare parts consists of items having different features such as life cycle phase, delivery time, or criticality. For example a company has recently introduced a new component to be used in a new device and it has not reached the stable life cycle status yet. ABC-analysis shows that it belongs to group B. However, it is still possible that the part will be changed and will not be a part of the final configuration in the designed product. This might cause miscalculations in the inventory levels and hence, too large inventories for the upcoming obsolete parts.

Other situation where ABC-analysis would need more classification criteria is related to delivery times. Company might have classified some parts to group C. Strict customs clearance processes in the manufacturing country however make the part critical as it is urgently needed for the production plant to be able to restore functionality. If the delivery time would have been one of the classification criterion, the part would have received more attention. (Flores et al. 1992, p 71)

As it was seen, classification models using only one criterion might not be the most suitable model for classifying heterogeneous spare parts and hence, does not provide accurate results in real life (Guvenir and Erel 1998, p 29). Thus, a multiple criteria ABC classification model is suggested by Flores and Whybark. In this model Flores and Whybark suggested to take one or more criterion into account such as substitutability, obsolescence, criticality, delivery time, commonality, and/or reparability. Although, it was mentioned that the number of classification criteria should not exceed three because otherwise the model becomes too difficult to handle in practice.

With multiple criteria ABC classification it is possible to create different kinds of categories for spare parts and further apply different rules to them. By looking at figure 4 below, different groups such as AB, AC, BA, BC, CA and CB can be created. A company may implement different types of classification models depending whether it is a case of sales, stocking, or service. Flores and Whybark reported that some companies have achieved savings and reductions in delivery times by implementing simple multiple criteria analysis models (Flores et al. 1992, p 74).

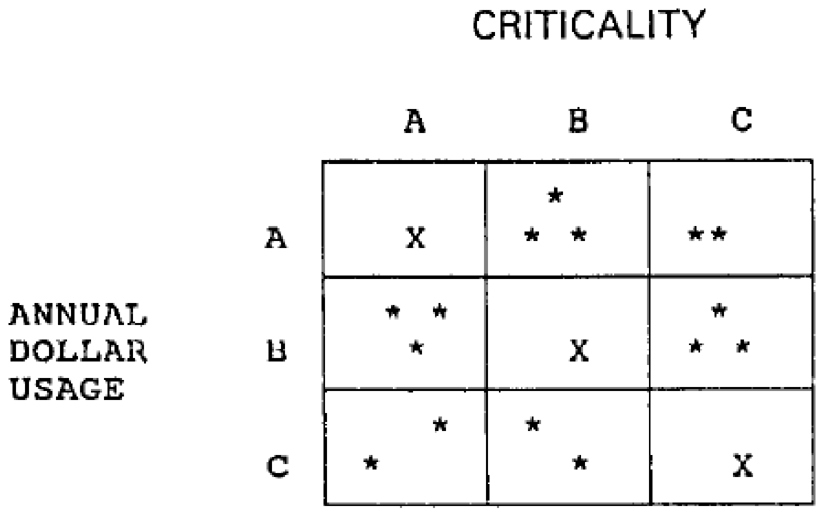


Figure 4. Multiple Criteria ABC Classification (Flores et al. 1992, p 73)

2.1.2 VED analysis

VED analysis has been a common tool for spare parts classification purposes. VED analysis divides spare parts into three different groups based on their criticality. The groups are called Vital, Essential and Desirable, hence the name, VED.

- Vital parts: severe losses and down-time can be expected due to non-availability of the spare part
- Essential parts: medium sized losses and reduced performance can be expected due to non-availability of the spare part
- Desirable parts: small losses, no effect on performance due to non-availability of the spare part (Botter et al. 2000, p. 662)

The VED-analysis model is easy to implement in reality as the classification is based on experts' opinions but it is seen to suffer from subjectivity to some extent (Bacchetti et al. 2012, p 723). Experts can be from various functions such as engineering, material managing, and quality control departments. Although evaluation is done by experienced workers, there might still be variation and different opinions over some spare parts' criticalities. Because of that, it has been suggested that more factors should be taken into account although, gathering such data might be problematic. Criteria such as quality problems, production losses, environmental and safety aspects are suggested to be considered in academic literature (Roda et al. 2012, p. 532).

Different conversions of the VED-analysis model are suggested due to the models' simplicity. Botter and Fortuin suggest a two-dimensional model where spare parts are classified with VED and FSN analysis models. FSN (Fast, Slow and Non-moving) - analysis divides spare parts into three categories based on their demand (Botter et al. 2000, 664). Bosnjakovic suggests a three-dimensional model where the used classification models are: ABC, VED and FSN. As there are multiple variations for criticality criterion, Bosnjakovic uses a decision tree with VED-approach to determine the criticality for each of the spare parts (Bosnjakovic 2010, p. 502). Figure 5 below illustrates the three dimensional VED-analysis approach where components have been grouped based on the equipment criticality, logistics characteristics and the probability of failure.

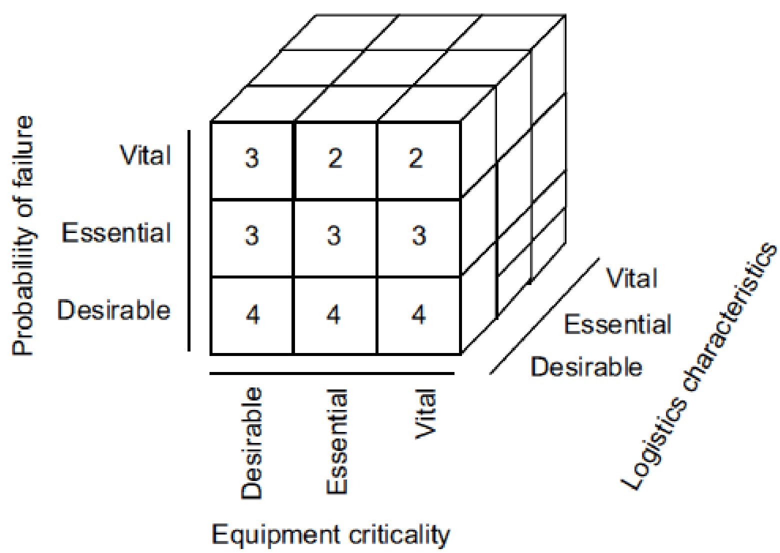


Figure 5. VED-analysis combined with other classification criteria (Molenaers et al. 2012, p. 575)

2.1.3 AHP-analysis

Analytical Hierarchy Process (AHP) is a systematic procedure used for spare parts classification that can utilize both qualitative and quantitative criteria for classification. AHP was developed by Thomas Saaty in the 1970s and it is used for supporting decision making in complex problems. The model is formed by composing different decision making methods together. Methods such as a pairwise comparison, hierarchical modelling and mathematical vectors can be utilized in the AHP-analysis (Marquez 2007, p. 116). Multi-attribute classification model was created to overcome the limitation problems faced with one- or two dimensional classification methods such ABC-analysis. Petrovic (1992) proposed a multi-attribute model where in total seven criteria were considered such as availability of the required system, essentiality, price, dimensions and weight of the part, market availability and reparability. The following year, Fuller et al. (1993) developed a classification model where six different criteria were adopted in the model (Braglia et al. 2004, p. 56).

Based on the previous research findings and developed multi-attribute classification models, Braglia et al., (2004) suggest a multi-attribute decision making (MADM) classification model based on two approaches: reliability centred maintenance (RCM) and AHP. RCM is a widely used practical method for defining a suitable maintenance strategy for different needs. RCM is a process where the most suitable maintenance plan can be developed in order to sustain the most effective operational capability. RCM utilizes failure mode, effect, and criticality analysis (FMECA) tool to identify critical components (Duffuaa & Raouf 2015, p. 245). Like in RCM in Braglia's model, the decision tree approach is used in finding the right alternative in every pairwise comparison node. This can be a difficult approach to implement as many criteria need to be considered and some of them can be intangible and hence ambiguous.

Braglia et al. (2004) use Multi attribute spare tree analysis (MASTA) to create four criticality groups for components in the first phase and in the latter phase, suitable inventory management policies (IMP) are created for each class. Figure 6 below illustrates the different created groups. In total, seventeen criteria were chosen in the model which is much more than has been seen in the previous studies.

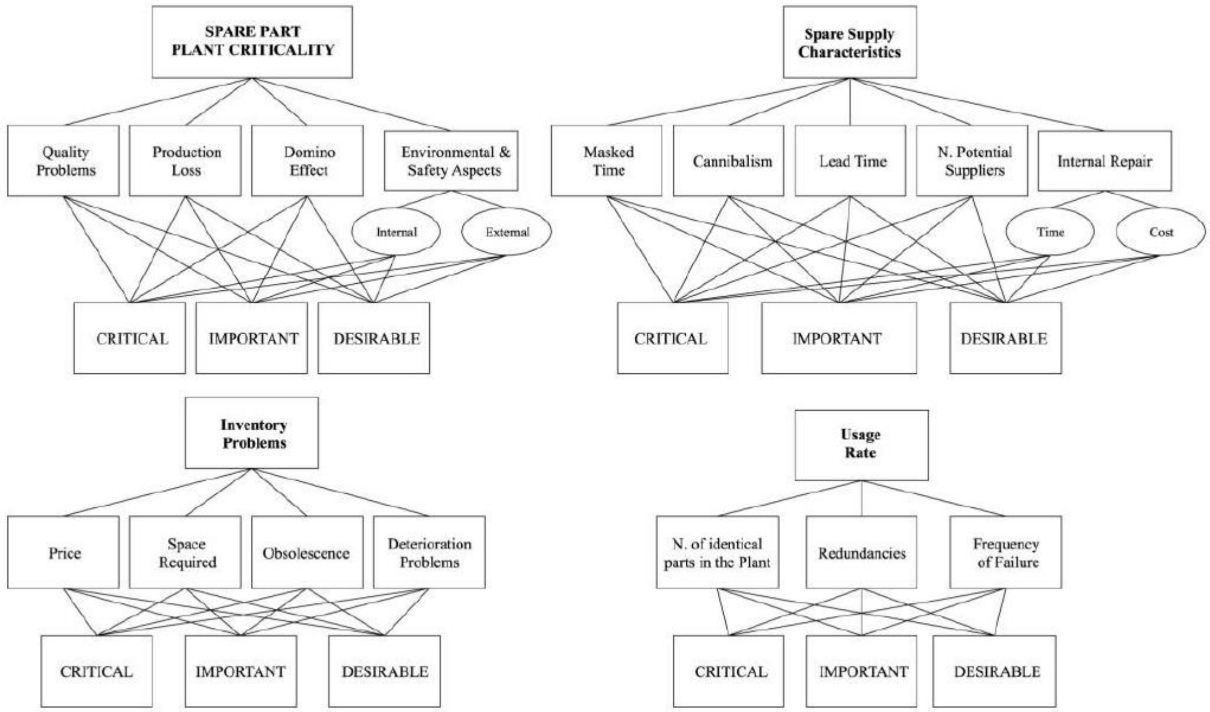


Figure 6. Four classification groups (Brablia et al. 2004, p. 60)

AHP process consists of four steps:

1. Defining the top level elements and suitable sub-elements for every level. The process begins by defining the objectives for the top level followed by intermediate levels which contain the classification criteria and finally the bottom-level, where the alternatives are listed.
2. Carrying out the pairwise comparison for every sub-element. In practice, the weights for the objectives, criteria and alternatives are decided. The results of the pairwise comparison are then converted into a score by using the discrete nine-point scale, where 1 is equal, 3 moderate, 5 strong, 7 very strong and 9 is extremely different.

3. Once the pairwise comparison is carried out and the matrix developed, the next step is to calculate the normalized eigenvector of the matrix.
4. The final step is to validate the priorities in order to create the overall ratings for the top-elements by using the inconsistency ratio. (Braglia et al. 2004, p. 63)

The goal of the process is to define and classify the top-layer element. The element might have several sub-elements that combined together form the overall result. Each sub-element has criticality alternatives which are presented on the lowest layer. Once the overall hierarchy structure is finished, the pairwise comparison can be carried out. Wong (2010) points out that the possibility to pairwise comparison is of a great importance compared to other classification models where the relative weighs are difficult to rationalize. Once the comparison is carried out, the priority weighs will be calculated by a mathematical formula. (Wong 2010, p. 56)

Braglia used a paper mill plant as a case example and the above presented classification groups in figure 6 were developed for that subject mill. Figure 7 below shows the decision tree used for the spare parts classification where the decisions in every node are done by using AHP-analysis. In this model, every alternative (Critical, desirable and not important) is given a range and based on that, the pairwise comparison can be done. For example delivery time can be critical if it is more than 4 months and important if it is between one to four months. (Braglia et al. 2004, p. 60)

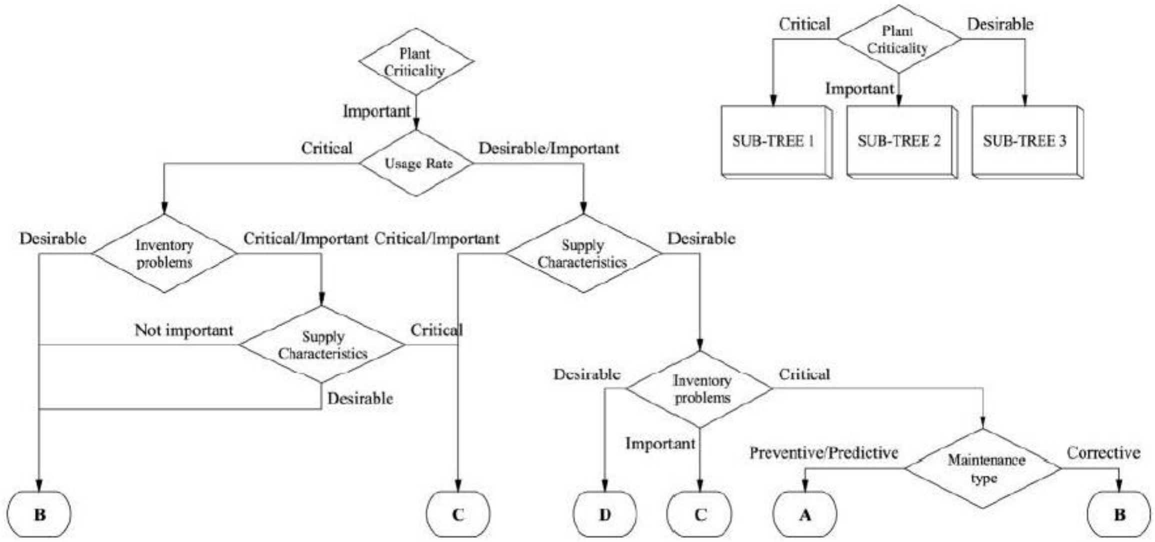


Figure 7. The decision making tree for grouping spare parts (Braglia et al. 2004, p. 59)

2.1.4 FSN-analysis

When categorizing spare parts based on their demand pattern or inventory consumption rate, it is called an FSN-analysis. In this model the parts are categorized into three different groups: fast-moving, slow-moving and non-moving parts (Stoll et al. 2015, p. 227).

- Fast-moving items (F) have high demand and consumption rate
- Slow-moving items (S) have slight demand and consumption rate
- Non-moving items (N) have no demand for over two years.

FSN analysis is suitable for spare parts classification as is also takes slow-moving parts into account (Vrat 2014, p. 37). Where most of the models such as the presented ABC-model focus on fast-moving items, FSN approach thinking can be applied to slow – and non-moving spare parts as well. Slow-moving parts typically have very sporadic demand pattern and therefore inventory control might become difficult in terms of keeping the wanted level of service and inventory turnover (Vrat 2014, p. 38). As the FSN-analysis takes only one criteria into account, Gelders and Van Looy suggest a model where in addition to the consumption, the functional role is also taken into account when developing guidelines for slow-moving parts (Molenaers et al. 2012, p. 571).

2.2 Spare parts demand

Spare parts demand patterns differ from normal consumer parts. It is common that a company has a small amount of items which demand can be predicted relatively well and large amount of items that have low and unpredictable demand patterns. This kind of situation makes it difficult to predict the needed amount of spare parts and possibly leads to large inventories causing unwanted costs. Together with multiple other classification criteria such as criticality, delivery time, and price, the formed matrix might become difficult to control which can for example end up causing the increase of safety stocks (Huiskonen 2001, p. 130). Hence, companies have put more effort on developing installed bases where customers' equipment and sites are listed. Up to date installed base allows service providers to trace possible leads and adapt inventory levels to match with the sales potential calculated from the installed base. Companies can adapt their inventory levels if sudden changes happen such as, the customer announces not to continue with a service contract anymore or some product family becomes obsolete. In practice, when a customer announces that it will shut down a production plant and increase capacity elsewhere, the service provider can anticipate that the demand for spare parts decreases in that area where the production decreases. Also when a vastly installed product family becomes obsolete, service providers may try to optimize inventory levels for the existing installed base to avoid holding too large inventories of parts that will eventually become obsolete. An aspect worth mentioning is the difference between suddenly increasing and decreasing demand. For the service provider operating without their own inventories it is easier to adapt to suddenly increased demand as it can order parts directly from the manufacturer. This might have negative impact to delivery times but when the demand suddenly drops and the service provider has large inventories, it is more difficult to adapt inventory levels as there are no markets anymore. (Pince & Dekker 2011, p. 83)

Fortuin and Martin summarizes the need for service parts as follows:

> *"Service parts are needed for maintenance of industrial systems as well as for consumer products."*

As the definition above indicates, service parts are needed for maintenance, either for planned or reactive type. Depending on the location, size of the production plant and the technical know-how, three types of different environments can be distinguished that need service parts:

1. *Technical systems under client control.* This environment consists of machines installed in a customer's production plant. Typically the customer has their own maintenance department performing maintenance and managing spare part inventories.
2. *Technical systems sold to customers.* Machines or systems that are installed at the customer's production plant or site for being able to provide more services. For example copy machines and coffee machines. Usually the company that sold the system is providing services and spare parts as well.
3. *End products being used by customers.* Normal consumer products such as computers, cars, and kitchen fittings. Once there is need for maintenance, the customer usually takes the broken machine to a third party service provider which can be for example a local repair shop. (Fortuin & Martin 1999, p. 953)

As mentioned above, many factors affect the demand of spare parts and hence, the demand is usually lumpy and sporadic and normal forecasting models usually fail to provide accurate forecasts (Botter et al. 2000, p 656). Usually the need for spare parts arises from system breakdowns or proactive maintenance. The consumption rate also depends on the reliability of the device and the size of the installed base, the more installed devices, and the more possibilities for equipment breakdowns (Macchi et al. 2011 p. 175). Due to these facts, service providers need to be prepared for two kinds of situations: predictable and non-predictable demand. Predictable demand arises from scheduled and proactive maintenance where parts demand can be somewhat foreseen and service providers can be prepared with safety stock whereas the latter, non-predictable demand arises from sudden reactive maintenance needs caused by a sudden component failure (Celebi et al. 2008, p. 1782). To overcome the above listed problems, Cavalieri presents two spare part demand forecasting models: reliability and time series based forecasting. Figure 8 below shows these different forecasting models.

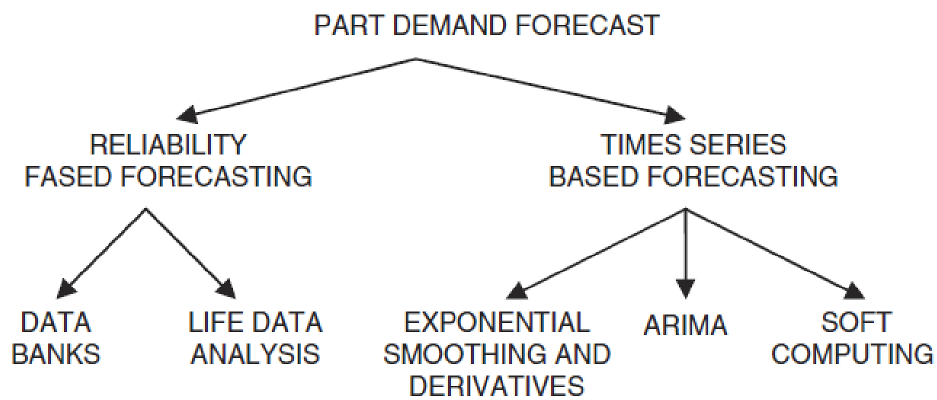


Figure 8. (Cavalieri et al. 2008, p. 385) A decision –making framework for managing maintenance spare parts

Reliability-Based Forecasting (RBF) is based on the size of the installed base. The main object is to predict how many spare parts the installed base might require during its lifetime. Component frequency failures can be estimated from databases with the help of service experts. Parts reliability can be assessed based on their age, duty and purpose of use. Petrovic and Petrovic developed a tool for calculating predicted failure rates for spare parts. The equation requires the data of parts failure rates (λ_j),

$$\lambda_j^{predicted} = m * e * n_j * \lambda_j \qquad (1)$$

Where the “m” is size of the installed base, "n_j" is the number of identical parts of type “j” installed in each system and “e” is the density of operating conditions. The equation has two downsides:

1. Possible lack of reliable data in the database in terms of failure rates
2. Quick product lifecycles and the complexity of electronic devices

For the first system introduced, *Technical systems under client control,* the demand arises from needed maintenance. Studies have shown how reliability analysis can be utilized in spare parts demand forecasting. Parameters for critical components such as Mean Time to Failure (MTTF) can be used when calculating demand for the chosen period of time. For the reliability analysis forecasting methods, the demand is always based on the assumption that the part is replaced only just when it fails. The maintenance intensity can vary depending on the customer preferences and possibilities to perform maintenance. It is possible that the site is not accessible all the time and therefore, the machines need to be maintained whenever possible. As an example remote production plants where access is limited due to weather conditions or vessels that are operating in remote locations. For this matter, EUT Maintenance Model was introduced by Geraerds in 1995 where the demand for spare parts is derived from two factors:

- the chosen maintenance type
- the scale of operation

In this model, preventive maintenance intervals are planned beforehand and the maintenance programs include tasks that need to be done and hence, some predictions of the spare parts demand can be drawn. However, it is still noted that long term planning is difficult and statistical data is needed for demand simulation purposes. Despite the long term forecasting difficulties, this approach can be used to determine which installed parts need special attention and will be handled as service parts, and to provide an estimation of the fast and slow moving parts and which parts can be ordered on demand basis. (Fortuin and Martin 1999, 956-957)

Time-series-based forecasting (TBF) is based on spare parts order history and no technical data or failure rates are needed, unlike with RBF. TBF method, however, requires sales data, preferably from multiple years, for being able to predict the future demand. As the sales data is most commonly taken from the company's order management system, it is possible to also pay attention to average purchase prices and delivery times and other important factors. Like mentioned above, spare parts demand cannot be predicted with normal forecasting methods and thus, for example in time-series based forecasting methods would not give accurate results. Based on the previous mentioned reason, the time-series based forecasting method which is based only on the historical demand data, might not be the most suitable method for analyzing spare parts demand. (Cavalieri et al. 2008, p. 386)

Ghobbar and Friend suggest a method where lumpy and erratic demand can be predicted by categorizing spare parts demand into four different categories based on two factors: ADI coefficient and coefficient of variation (CV). ADI coefficient is measured by time between two orders of the similar part as shown in the equation number 1 below. CV is measured by the average demand during the observed time period as presented in the equation 2 below:

$$ADI = \frac{n_0}{T}, \qquad (2)$$

where n_0, is the number of periods with zero demand and T is the number of all periods under the scope.

$$CV = \frac{\sqrt{\sum_{i \in \hat{T}} (d_i - \bar{d})^2 / card(\hat{T})}}{\bar{d}}, \qquad (3)$$

where d_i is the demand rate during the period i, $\bar{d}$ is the average demand during the period and T is the time periods that contain demand.

Based on the results from the above formulae, the demand can be categorized into the following groups which are presented in figure 9 below:

1. Smooth demand: a couple of time periods when there is no demand during the observed time frame
2. Intermittent demand: random appearance, the rest of the time there is no demand
3. Erratic demand: demand sizes vary a lot
4. Lumpy demand: has time periods without demand and is very variable when it occasionally has demand.

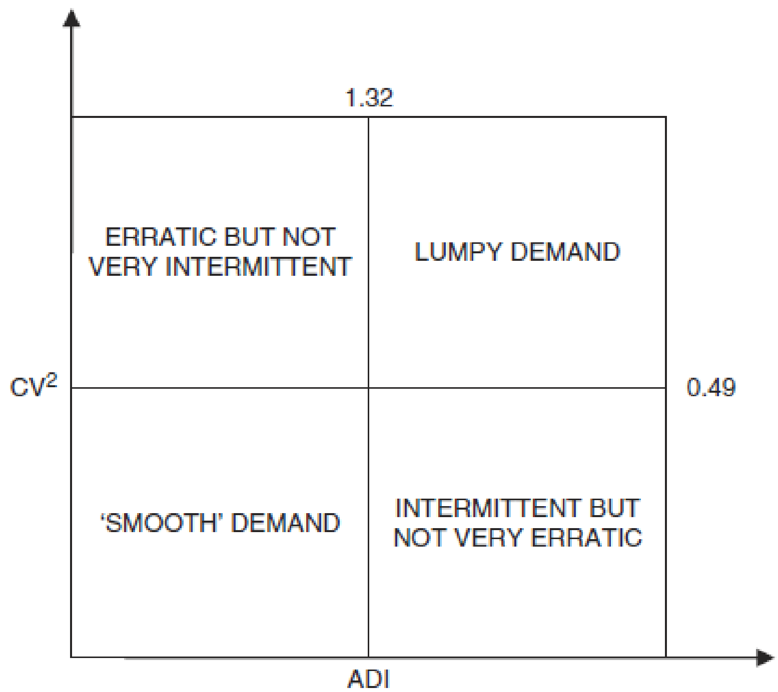


Figure 9. Demand pattern categorization (Cavalieri et al. 2008, p. 386)

According to Cavalieri, it is difficult to choose the correct forecasting method. Time-series-based forecasting can be applied to smooth and erratic demand but on the other hand, more advanced methods need to be developed for intermittent -and lumpy demand (Cavalieri 2008, p. 386).

2.3 Spare parts criticality

Different spare part classification models have been presented in the previous chapters. Some of the models do not take the criticality into account, which from the literature point of view, has been seen a fundamental criterion to approach spare parts classification (Braglia et al. 2004, p 57). There is not a common understanding how to define and measure spare parts criticalities (Molenaers et al. 2012, p. 571). The criticality can be seen differently depending on the company’s department, from the maintenance point of view the critical item might be a totally different to ones that financial department classifies important. Unavailability of one part might cause severe problems to the operating system and therefore is seen important from the maintenance department point of view, but on the other hand the demand for such an item might be very insignificant and cause intolerable holding costs for the company (Roda et al. 2014, p. 531).

The first classification model where two criteria had been taken into account was presented by Flores and Whybark in 1985. Duchessi (1988) suggested a more advanced bi-criteria model where two criteria are used for spare parts classification: price and criticality. In this approach the classification model included downtime cost, lead time and number of the failures per unit time (Almeida et al 2015, p. 276). Downside of this model was that it suffered from subjectivity as the classification was based on experts’ evaluation even though only experienced experts were utilized in the project (Roda et al. 2014, p. 533). Gajpal (1994) approached the criticality from the same direction defining an item to be critical when its failure can cause production stoppages while no replacement parts are available or delivery times are long (Altay et al. 2011, p.175). Braglia (2004) approached the criticality issue by combining reliability centered maintenance (RCM) with AHP. This model was based on a decision making diagram which was seen as an applicable model to classify each item. Braglia also pointed out that criticality classifications were formerly based on inventory related criteria such as inventory costs and usage rates. Nowadays when companies have production planning systems, it is possible to do analyses of inventory sizes, life cycle related questions and stock-out situations. The drawback of these models however, is that they are usually based on one or two dimensional approaches making it difficult to control items that have different kinds of features. To overcome this problem, Braglia presented a multi-criteria classification model approach. (Braglia et al. 2004, p. 56)

Even though different departments have different point of views, it is important to find a way where each parties' needs can be satisfied in a way where the continuity of operations is not jeopardized due to a lack of spare parts and not forgetting to optimize inventory costs (Cavalieri et al. 2008, p. 379).

It is seen, that fundamental spare parts classification including criticality considerations enable further inventory control decisions (Macchi et al. 2011, p 174). Huiskonen (2001, p. 129) has divided criticality into two different classes: process criticality and control criticality. The process criticality is related to the time that can be withstood in a case of sudden component failure. In other words, Huiskonen (2001, p. 129) suggests that the measure of criticality could be linked with the time in which the machine needs to be maintained. For this matter, the process criticality can be divided into three levels:

1. The failure is so severe that the maintenance actions need to be carried out immediately and the spare parts should be available.
2. The operation can be continued with a reduced speed and the spare part is needed with a short notice.
3. Component failure does not have an effect to operations and long delivery times can be withstood.

The control criticality is not directly related to the consequences of the failure but more in controlling the situation when a sudden failure occurs. Such factors like predictability of the failure, the number of suppliers and delivery time can be considered when thinking about the control criticality. These factors affect the logistical questions such as how much time there is to react to the sudden demand and the volume of spare parts that should be in the stock. It is important to know if there is time to operate or not because that affects the stocking policies. If the failed component is not critical and there is time to operate, the time buffer can be used, meaning that parts can be ordered directly from the supplier instead of using own stock. In the latter when there is no time to operate, stock buffer needs to be used if available (Huiskonen 2001, p 129).

Dekker separates criticality into three different levels: vital, essential and auxiliary. Dekker also emphasizes that the equipment function is more important than the equipment itself and for example a fan can in some cases be vital, and in some cases only auxiliary equipment, and hence, the level of criticality is different. This might have an effect when determining the desired service level for the service parts. Based on the items' criticality, Dekker separates demand into two different classes: critical and non-critical demand. Critical demand occurs when the need for the spare part is based on the failure of a part installed in a vital device. Respectively, non-critical demand originates from essential or auxiliary devices (Dekker et al. 1996, p. 69).

According to Bosnjakovic (2010, p. 500) and the criticality definitions presented in the previous sub-chapter, four different criticality groups can be distinguished. Criticality can be divided into plant production, supply, safety and inventory related criticality groups and the overall spare part criticality is derived from the clusters.

Production criticality is related to the consequences caused by a sudden part failure. By proactively maintaining equipment, the risk of a sudden failure can be minimized and production or operation can be continued without stoppages. However, sometimes a failure can still occur and the severity depends on how important the failed part is for the device or the function. Not every item share the same importance, some items can cause an instant stoppage for the production whereas some part might be only for auxiliary purposes and hence, does not have such a great impact. The same feature applies on the system level, some machine can be critical for the operation and some might not be that critical for example due to the redundancy built around the system. Because of these peculiarities, the criticality of a spare part can be defined by the criticality of the machine. VED-analysis can be applied in defining production critical spare parts. Like it was presented above in the text, VED-analysis has three different criticality groups: vital, essential and desired. Bosnjakovic recognizes three failure modes in which the machine can be classified as vital:

- machine failure causes a sudden downtime and the production or operation cannot be continued
- machine failure causes a sudden and intolerable decrease in production efficiency
- machine failure affects the production quality dramatically

Equipment is classified as essential when the sudden part failure does not cause stoppages in the production, but causes significant power reduction or loss of power. Failure of the desired item does not cause stoppages or reductions in the production and therefore the failure can be withstood longer without replacement spare parts.

The criticality group for the individual item is dependent on the criticality group of the equipment in which the item is installed. This makes it difficult to categorize spare parts as the item might be critical for the equipment but the equipment might not be critical for the process and vice versa. For determining the criticality, a joined model where criticality gets points from one to ten for both item and machine is suggested in the literature by Bosnjakovic (2010, p. 500). By using this model, the overall production criticality can be derived from the following formula presented below:

$$Criticality = \sqrt{machine\ criticality * spare\ part\ criticality}, \qquad (4)$$

The results from this equation can be interpreted as follows:

- values from 1 to 3 equals criticality level 1
- values from 4 to 7 equals criticality level 2

- values from 8 to 10 equals criticality level 3

Second criticality class described by Bosnjakovic is similar to the control criticality approach presented by Huiskonen (2001). In this categorization, spare parts are classified based on their availability. In Bosnjakovic's model, the availability is defined to include only delivery time. The most critical parts in terms of delivery time are parts that have a lead time of over four month. Essential parts have delivery times from two weeks up to 4 months. Respectively desired parts have delivery times of less than two weeks.

Safety related criticality is related to the consequences of what might happen if there is a sudden stoppage in production or operation due to an item failure. Spare parts are considered to be critical if the lack of such items can cause danger to people, environment, or safe operation. If the lack of spare parts causes only minor safety related issues, the part is considered to be essential. In the rest of the cases the spare part is classified as desirable.

Spare parts in which usability weakens or quality deteriorates over time, can be seen as critical from the inventory point of view. Spare parts might require lots of space causing stocking costs and also transportation might be difficult. Depending on the company and its policies, the criticality from the inventory point of view might vary. Companies might emphasize inventory turnover and demand rates whereas some might focus more on ordering and stocking costs. (Bosnjakovic 2010, p. 499-500)

Table 1 below gathers and summarizes different criticality definitions presented in academic studies through different years. It can be seen that the criticality definitions are mainly focused on considering the consequences caused by the item failure if a replacement part is not available. Therefore, also the importance of the availability arises in the academic studies when different criticality criteria are being considered.

Table 1. Criticality definitions presented in the academic literature from 1988 to 2015

Year	**Author**	**Definition for criticality**	
1988	Duchessi et al.	"Spare part criticality is defined by considering simultaneously downtime cost, lead time and number of failures per unit time." (Roda et al. 2014, p. 534)	
1994	Gajpal et al.	Spare parts criticality is assessed through a weighted measure of stock out implication, type of spare required (level of standardization) and the lead time. (Olhager and Persson 2007, p. 315)	
1998	Dekker et al.	"Equipment criticality is defined here as the importance of equipment for sustaining production in a safe and efficient way." (Dekker et al. 2998, p. 69)	
2001	Huiskonen	"Criticality is divided into process- and control criticality. **Process criticality** is related to the consequences in the process caused by a component failure. Can be considered as the time in which the problem needs to be solved. **Control criticality** is related to controlling the situation including criteria: predictability of failure,	

		availability of spare part suppliers and lead-time.” (Huiskonen 2001, p. 129)	
2004	Braglia et al.	“A criticality classification of spare parts is generally based on administrative efficiency considerations such as inventory costs and usage rates” (Braglia et al. 2004, p. 56)	
2008	Porras and Dekker	“Porras and Dekker defines a number of machines in which the spare part is installed as a criticality criterion. Non-availability of a spare part can affect to large population of machines. (Stoll 2015, p. 226) The criticality is divided into three groups: high, medium and low. (Porras & Dekker 2008, p. 104)	
2015	Stoll et al.,	“The criticality evaluates a spare part, for example according to the risk in procurement and storage, or consequences caused by machine failure if the spare part is not available.” (Stoll et al. 2015, p. 225)	

2.4 Spare parts life cycle management

When discussing the product life cycle, a few notions are important to make. Life cycle thinking can be divided into production and service phases where the production period is usually much shorter than the service period which continues after production is already stopped (Fortuin and Martin 1999, p. 950). The figure 10 below illustrates the different phases during the product life cycle.

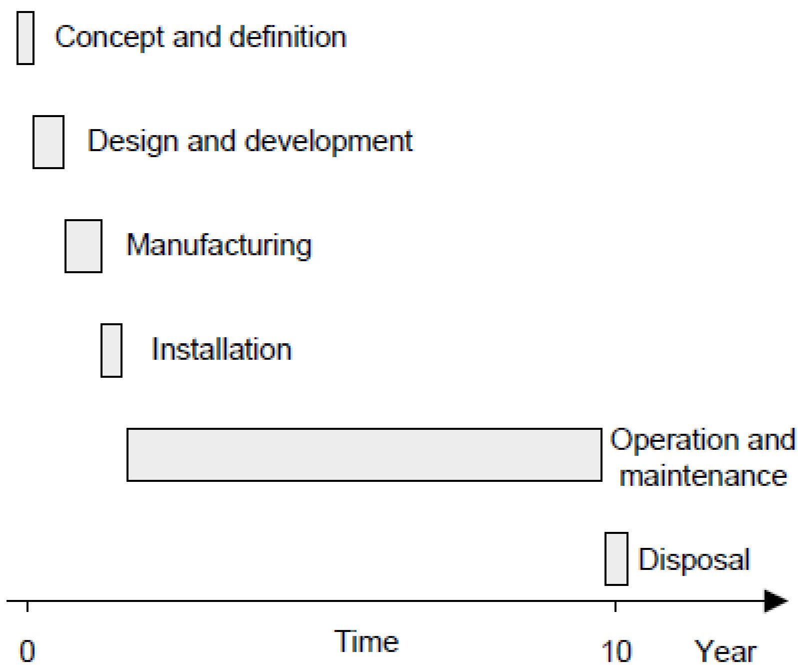


Figure 10. Product life cycle phases (Carpentieri et al., 2007, p. 473)

According to Fortuin and Martin, the product life cycle can be divided further into three phases: initial phase, normal phase and final phase.

1. *The initial phase:* the phase where the equipment and systems are just introduced to the market. As the components used in the system are new, no historical demand data is available.

2. *The normal phase:* the phase where the equipment has reached the stabile status and some information of the demand and other technical issues are gathered.
3. *The final phase:* in the final phase, the production has stopped but the service period continues. During this phase, maintenance responsible persons are usually placing final orders for spare parts. (Fortuin and Martin 1999, p. 951)

If a critical part for the machine fails during the first two phases, initial and normal phase, the spare parts are normally available from the supplier and can be ordered on demand. After these two phases when the product is moving to the final phase, obsolete, normally three options for managing inventories for final phase products are recognized:

1. Placing a large order when the regular production is still running
2. Arranging some extra production cycles
3. Utilizing spare parts from used products or machines

Typically the customer and the supplier can discuss the so called final order. For the customer, the end of the life phase is problematic because spare parts consumption rates are usually sporadic and future demand is not known. The size of the final order depends on how long the machines will be used, the size of the installed base, the price of the spare parts and how critical the machine is for the whole production line. As the accurate demand is not known, the product owner might face two situations which both are not eligible, having too large inventories which cause holding costs, or too low inventory levels which might ultimately cause stoppages to the whole production system as the spare parts are not available anymore. (Teunter & Haneveld 1998, p. 35) However, some advantages can be found from the last buy method. The production costs are very low for the parts because those are manufactured at the same facilities as normal parts and thus, economies of scale can be still utilized during this phase (Li et al. 2016, p. 376).

Once the normal production period for the product family has stopped, companies may arrange extra production runs for producing spare parts. This is possible by maintaining the existing production equipment in good shape or creating smaller facilities only for spare parts production. This alternative is seen to have both advantages and disadvantages. The production costs are higher than in the first option where one final large batch is made parallel with normal production. The higher production costs in extra production rounds are related to the rising setup costs and loss of economies of scale due to small batch sizes. However, as there is a possibility for extra production runs, the demand planning horizon is not long and thus, the level of uncertainty stays low having a positive impact on inventory levels.

The third suggested method for managing spare parts after the end of production phase is related to refurbishing the existing failed and returned parts by the customer. The re-use methodology is seen as an environmentally friendly option and it is suitable for electronic parts such as cards and frequency converters more than for mechanically worn out parts such as bearings. The process itself is simple, the defected returned product is disassembled and the reparable components are taken for refurbishment before launching those back to the market. As the product life cycles are getting shorter and shorter, customers are still requiring long lasting products which means that the production can be stopped even though lots of customers are still using the products (Behfard et al. 2013, p. 498). This is problematic from the equipment manufacturer point of view because the demand for the spare parts is not known and also the amount of returned units will remain unknown. Despite the uncertainty of the returned products, this method shows moderate remanufacturing costs compared to the extra production rounds (Inderfurth & Mukherjee 2007, p. 21). The figure 11 below shows the demand for new products, spare parts and return figures for the used products through the product’s life cycle.

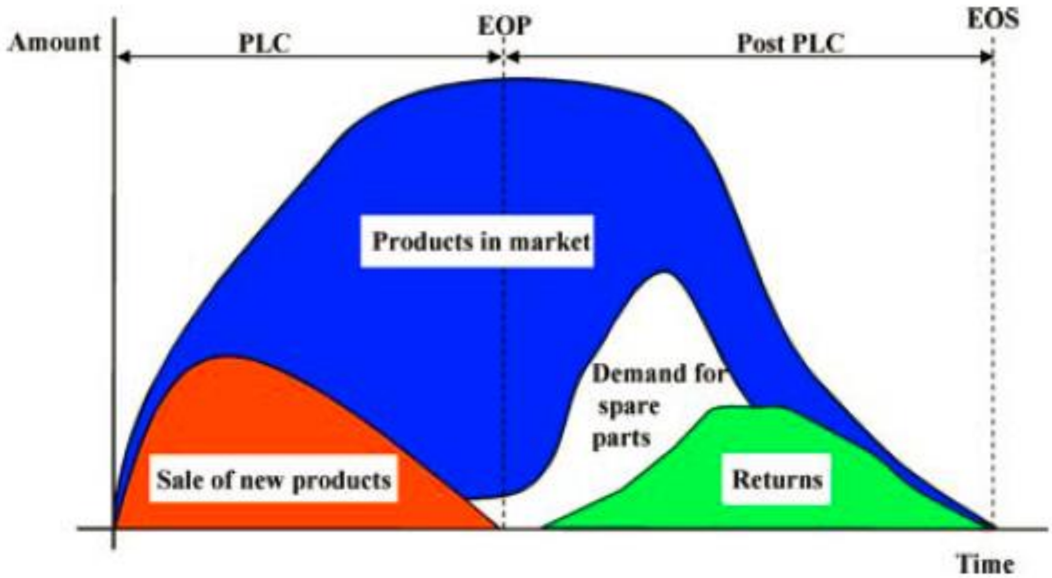


Figure 11. Demand statistics during different life cycle phases. (Inderfurth & Mukherjee 2008, p. 20)

As mentioned, there are three different ways to adapt to the end of the product life cycle phase. However, recent literature studies raise a fourth method that has long been ignored in the literature but due to the short product life cycles but long lasting products, this method is now gathering popularity. In this method, returned parts are also refurbished but those will be used by the customers who are not upgrading their systems yet. These, so called *phase-out* parts are not only cheaper to refurbish than the failed parts but also cheaper to acquire than the new parts (Krikke & van der Laan 2011. p. 5184). Phase-out method is seen as a lucrative method due to cost savings and positive environmental impact, but it suffers from uncertainty in return quantities. Companies may use only the phase-out method in providing spare parts but at the same time taking risk in facing stock-out situations which might cause penalties because of possible maintenance agreement contracts. As the number of old installations reduces every time a customer upgrades its systems to newer ones, the number of phase-outs reduces and return rates become more random at the same time (Pourakbar et al. 2013, p. 1562). At the beginning of the service period, the demand for repair is usually high and the number of phase-outs relatively low as the systems are not old yet, but as the time goes by this changes and phase-outs increase. This makes forecasting more difficult and therefore, companies may need to adopt the combination of both last-time-buy and phase-out returns to achieve more optimal inventory models for obsolete spare parts. (Krikke & van den Laan 2011, p. 5184)

3 Industrial After Sales Service Environment

3.1 Customer service

The meaning of service is difficult to define precisely as it has evolved in the long run from one direction to another. In the early 1990s, service in the industrial context had been defined to be a performance that *"do(es) things for you. They do not make things"*. This definition indicates service to include only intangible components as it is seen to be a function instead of a tangible product. However, drawing the line whether the service is only intangible or tangible might be difficult to conclude. In a restaurant, the service includes food and drink and retail services provide goods that can be classified as tangible goods. However, a product that can be classified as a service, can also have intangible features. As an example, car dealers may offer car leasing contracts including extended warranty, maintenance, and annual inspections. (Johns 1999, p. 959) Instead of categorizing services purely into tangible and intangible components, Kotler recognizes five different service groups (Kotler 2012, p. 356):

1. *Pure tangible goods* – tangible goods such as food with no service built around
2. *Tangible goods with accompanying services* – tangible goods such as cars, laptops and bikes provided with maintenance and extended warranty
3. *Hybrid* – a service consisting of equal amount of tangible and intangible components like fast food restaurants where the preparation of the meal is part of the service
4. *Major service with accompanying minor goods and services* – majority of this service includes intangible components such as a cruise on a large vessel where food and drinks are served bringing small tangible components
5. *Pure service* – purely intangible service such as consulting

Gummesson continues along the same path arguing that the division between tangible and intangible services is not relevant anymore and instead, services in many cases, should be considered to include both components. In other words, customers do not buy goods or services, instead, they buy an offering consisting of goods and services (Gummesson 1994, p. 78).

3.2 Industrial after sales services

Industrial after-sales has become an important source of income for many companies. Cohen emphasizes that companies should focus instead of providing only products, to provide also service solutions such as spare parts, modernizations, and maintenance services. Equipment manufacturers might have a lot of different types of products that they are offering, which makes it difficult for the after-sales functions to store the correct spare parts while keeping inventory costs low. As the demand for spare parts usually arises from emergency breakdowns, it is difficult for companies to have the correct spare parts available all the time, which eventually results in negative customer satisfaction. Thus, the after-sales services are usually seen as a reactive type instead of proactive where the maintenance is more scheduled and unexpected failures do not occur that often (Cohen et al. 2006, p. 129). Figure 12 below illustrates the differences between manufacturing and service supply chains. Where the manufacturing supply chain is seen as straight forward consisting of the steps of buying the material, manufacturing the device, and eventually selling it, the after sales supply chain is more complicated. The service period starts once the device is sold and it consists of the lifelong product support until the device is replaced. If the product is reparable it can be refurbished and resold once again for the customer still using the old system.

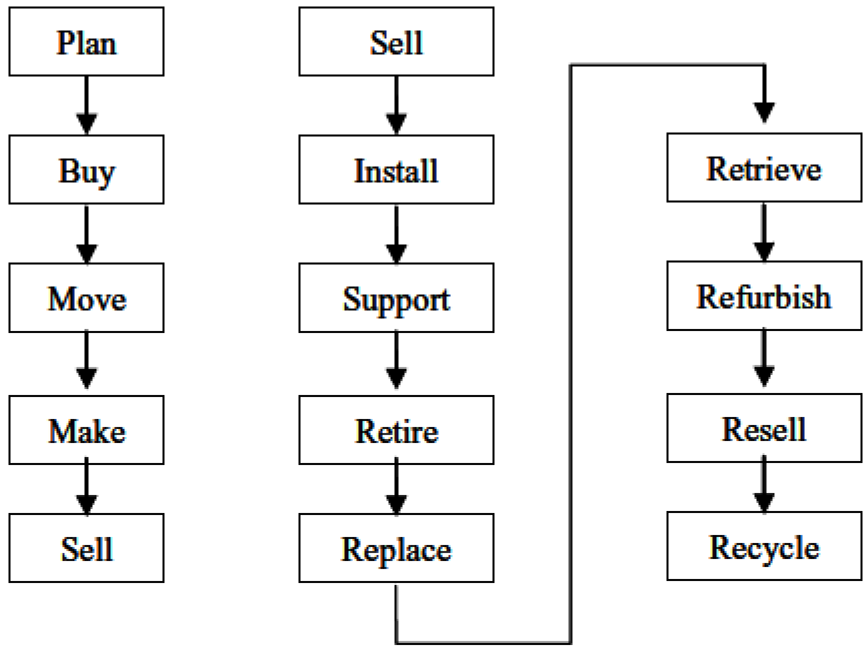


Figure 12. Differences between manufacturing supply chain (left) and after-sales supply chain (right) (Rolstadaas et al. 2008, p. 384).

Customers and suppliers might have had different point of view towards the logistics aspects in the past. However, as the fundamental problems are still the same regardless of the aspect, both parties are trying to optimize inventories so that not too much money is tied up or stock-out situations would not happen and therefore, the co-operation between the customer and supplier is seen as important. The logistics elements have been presented in figure 13 below. It can be seen that the logistics comprise of four different elements: strategy/policies/processes, network structure, management of relationships, and coordination/control. The strategy/policies/processes –element from the supplier point of view mean what kind of service level is offered for different customer segments. In practice, it can mean for example spare parts availability agreements where the availability of spare parts is guaranteed within 48 hours regardless of the location of the vessel or production plant. From the customer point of view, the problem with spare part availability agreements may arise from the concern that the supplier is not capable of delivering the parts despite the agreed agreement. The network structure defines the logistics structure and how many parties there are in the logistics chain. Huiskonen (2001, p. 128) states that logistics structure is typically considered only from one parties point of view even though the structure consists of multiple parties where for example inventories can be owned either by the supplier or the customer and therefore, some inventory management approaches such as just-in-time (JIT) requires co-operation between both customer and supplier in order to achieve an efficient network. This leads to managing supply chain relationships. The better it has been assumed, the more efficient the supply chain becomes. This can include for example risk sharing and taking responsibility of control related issues. These three mentioned aspects together define the guidelines for a coordination and control system. The coordination and control include components related to inventory management such as inventory control guidelines, continuous performance evaluation, and software systems which are used to control the inventory related systems. The co-operation between different parties in the inventory control does not necessarily need to be based only on formal contracts and agreements but also on trust between the customer and supplier. (Huiskonen 2001, p. 128)

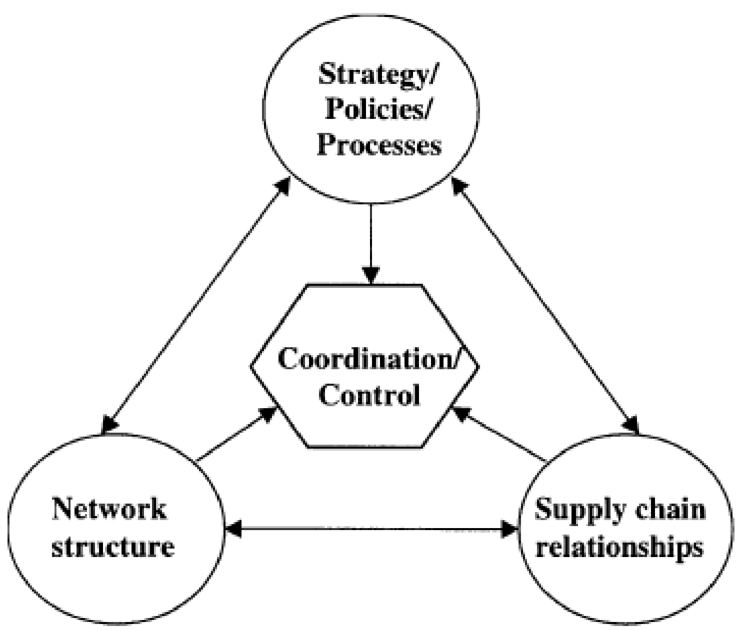


Figure 13. After-sales elements and their connections (Huiskonen 2001, p. 127)

3.3 Linking maintenance and spare parts demand together

In the industrial context, companies may have built a service portfolio containing different after sales services for different customer needs. The services can be divided into on-site and on-line services depending on how and where the service is delivered. On-site service is performed at customers' site whereas on-line service can be provided via internet connection from the service center. Typical examples of on-site services are maintenance, retrofits and modernizations. Figure 14 below illustrates what kind of services the service portfolio can include. As the focus in this study is in the after-sales phase, the linkage between maintenance and spare parts are discussed in more detail below. (Rolstadaas et al. 2008, p. 387)

<table>
<tr><th>Services</th><th>Pre-sales</th><th>Sales</th><th>After-sales</th></tr>
<tr><td rowspan="3">1. General support</td><td colspan="3">Helpdesk, contact, hotline</td></tr>
<tr><td></td><td colspan="2">Training, upgrades</td></tr>
<tr><td></td><td colspan="2">Spare part management</td></tr>
<tr><td rowspan="3">2. Self support</td><td colspan="3">Product information, product news</td></tr>
<tr><td colspan="3">Software download</td></tr>
<tr><td></td><td colspan="2">Troubleshooting database</td></tr>
<tr><td rowspan="4">3. Remote support</td><td colspan="3">Remote consulting</td></tr>
<tr><td></td><td colspan="2">Remote optimisation</td></tr>
<tr><td></td><td></td><td>Remote diagnostic</td></tr>
<tr><td></td><td></td><td>Remote control</td></tr>
<tr><td rowspan="4">4. On-site support</td><td></td><td colspan="2">Process support, optimisation</td></tr>
<tr><td></td><td colspan="2">Optimisation</td></tr>
<tr><td colspan="2"></td><td>Maintenance</td></tr>
<tr><td colspan="2"></td><td>Repair</td></tr>
</table>

Figure 14. Service portfolio through different sales phases (Rolstadaas et al. 2008, p. 388)

The maintenance term has received many different definitions in academic literature. The European Federation of National Maintenance Societies defines maintenance as follows: *"All actions which have as an objective to retain an item in or restore it to, a state in which it can perform the required function. The actions include the combination* *of all technical and corresponding administrative, managerial, and supervision actions."* (Stamboliska et al. 2015, p. 9). Maintenance can be further divided into reactive -, preventive -, predictive - and proactive maintenance types. Companies' attitude towards maintenance has become more positive through the time as the awareness of the linkage between equipment reliability and production quality has become apparent. Condition monitoring technologies have made it possible to move towards proactive maintenance approaches where the problems are recognized before they escalate into production problems.

As there are many different approaches to maintenance nowadays, the companies' maintenance strategies can be dependent on many factors. The relation between the costs of maintenance and downtime is a popular approach when choosing a suitable maintenance strategy. Also factors such as expected machine lifetime, required availability, and product portfolio can be taken into account. All of these decisions have direct linkage with the spare parts demand. It can be seen that the demand for spare parts starts once the primary machine is sold and needs maintenance. In this sense, the function of spare parts is to preserve the machine into a state where it was before the failure (Wagner et al. 2012, p. 81). Before the maintenance practices had been developed, time-based maintenance was widely used for example in the aviation industry. During that era there was a belief that time-based maintenance reduced failure frequencies however, some studies show exactly the opposite. Instead of reducing the frequency of failures, with some complicated components, the failure frequencies actually arose. These findings led to the birth of the so called "bathtub curve" in which the failure rates can rise just after the installation and at the end of the life cycle. Following time-based maintenance scheme, failures might actually increase as the overhaul resets the machine to the phase where probability of failure is higher. The figure 15 below illustrates the bathtub – and the most common failure pattern curves. (Duffuaa & Raouf 2015, p. 246)

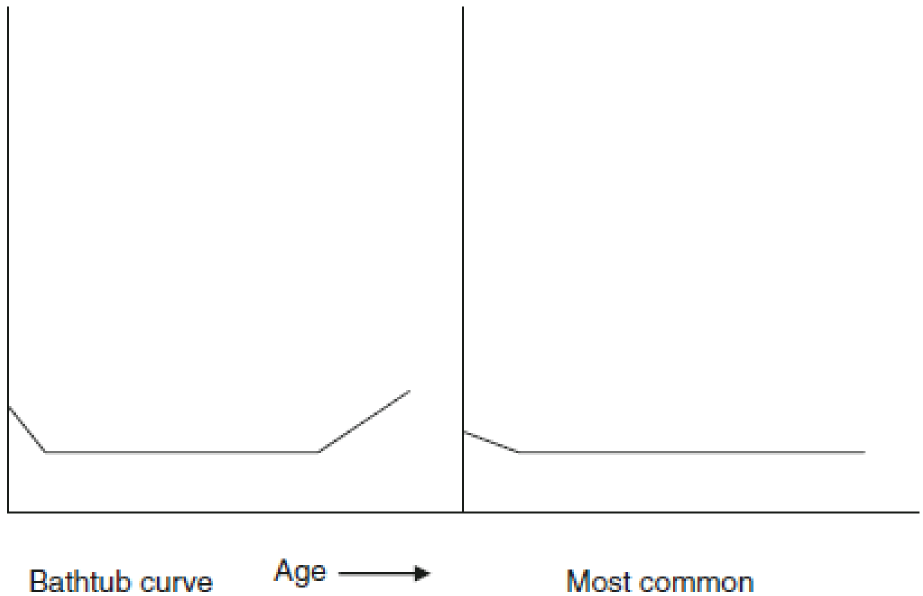


Figure 15. Failure probability for ageing components (Duffuaa & Raouf 2015, p. 246).

Typically component failures are of a random nature and might occur due to too heavy loading, misuse of a machine, electrical peaks, or lubrication problems. These relatively random events can be monitored with existing technology and corrected by using condition-based maintenance approaches. This can be considered as a basis for reliability-centered maintenance which is presented in more detail in the following sub-chapter.

3.4 Reliability-centered maintenance (RCM)

Reliability-centered maintenance (RCM) is a methodology that utilizes failure mode, effect, and criticality analysis (FMECA) approach to define the most suitable maintenance plan to ensure high reliability and operating performance. RCM will be presented in a more detailed way as it can be used as a method to identify operationally critical components (Selvik & Aven 2010, p. 324). Other maintenance types will not be presented as the maintenance itself is outside the scope of this study.

The main goal in RCM is to determine an optimal maintenance plan which is cost effective and minimizes downtime risks and other impacts of possible failures. Also maintaining the system in economical way is of great importance in the RCM approach. More specific goals can be named such as to restore the equipment to the inherent condition in a case of sudden component failure, to utilize failure statistics and information for product development purposes, and to perform the mentioned goals in an economical and cost effective manner (Duffuaa & Raouf 2015, p. 247). The basic principles in RCM are related to the equipment preservation on the system level. The focus in RCM is to maintain the system level performing how it is meant to do instead of keeping it “new”. This distinguishes RCM from the other maintenance approaches such as time-based preventive maintenance which in some cases might increase system failures like it was discussed above. (Duffuaa & Raouf 2015, p. 248)

The first phase in the RCM process is to define the system boundaries and reduce the number of components for further analysis. The purpose is to find important components that are identified from the performed criticality analysis. At this stage, all the possible failure modes are listed. The criticality analysis can be carried out with the help of qualitative analysis combined with failure frequency data and considering the consequences of failure. Selvik and Aven list the following categories regarding the criticality classification:

- *Operational consequences (production availability)*
- *Hidden failure consequences (relevant for redundant systems)*
- *Non-operational consequences (including both direct costs and commitments)*
- *Safety and environmental consequences (Selvik & Aven 2010, p. 324)*

During the second phase, different maintenance strategies can be implemented for components having different criticalities. For the non-important items, maintenance strategies such as corrective maintenance or Run-to-Failure (RTF) could be considered based on failure and lifetime related aspects. This can done by utilizing the decision tree approach where the most suitable maintenance plan can be defined by going through the nodes as shown in the figure 16 below. The questions and the structure of the decision tree depends on need, and the decision tree shown below is only one example of how the maintenance plan can be defined for every device. Once the tasks are defined, the maintenance intervals need to be assessed. There is not the one and only way to define the maintenance optimization and hence, mathematical optimization, maintenance experts, and operational experience can be utilized when defining the maintenance intervals for each device.

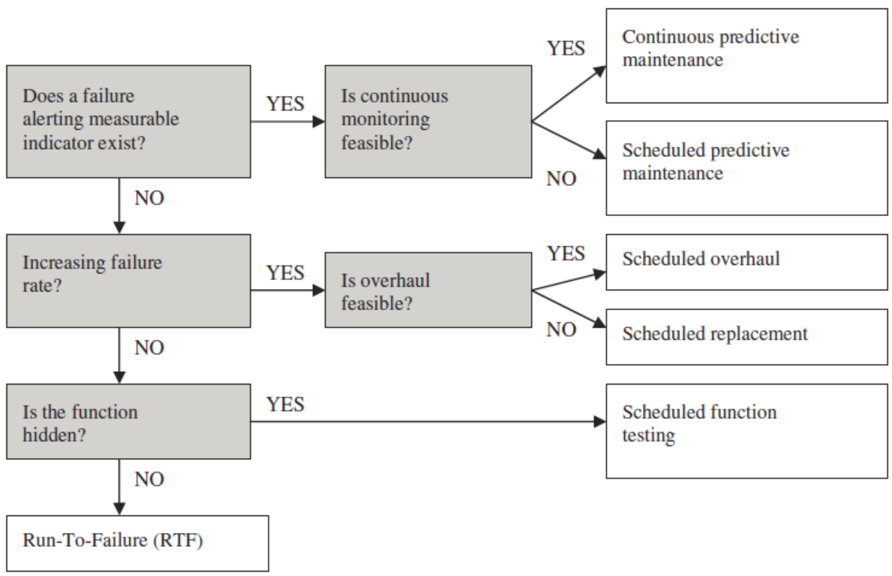


Figure 16. RCM decision tree for defining suitable maintenance approach (Selvik & Aven 2010, p. 326)

The third phase in the RCM project is related to the actual implementation of the RCM method within the company. This includes managerial decision making on how the results will be utilized in practice. The developed guidelines need to be communicated through the organization and the results evaluated to make sure the RCM is not overlooking any important components or devices. Like in every project, proper documentation needs to be carried out and should there be any changes, these also need to be communicated and documented well. (Selvik & Aven 2010, p. 327)

4 Spare Parts Management

Spare parts inventory management is demanding and diverse due to service part sporadic and random demand patterns. Where demand forecasting for parts needed in production is performed with the help of modern ERP-systems, the demand forecasting for spare parts often falls on the shoulders of maintenance experts. Managing spare parts can be seen as a double-edged sword, companies do not want to tie money into large inventories but at the same time high service levels are desired. Bacchetti and Saccani (2012) suggest a four steps decision making approach for developing and managing spare parts inventories which is presented in figure 17 below.

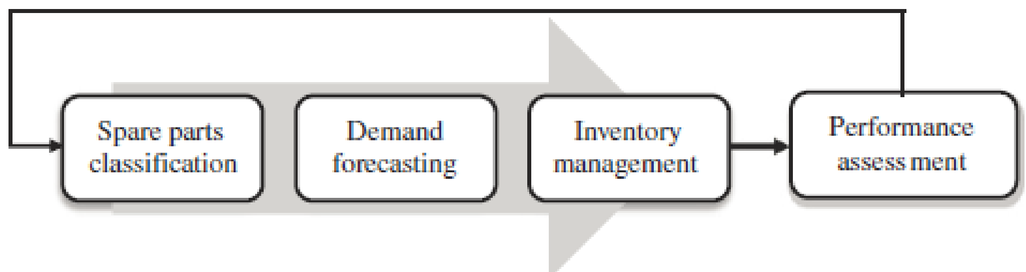


Figure 17. Four decision making steps for better inventory management (Bacchetti & Saccani 2012, p. 733)

Unlike in Cavalieri's model, in this model it is expected that part coding is already carried out. Cavalieri emphasizes how important product coding is and suggests that at least information about technical details, physical location, and supplier should be included (Cavalieri 2008, p. 381).

When the demand rates and quantities are known, a stock management policy can be set up. As the spare parts have different characteristics in terms of criticality, delivery time and price, different policies can be set up for each of the part. Stocking policies might vary from non-stock to multiple item stocking methods depending on the demand patterns. The final step for developing inventory management includes test and validation of the achieved results and possible adjustments can be executed during this phase.

Table 2. Steps for improving inventory management (Bacchetti & Saccani 2012, p. 733)

Step	**Objective**
Spare parts classification	A phase where spare parts are categorized by their technical and financial features. Sets a foundation for demand forecasting.
Demand forecasting	Like it has been mentioned, service parts might require special forecasting methods if the demand is low or sporadic. In this phase, spare parts can be further categorized based on the demand patterns.
Inventory management	Adopting a stock management policy for spare parts. Depending on the spare part category, the stocking policies might vary from non-stocking to storing multiple items.
Performance assessment	Once the inventory management policy is set up, assessment of the achieved results can be carried out.

4.1 Spare parts classification

After the product coding is established, classification model for spare parts can be implemented. As there are high amounts of different kinds of components used in manufacturing plants, and typically they do not share the same features, it is suggested to distinguish parts from each other by classifying them. Parts can be classified by using technical and financial features such as criticality, life cycle phase, delivery time, and price (Fortuin & Martin 1999, p. 952). As the spare parts have different features and hence, do not share the same technical specifications, it is important to implement a proper spare parts classification approach before considering any inventory policy related questions. The adopted classification model should take multiple criteria into account yet, keep the model simple. Many studies approach classification from the criticality point of view allowing the use of different inventory management policies for different criticality groups (Macchi 2011, p. 175).

4.2 Demand forecasting

Normal forecasting methods cannot be applied to spare parts due to low consumption rates and sporadic demand. Normally, when a sudden component failure occurs, the component needs to be replaced as the machine cannot function without it. Due to this random nature of failures, the failure interval might be anything from days to years. As the failure interval might be long for some items, the spare parts consumption rate is more dependent on the size of the installed base rather than only failure frequencies. When all of these peculiarities are combined, it can be noticed that the most used forecasting methods might not bring desirable results. (Cavalieri 2008, p. 382)

4.3 Service parts inventory management

Inventory management is a subject that has been under research for decades however, the literature around it has focused mainly on controlling parts needed in the production line, not in the service environment. Fortuin & Martin (1999) argue that two different policies are the most commonly used methods: Material Requirement Planning (MRP) and Just-In-Time (JIT). But as this thesis focuses specifically on service parts, the inventory management policies used in the manufacturing process will be left outside the scope, and the problems related to service parts inventory management are only shortly discussed.

Typical problems in spare parts management are related to stocking quantities, order quantities, and order frequencies. For low demand service parts, it is not always easy to decide whether to stock a part or not. Normally, in these kinds of situations comparing stocking costs and stock-out costs will give an indication of the stocking profitability. Once the stocking decision is made, the stocking quantity needs to be decided. Depending on the type of service part and demand rate, economic order quantity (EOQ) method can be used. However, some spare parts might have extremely low demand rate, one piece per year or even lower thus, EOQ might not be the most suitable method and more attention is needed when deciding how many parts should be stored. The final step is to decide when to place the next order which is called the re-order point. If the order is placed too early, unnecessary inventory costs will be faced. On the other hand, if the order is placed too late, penalty costs might be possible due to stock-out situations. (Bosnjakovic 2010, p. 499).

4.4 Performance assessment

The final phase of developing the inventory management is the assessment of achieved results. It is suggested to test the new policies with the help of simulation. Cavalieri suggests a discrete-event simulation which is suitable for complex problems under the chosen conditions. It allows to test the service levels where the spare parts are being classified based on their criticality.

Numerous different case studies have been performed under simulation purposes. For example Smidt-Destombes et al. (2006) simulated the availability with different variables such as maintenance task, inventory levels, repair capacity, and maintenance job priority. Other simulations have been performed to study optimal replacement ages and spare parts inventory policies with parameters such as shortage costs, item failure statistics and lead times. What is worth mentioning is that the simulation can be used also to find an optimal inventory policy, not just estimate the developed policy. (Cavalieri et al. 2008, p. 391)

5 Developing Spare Parts Classification

5.1 Case company introduction

The case company operates in the field of robotics and power and automation technology. The company consists of four divisions: Electrification Products, Discrete Automation and Motion, Process Automation, and Power Grids. The Electrification Products division manufactures low- and medium voltage circuit breakers, switches and wiring accessories. This division also produces solutions for residential buildings that integrate electrical installations, ventilation systems, and other communication networks. The Discrete Automation and Motion division manufactures rotating machines, frequency converters, and power electronics that increase energy efficiency. The Power Grid division is focused on providing solutions for growing network complexity, integration for renewable energies, and grid automation. The division offers turnkey solutions for power plants and power transmission grids along with consulting and service offering throughout the systems' lifecycles. The Process Automation division provides systems for different industrial segments such as oil and gas, pulp and paper, metals and minerals, and marine. This division is divided into seven business units: Control Technologies, Marine & Ports, Measurement & Analytics, Oil, Gas & Chemicals, Power Generation, Process Industries, and Turbocharging.

This study is made for the Marine & Ports business unit which is responsible for marine related systems and solutions. This business unit is divided into Local Business Units and Global Service Units. The system units provide solutions for new build vessels whereas the service units provide after sales services for operating vessels. Every service unit has its own allocated vessels which they are responsible for providing services to. In addition to spare parts, the subject service unit provides training, maintenance, and modernization services globally for its customers.

5.2 Current classification models used in the case company

Spare parts classification is a subject that has been discussed in the case company for a long time. Many recommended spare part lists based on criticality have been created for existing vessels over time but the consensus of the classification models and criteria is still missing. Usually these lists for existing vessels have been created by a person working in the service department who has defined the criteria and classification models for spare part analysis. Due to this, different criteria for criticality and different models for criticality assessment have been used making the lists incomparable. Partly because of these reasons, the implementation and the further use of the lists have not progressed.

Short email-interviews sent to the product factories revealed the situation in the case company’s other units at the moment. It turned out that some of the interviewed units do not have classification tools in use and some of them have experience based spare parts classification m (Person X, 2016 & Person Y, 2016). Typically the spare part recommendations are done by service technicians on a case by case basis but no advanced classification models are in use. The experience based classification model is easy to implement but might suffer from subjectivity as the procedures might vary because humans are involved. In one of the case company’s after-sales team which is responsible for providing propulsion motor related spare parts, spare part classification is carried out with the help of Reliability-centered Maintenance (RCM). With RCM, the parts that are critical for the system are recognized and based on that, different criticality level for every component can be given. Based on the findings in the other after-sales team, this approach seems to provide accurate and reliable results. It was noticed that the parts that had been classified by service technicians, 80% were the same as was found critical during the RCM process and hence, some parts needed to be added to the earlier created recommended spare part lists.

It also turned out that the product factories do not keep records and separate how many pieces are sold as a spare part and how many as a normal part (Person Z, 2016). Also statistics of the failure frequencies were not available because active recording of the incidents is not carried out. One of the product factories informed that they have had plans of developing a classification tool for sales support purposes but however, at the moment of writing this thesis, those have been only plans (Person Y, 2016).

Statistics of the failure frequencies and records of how many items have been sold as a spare part would be beneficial when developing guidelines for further inventory management. Such information would allow the development of probability based classification tools even though those sales figures would not give the total consumption of the basic bulk components as there are many after sales companies selling the same OEM components. Those numbers would still give a rough indication of the distribution between emergency and non-emergency spare part sales. Statistics would be beneficial for example if some part is classified as medium critical but the probability of the item failure is extremely low, the part could be stored in the central stock instead of on board. Respectively, if the part is classified as non-critical but it keeps failing frequently, on board stocking could be considered. Also when considering stocking quantities, the failure frequency numbers would give a rough estimation of the needed amount of SKUs over the reviewed period.

5.3 Benefits of the spare parts classification

There are many ways to classify spare parts. The simplest classification models take only one criterion into account for example dividing spare parts into fast and non-moving parts. These models are suitable for high volume products where the demand pattern is somewhat predictable. Whereas, more advanced classification models would provide better results in inventory management related decisions for companies operating in the industrial after sales environment. These models do take multiple criteria into account forming a more comprehensive picture of the spare parts. When only one criterion is taken into account, for example demand, other important aspects will be left outside such as the criticality, delivery time and life cycle phase, to name but a few. All of these are important when deciding what to stock, where and when. From the supplier point of view it is important in terms of customer satisfaction to store parts that might not bring most of the profit but are seen important from the customers' operational continuity point of view. These parts in other words mean the critical parts which without the vessel cannot operate anymore and cannot be found by classifying spare parts based on for example only demand. Making the criticality more visible, it will help customers to form a larger picture of the situation controlling related questions. Based on the provided spare part classifications, customers may choose spare components that best fit their operational needs and be able to optimize the spare part investments. The provided information also helps customers to make stocking decisions. For example if the spare part is critical and has a long delivery time, but the crew cannot replace it by themselves, the part could be stored in the central warehouse instead of on board the vessel. Respectively, if the spare part is critical, has long lead time and the crew is capable of changing the part, it might be sensible to have it on board. Overall, the aim of the spare parts classification is to develop guidelines and a harmonized process so that the recommended spare part lists would be comparable and similar to each other no matter who is the creator of the list. Also by classifying spare parts it is possible to provide assistance for customers in stocking decisions in order to have the correct spare parts in the correct place.

Life cycle related questions are also of a great importance when planning future inventory levels. Suppliers and customers need to be prepared to the end of the products' lifecycles. In some cases, suppliers have informed beforehand that the technical support and after sales services will not be guaranteed once the device reaches an obsolete life cycle phase. When the sold installed base is large, it possibly would be a strategically wise decision to store some of the upcoming obsolete key parts in their own inventory. In that way, the availability can be sold to the customers even when the production of the device has already stopped.

5.4 Spare part sales analysis

The case unit sells spare parts for both new build vessels and for operating vessels. Also so called energy efficiency devices (frequency converters) are being sold for the marine customers by the case unit. This sub-chapter provides an overlook for the spare part sales over the past four years. This time period was chosen mainly because the case company changed the ERP system in 2010 and the older data was not easily available anymore. It is seen that reasonable conclusions can be drawn by using the available data from the past four years. The following statistics are based on spare part sales including energy efficiency products -, new build-, and repair sales but further analysis is based only on the actual emergency spare part sales. This is done because the new build spare part sales is not what one could call as a normal spare part sales. These spare parts for so called new build vessels are sold for the new vessels as recommended spare parts which in practice means that there has not been real use for those parts yet. Also when these spare parts are being ordered several months before the vessel is ready to sail, the delivery time is not crucial. The service unit also deals with repair cases and those have been excluded as well because this study focuses on the actual non-repairable spare part sales. The repair cases are also important as it can be seen as one way to adapt to the end of the life cycle phase from both a customer and supplier point of view. These so called return and phase-out methods as a way to manage spare parts during the obsolete life cycle phase were discussed earlier in this study.

The sales figures are shown on order line –level in figure 18 below. The blue bars represent the total sales including new build -, energy efficiency – and normal spare part sales. It can be seen that in 2014 the sales have doubled on order line level compared to 2013 sales figures. This can be explained by the number of vessels that were built during that year and therefore the demand for the new build spare parts was higher compared to the previous years. The demand for normal spare parts is illustrated with orange bars and it has been stable and only a little fluctuation from year to year can be detected in these numbers from figure 18 below. What is worth mentioning is that the number of individual items (grey bar) is relatively high compared to the normal spare part sales (orange bar) meaning that there is not many of the same items that customers are purchasing.

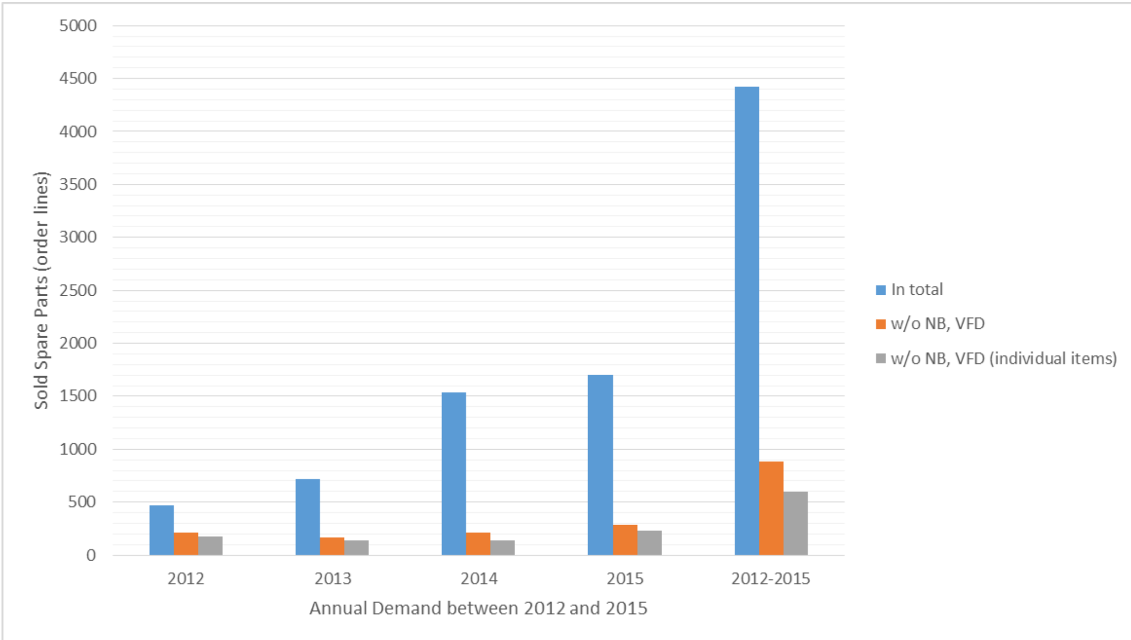


Figure 18. Case company's sales data between 2012-2015

Like it has been mentioned in the literature, the demand for spare parts is usually very lumpy and sporadic and the case company is not an exception. From table 3 below, it can be seen that there are approximately 50 products that have had demand of over ten units over the observed four year period between 2012 and 2015. 31 products have had demand between seven to ten units during the observed period. The majority of the parts have had demand between only 1-3 units. When considering this from the stocking point of view, a high service level can be seen as difficult to achieve as there are so many products with low demand. From the financial point of view, stocking these items would also be difficult as the inventory turnover would be relatively low and hence, tying assets at the same time.

Table 3. Case company's sales distribution between 2012-2015

Demand (pcs/2012-2015)	Individual items
1	268
2-3	183
4-6	74
7-10	31
>10	52
Grand total	608

The same sales data from 2012 to 2015 is presented in a graphical form in figure 19 below.

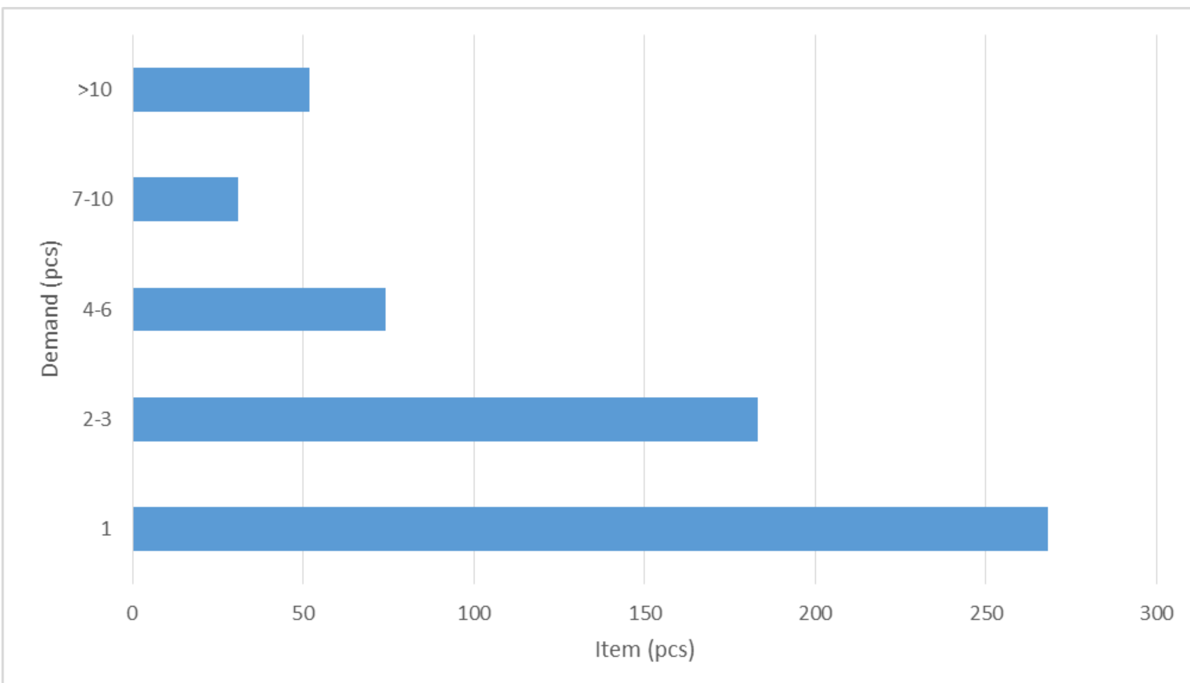


Figure 19. Case company's sales data between 2012-2015 (order lines)

As it has been discussed, the demand for spare parts is often sporadic and intermittent and the case company is not an exception. Clear demand patterns cannot be found and therefore traditional forecasting methods cannot be applied. Popular Pareto-analysis would give an indication of the most demanded spare parts from the past but as the quantities for many of the items are low, the future demand for all of the items cannot be predicted accurately by only looking at the historical sales figures. Also the presented FSN-analysis would most likely fail in being efficient, and a reasonable way of classifying spare parts, as there are numerous parts that have demand of only one piece within the 4 year period, meaning that there are years when some spare parts do not have demand at all. For these reasons, classification models that are based only on consumption rate would not be the most suitable ones in finding the most critical spare parts.

5.5 Criticality definition and the chosen classification model

There is not a consensus which classification model and criteria would be the most suitable one to be used in the after sales environment. In fact, it is said that research literature does not even know the existence of a systematic and well-built criticality assessment process (Zeng et al. 2012, p. 393). In general, spare parts classification models can be seen to consist of two main components. First, the criteria and the number of different criteria need to be decided. Once those have been chosen, different groups need to be created based on the criteria and this can be done with the help of decision trees or mathematical weighing for example. The spare part classification model suggested in this study is based on Huiskonen's, Bosnjakovic's and Molenaer's studies. Huiskonen (2001) divided criticality into process- and control criticalities. For the control criticality, three sub-categories were suggested such as failure predictability, number of suppliers, and delivery time. In this study, the process- and control criticality thinking is applied. The process criticality was related to the time that the problem caused by a sudden component failure can be withstood. Three levels introduced by Huiskonen were:

1. The failure has to be corrected immediately because otherwise, the operation cannot be continued
2. The failure is semi-severe but operation can be continued with reduced power and speed with the help of temporary arrangements.

3. The failure is not critical and can be tolerated for a relatively long time. (Huiskonen 2001, p. 129)

What is worth mentioning is that Huiskonen did not separate machine and system level criticalities. However, this in some cases might cause problems as the machines might share different level of importance depending on the vessel. Figure 20 below illustrates the case company's typical scope of supply. Typical project delivery includes generators, transformers, frequency converters, thruster motors, and the electric main propulsion units. The system is designed with redundancy, meaning that if for example one generator fails to operate, it does not stop the whole vessel. The same redundancy is built around the propulsion system, if one propulsion unit fails the vessel is still operable but with reduced power. In a nutshell, some specific part can be critical for the machine but one machine might not be that critical for the vessel which means that some component can be both critical and non-critical on the system level depending on the scope of supply and the amount of redundancy.

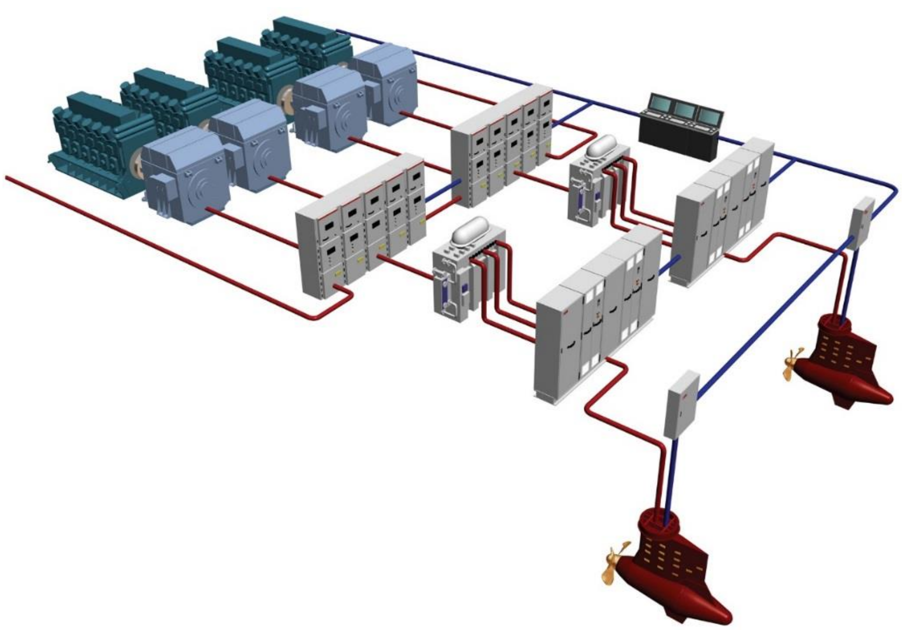


Figure 20. Example layout of the scope of supply in the cruise vessel projects

Bosnjakovic (2010) used the redundancy thinking approach regarding spare parts criticality classification in his study. VED-analysis was applied and three categories were introduced just like Huiskonen did as well. (Bosnjakovic 2010, p. 501)

1. Vital equipment: the stoppage of the machine causes downtime or significant decrease of quality for the whole production.
2. Essential equipment: machine stoppage causes reduced production but no instant stoppages.
3. Desired equipment: failure of the desired equipment does not cause any stoppages or decreases in production.

As it turned out that the case company's product factories do not have data of the failure probabilities or spare part usage rates available, it was not possible to create a mathematical based classification model. Instead of having only one or two criteria for classifying spare parts, a classification model based on mathematical approaches can consist of multiple criteria, both qualitative and quantitative. With the help of a mathematical classification model, the criticality could be built around multiple criteria such as equipment criticality, item failure probability, and spare parts usage rate where every criterion will be weighted and the total criticality is the sum of each of the sub-clusters. For example some specific spare part might be critical for the machine but if statistics show that the failure of the part is unlikely, one could store such parts in the central stock instead of having those on every vessel.

Also taking the limitations regarding the available data for different criteria into account, the critical component in this study is defined as follows: *"Component is critical when its failure affects safe and reliable operation. In the worst case, the failure prevents the operation causing downtime and possibly unwanted costs such as compensation for the cruise customers due to a missed port of call. The more critical the component is for the system, the less there is time to react to the situation. Hence, the more vital the component is for the system, the closer to the vessel it needs to be stored."*

Considering the above defined criticality definition, the qualitative VED-analysis based on a decision tree model was seen to be suitable to be applied in this study. The criticality classification model applied in this study provides answers to how severe the component failure can be for both machine and system levels, and how much there is time to correct the failure. This model was chosen as it is seen as flexible to use and was suitable for the available time frame as well. Two criteria were included in the model and therefore, there was no need to consider mathematical weighing between different criteria. If the classification model presented in this study had more criteria, the model would become too complicated to handle as the number of different possibilities and groups grow uncontrollably. Spare part criticality has been enthroned in multiple academic publications and partly therefore, it is used as the main criterion in the proposed classification model. By identifying critical components, safe and efficient operation can be improved and a further development of the inventory policies can be carried out based on the criticality analysis.

Even though time as a classification criterion is subject to subjectivity to some extent, it was still seen as important to include it in the model. In academic studies, delivery time is often suggested to be taken into account. If a spare part is classified critical partly based on the delivery time, what happens to the criticality when the delivery time changes? It might be that some spare part is available from the supplier's stock at the moment but not tomorrow anymore because the spare part was sold out and the lead time for the part is therefore longer. This means that the spare part which, today was not critical, might turn to critical tomorrow depending on the stocking levels. If the company prepares spare part lists for the customers, it can be that the component was critical on one recommendation list last year but not anymore on the latest list making it difficult to prepare unambiguous spare part lists. Therefore, the time component used in this study is related to the customers' operational needs by considering how much the customer has time to fix the problem in the case of a sudden component failure.

The more vital the component is for the system, the less there is time to control the situation.

The classification model is built in a way that the component criticality on the machine level is defined first as it was set to be a ruling criterion. Like it was mentioned earlier in this study, it is seen that the equipment can share different criticalities depending on the vessel and therefore, drilling down to the machine level in defining criticalities is justified. The process can be started by looking at every individual component and then estimating what happens on the machine level if a component fails. At this phase there are only two possibilities, the machine can either operate normally or it fails to operate. This is called the "machine criticality". After completing this phase, the view can be expanded on the system level by asking "What happens on the system level if some certain machine fails to operate?" At this stage, there are three possibilities how the machine failure affects to the whole system:

1. Non-vital: the machine failure does not cause any significant problems to the system and the operation can be continued normally. "Made-to-order"-delivery times can be withstood.
2. Essential: machine failure can effect performance but does not prevent operation. The problem can be withstood with temporary arrangements.
3. Vital: machine failure can effect performance and could prevent operation. The problem cannot be withstood long and needs to be repaired in the next port.

Once the machine criticality is defined, it is possible to estimate what happens on the system level. If the machine is classified as non-critical, the system criticality is always non-critical in these kind of situations as the machine continues working normally and hence, does not cause any problems on the system level. If the machine is defined vital for the system, then there are three possibilities for the system criticality as defined above. In this case the failure either has no effect on operation, the system can be used with reduced power but not having operational risk or reduced power with having risk of operational continuation. The system criticality estimation in this study is dependent on the redundancy. For example if the vessel has six generators and one fails to operate, the effects for the operation are seen as non-vital on the system level whereas if the vessel loses one of the two cyclo frequency converters totally, the results are more severe for the system as the propulsion torque reduces to half and possibly prevents the operation after the next port of call. Table 4 below summarizes the criticality criteria and their descriptions.

Table 4. Summarized definitions for machine and system criticalities.

Criticality Criteria	Description
Machine Criticality	Machine criticality is related to the consequences caused by a sudden component failure. Two groups can be distinguished 1 and 2. Sudden item failure in group 1 products does not have an effect to machine operation whereas group 2 products cause stoppages on machine level.
System Criticality	System criticality is dependent on the machine criticality. Parts that are considered machine critical are taken into closer inspection within the system wise. System criticality is divided into three groups: 1. Non-vital: the machine failure does not cause any significant problems to the system and the operation can be continued

		normally. "Made-to-order"-delivery times can be withstood.
	2.	Essential: machine failure can effect performance but do not prevent operation. The problem can be withstood with temporary arrangements.
	3.	Vital: machine failure can effect performance and could prevent operation. The problem cannot be withstood long and needs to be repaired in the next port.

5.6 Excluded classification criteria

Many classification criteria needed to be left outside partly due to the lack of reliable data. As the definition for the criticality evolved along the study, it was also noticed that the below discussed criteria are more related to the control criticality than process criticality but are still important to go through as controlling the spare parts can be seen to be the next step in developing the guidelines for inventory management.

Like it has been mentioned in the text above, Mean Time to Failure (MTTF) can be in some cases used for spare parts demand forecasting. When the size of the installed base is known, together with reliability analysis a rough understanding of the needed inventory levels can be formed. In the case company, the installed base is getting more and more accurate all the time however, the MTTF statistics is not available and therefore, this criterion cannot be utilized either within this study or for other inventory development purposes. It also turned out that the product factories are not keeping track of how many parts are sold as an emergency spare part. Even if this number was available, it would still be a rough indicative figure as there are other spare part providers on the markets for bulk items. Spare parts sales together with MTTF would however give an indication of the most failure sensitive parts and help for example customers to prepare the end of the life cycle when spare parts are more difficult to acquire. Or, service providers could plan inventory stocking levels with the help of these numbers.

As the case unit does not have its own active spare part inventory, the stock out costs were left outside. In the future, specifically if maintenance agreements will be consummated, this criterion will be important to think of. For the same reason deterioration problems were not included. If the case unit will set up a spare part inventory in the future, this aspect needs some consideration as well. For example bearing gaskets will deteriorate as time goes by. If the demand for these parts is very low such as one piece every two years and the spare part itself deteriorates within one year, the right timing and stocking quantities might become an issue as the part will lose its quality before it is actually needed.

Life cycle phase as a classification criterion was mentioned in many spare part classification and inventory management related publications and it is considered important also in this study as it is strongly linked with the spare parts availability. The life cycle data on machine level is available in the case company but precise and extensive life cycle data on a component level is not available. This is problematic when considering life cycle phase as a classification criterion on a component level. Usually when some machine or product family becomes obsolete, it does not mean that every component installed in the machine become obsolete, only some of them. Now when the data is available only on the machine level, it cannot be used for classification purposes because of the above mentioned reasons. The case company has divided the product life cycle into four different phases: active, classic, limited and obsolete. When the product is new and just introduced to the markets, it is called an active product. In this phase the production has just started and other services are available as well as spare parts. When the product moves to the classic phase, spare parts are still available but not in the same scale as in the active phase which might drive independent service providers and customers to increase stocking quantities. Later in the limited phase, the product is not manufactured anymore and the spare parts are not actively stored anymore. In this phase, spare parts that are in the inventory will be sold and repair and return services still provided. Later when the product moves to the obsolete phase, the after sales services are not guaranteed by the product factories anymore. Product families in this life cycle phase are old and skilful maintenance experts are difficult to find making it difficult even for system providers to offer customer support. For these reasons, life cycle phase on component level would offer help for both service provider and customers to prepare themselves to the obsolete life cycle phase. The importance of life cycle data was raised also during the customer interviews. It was understood that customers have difficulties to plan acquisitions as the component level life cycle data is not available and hence, sometimes it might come as a surprise that some component has become obsolete.

Safety and environmental related questions were considered important therefore, safety as a classification criterion is included in the criticality definition presented in this study. If a critical component fails it affects the vessel's capability to sustain safe operation. International Maritime Organization (IMO) has adopted a convention for the prevention of pollution from ships. This legislation is called MARPOL and it has six different annexes for the different types of pollution ranging from oil and bilge sewage to air pollution (IMO 2016). However, classification societies that operate under IMO do not make exact recommendations on spare parts that should be carried on board. Instead, for example Germanischer-Lloyd states the following:

> "*In order to be able to restore machinery operation and manoeuvring capability of the ship in the event of a damage at sea spare parts for main propulsion plant and the essential equipment shall be available aboard of each ship together with the necessary tools.*"

and

> “*The amount of spare parts shall be documented and a corresponding list shall be carried aboard.”* (GL-Group 2016, p. 22-1)

From that perspective, the best knowledge should come from the manufacturer as to what kind of spare parts are needed and what not in order to sustain safe and reliable operational capability.

6 Applying Spare Parts Classification Model to the Case Company

6.1 Key findings and evaluation of the model

The case study was carried out by analyzing a large cruise vessel’s installed base. The subject vessel was built in Finland between 1999 and 2000. As the vessel is getting relatively old, some of the machines are becoming obsolete and one purpose of the case study was to emphasize the unavailability of the components and recognize critical components installed in those machines. Project documentation back then was not on the level where it is nowadays meaning that the component lists are difficult to use as those are available only as paper copies and need to be scanned into electronic form. The lists are missing some of the key elements such as product codes and installed on board quantities. This causes problems when tracking the parts or possible replacement parts from the product factories and makes the business difficult from the after sales point of view.

Like it has been mentioned before, some machines can be critical on one vessel and non-critical on another vessel. For example one vessel might have six generators and some other vessel may have only two generators. The generators in the latter are more critical as there is not that much redundancy causing problems in power generation and further in propulsion and in many other applications in the case of a component failure. Therefore, system criticality needs to be evaluated on a case by case bases unlike machine criticality. When considering machine criticality, the level of redundancy is meaningless and therefore machine criticality can be re-used from one vessel to another. However, it is important to notice that the component lists might vary slightly from one vessel to another even though the machines are the same. Like it has been mentioned earlier in this study, the innovation cycles are getting shorter all the time and therefore, some of the components might have changed over time even though the machine is the same.

When the model was first tested, the definition for system criticality was a little bit different than what it is now in the final version. System-criticality was divided into three classes: vital, essential and non-vital. The difference was that the vital spare parts were defined in a way that its failure prevents the operation totally. By following this definition, it turned out that none of the components fell into that category due to the redundancy built in the system (see Appendix 1). Discussions with the commissioning engineers however raised a point that the failure can be severe enough that the port authority does not allow the vessel to continue the voyage before the major failure is maintained. This led to the changed definition of the vital components. The vital component is now defined in a way that it affects the performance and can prevent operation. Due to these changes, the list needs to be reevaluated at least for the parts that are classified as essential to see which components will eventually fall into vital category.

Another question that was discussed during the study was the need for having non-vital criterion under the system criticality. If a component has been already classified as machine vital, can it suddenly be non-vital on the system level? The customer interviews supported the approach of having non-vital criterion also on the system level. The approach was seen to be systematic and understandable regardless of the technical skills of the customer (Person A, 2016).

The model is easy to implement as the approach is straight forward and user friendly. Problems might arise when there is a high season on the commissioning and dry docking services and the service engineers are not available and thus their time is very limited to help with the criticality estimations. Another difficulty is related to the data availability. Receiving quotations for the installed components from the product factories can take a lot of time due to long component lists, missing item codes, and other information. Prices and delivery times can vary all the time, some components can become obsolete as time goes by and hence, the data becomes outdated. Keeping the data up to date can be time consuming and requires a lot of work both from the manufacturer and the service provider. In that sense, keeping a massive database for multiple vessels can be difficult and therefore, the costs and benefits should be discussed and studied.

It was stated in the academic literature that good classification models cannot be based on only one criterion nor either only on qualitative or quantitative models. However, if the classification model has multiple different criteria it may become too difficult to handle (Celebi et al. 2008). The disadvantage of this model is the subjectivity involved through the pairwise comparison for the machine and system criticalities. This has been tried to be eliminated by having unambiguous and well defined definitions for each criticality group. Hence, the number of groups in which the spare part can belong to, was seen favorable to limit to three. In this way, enough distinction can be made between critical and non-critical spare parts and yet, not having too many intermediate groups. The adopted decision tree approach allows other criteria to be added afterwards if found needed. During this study this was tested and the number of nodes and possible classification groups increased every time when a new classification criterion is added. Therefore, when adding new classification criterion to the model, attention needs to be paid to the growing number of different spare part groups.

6.2 Further development of the spare parts classification

Given the available time frame for the thesis, basic guidelines for spare parts classification were developed. Also it was investigated what is possible to do and what not in terms of the available data. The main reason for the excluded criteria was the lack of information that was available from the product factories. The criticality of the component is seen important to divide into machine and system criticalities as different system layouts exist affecting the redundancy and therefore, generic part lists cannot be created in that sense. However, the machine criticality is not dependent on the vessel and therefore can be re-used from one vessel to another.

The created classification model classifies components from the technical point of view and for how long the failure can be withstood. This offers a foundation for further inventory development purposes. When developing one’s own inventory, financial and logistics points of views need to be also taken into account. Factors such as inventory turnover, required space for the spare parts, and deterioration need to be considered. The purpose of this classification model is not to give guidelines for stocking quantities or re-ordering policies as it is a vast subject and would require another study. However, it can be used as a first step for better spare parts management by giving an idea of the parts that should be stored, and also an indication of the storing location. Stocking decisions also depend on the area of operation. For example the delivery time can be long if the vessel is operating in some remote location with difficult access, or due to strict customs clearance processes, but on the other hand the delivery time can be short for the same spare part if the vessel is operating near the local service units with decent inventories.

The next step regarding spare parts classification would be to classify as many vessels as possible to be able to build a larger database. Once there is enough classified spare parts, it can be used as a main source for the existing vessels. Preferably the chosen vessels should not be similar to each other so that the database would become diverse and have vessels with different redundancies as well. Finally, the database would have enough classified machines and components so that the user would be able to classify any vessel regardless the vessel’s installed base by using the information fetched from the database. Despite the vast database, it can be possible that the database does not have every item that is installed in the new devices and therefore in these kind of cases the missing parts need to be classified one by one and added to the database so that the next time the part is available in there.

The second step when it comes to spare parts classification is suggested to be the start of a RCM project for systems related machines and products as well. Like it was seen in the propulsion products after sales team, components that were found critical by service technicians, 80 % of them were found critical after the RCM project as well. For the case department, the implementation of a RCM project could assure the results received from the classification models developed in this study. All in all, there are no correct answers what it comes to spare parts classification and hence, the qualitative decision tree based on VED-analysis suggested in this study provides a good starting point for listing critical spare parts.

7 Conclusions and Discussion

7.1 Research objectives and results

The objective of this study was to identify different ways how spare parts can be classified in order to improve their availability. Three sub-questions were set up for being able to provide solutions to the actual research problem. Below, the research questions are listed and answered shortly based on the findings made during the study process.

1. What kind of classification models can be found from the literature?

Classification models can be divided into quantitative and qualitative models. Qualitative classification models are usually based on experienced engineers' opinions and therefore might suffer from subjectivity. However, in many cases the qualitative models have turned out to be practical as those are easy to implement and understandable to use. The most used qualitative model is the so called VED-analysis where spare parts can be divided into three groups based on their criticality.

The quantitative models such as ABC-analysis and FSN-analysis take such criteria as annual consumption or price which do not suffer from subjectivity to much extent. However, the data can be difficult to get and sometimes even impossible as companies may not keep record of the number of sold spare parts for example. Quantitative models based on one criterion are seen as insufficient to make enough distinction between spare parts that have different features and therefore are not seen as favorable to use in the after sales environment where spare parts are of a heterogeneous type.

In some academic publications quantitative and qualitative classification models have been combined. In this way, the advantages of both models can be utilized. One example is the AHP-analysis which was presented in the literature review part. In this model multiple criticality groups can be created. Each group can have multiple criteria which have been weighted and the overall criticality can be derived with the help of mathematical vectors. Problems can arise when considering how each of the criterion should be weighted and this problem has been also raised in the academic publications and also data gathering problems can be faced in this approach. The AHP-analysis with multiple criteria can quickly become difficult to understand and hence, the utilization of such models can suffer in practice. Partly therefore, simple models such as ABC and FSN analysis have sustained popularity as spare part classification models even though these models simplify situations by having only one classification criterion.

2. What criteria should be taken into account when classifying spare parts?

Especially in the industrial environment where large sums of capital are tied into machines and devices, a proper classification model for managing spare parts is of great importance. What is a good classification model and what are the good classification criteria then? These questions serve as the basis for many academic publications in the field of inventory management. By far, no consensus has been found and many authors emphasize that there can be different point of views on the critical spare parts within one company meaning that the important component from the financial point of view can be rather different compared to the maintenance point of view. Therefore, before considering any development steps to improve or develop spare parts classification, the reasons for implementation must be thought through thoroughly. In general, three different aspects can be distinguished: maintenance, financial and logistics. A component failure which can result in reduced production quantity or quality can be seen as critical and important from the maintenance point of view. If some part is expensive and its demand is very low, the financial department could classify that as a critical component as it ties capital in the inventories. If the failed component is installed in a plant that is located in a remote area, transportation might become an issue. Also if the component is becoming obsolete and requires a lot of space, the person in charge of logistics could consider it to be critical from that perspective.

The case company has recently paid attention to the inventory levels throughout the different business units. In that sense, the holding costs and demand patterns are of great importance. However, as the focus in this study steadily shifted into defining a classification model for critical spare parts instead of developing guidelines to inventory management so therefore, holding costs and demand rates were not considered anymore. In this study, spare parts classification was considered from the maintenance and customer points of view by presenting questions such as what are the critical spare parts which availability ensures safe and reliable operation. The classification model was built around spare parts criticality by presenting two criteria: machine and system criticalities. Machine criticality answers what happens to the machine when a component fails whereas system criticality provides answers to what happens on the system level when a machine fails to operate and how much time there is to fix the occurred problem. These two criteria were seen as sufficient to distinguish the level of importance between different spare parts and also to make visible the timeframe in which the failure needs to be corrected.

3. How spare parts classification improves the availability?

What to stock? Where to stock? How much to stock? These are the most common questions that arise in inventory management related literature. As spare parts have different qualities, it is important to define different classes for different spare parts. Like Bacchetti and Saccani suggest, spare parts management is an iterative process including four steps starting from spare parts classification and followed by the demand forecasting. Once these steps have been implemented, it is possible to set up guidelines for inventory management and observe its performance.

In this study, a two-step decision tree classification model based on component criticality was applied. The first criticality group consists of components that are classified as non-vital for the machine and/or system levels. As these components are not vital, long delivery times can be withstood without major problems. The second criticality group consists of components that are classified as vital for the machine and essential on the system level. From the technical point of view, even a long delivery time can be withstood for some time with the help of temporary arrangements, but the problem might be inconvenient in the long run for the vessel operator as the failed machine is not working properly. As the need for the group two parts is not urgent, the recommendation is to keep these spare parts either in the central stock or to make a spare parts availability agreement with the supplier. The third criticality group consists of all the remaining components which are machine and system vital parts. Regarding these parts, the problem needs to be fixed latest during the next port of call and therefore, the recommendation is to keep the parts on board. The figure 21 below shows the decision making steps for the criticality classification.

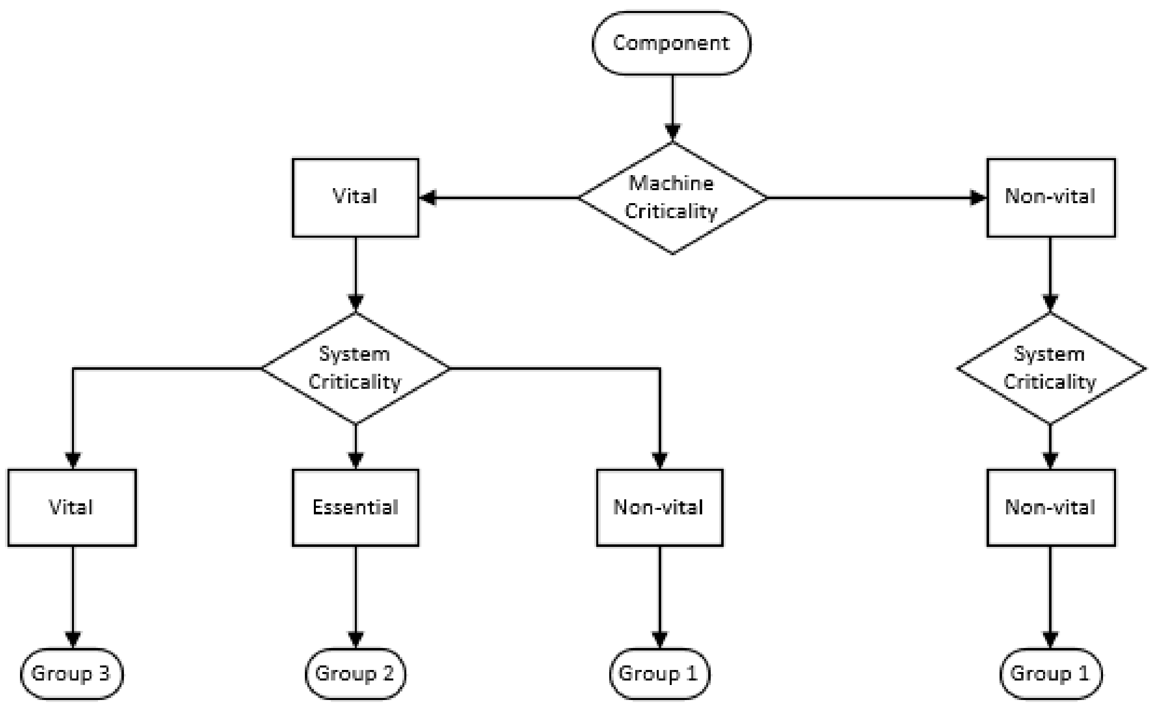


Figure 21. Decision steps for defining the overall component criticality

The applied classification model in this study can provide answers to the first two questions with the help of presented process criticality related classification criteria.

What to stock and where to stock? Parts which failure can prevent operation should be stored on board. Parts which failure can have an effect on performance but do not prevent the operation, can be stored either in the central stock or the customer and supplier can make a maintenance agreement where the supplier guarantees the availability of the subject spare parts. Finally, the parts which failure does not have an effect on the operation and the failure can be withstood for a relatively long time, can be ordered on demand from the supplier. In table 5 below, different groups are separated in terms of machine and system criticalities. In total, based on Molenaer's study (Molenaers et al. 2012, 575), three different criticality groups are created in order to be able to separate the characteristics and yet, keep the model simple enough by not creating too many groups.

Table 5. Criticality groups based on the results of the logical tree

Criticality Groups	Definition
Group 1 **On Demand Parts**	• The component failure does not cause notable problems to the machine or the system • Problems can be withstood for more than week • Order on demand from the supplier
Group 2 **Central Stock Parts / Maintenance Agreement Parts**	• Component failure causes noticeable problems and can be withstood for a short period of time • Recommendation to keep spare parts in the central stock or having maintenance agreement with the supplier

Group 3 **Onboard Parts**	• Vital for the system and the failure needs to be corrected immediately • Port authority dictates the repair to be done before the operations can be continued • Recommendation to keep spare parts onboard

Spare parts classification based on operational need provide a good foundation for further co-operation between the customer and the supplier in terms of deciding who will stock what and where. For being able to develop guidelines for spare part inventory, further studies need to be concluded. The classification model considered in this study allows more detailed spare part recommendations to me made so that the customers would have enough information to decide the risk level they want to take.

7.2 Suggestions for the case company

Feedback from customers needs to be taken seriously. Last year the case unit received questions regarding spare part recommendations for new build vessels as well as negative feedback from customer satisfaction surveys related to long lead times. Based on the made findings during the study, two main suggestions can be given. First is to start offering more detailed spare part recommendations to the customers. Customer interviews raised alarming issues in what might happen in the worst case when the spare part recommendations are insufficient. When the case company provides spare part recommendations, the customer then inserts the recommended spare parts into their maintenance management system called AMOS. If some operationally critical components are not recommended, the customer might not have inserted the parts into their AMOS. In a case of sudden component failure, the missing component in the system is more time consuming to acquire as the type and specifications are missing and the AMOS is not giving any alerts. By providing more detailed information of the spare parts, customers could be able to form a better picture of the spare part lists and then decide the risk level what they are able to withstand on their own.

Long lead times need some consideration as well. The maritime industry is a very hectic and capital intensive environment where machine failures can result in great losses and therefore the delivery times should be minimized. The lead times should be emphasized on the spare part recommendation lists because that would be helpful for the customer to understand the connection between the critical spare part and its availability. Life cycle phase related issues have been discussed in this study and it was a subject raised by the customers during the interviews as well. More focus should be put on managing life cycle data on the component level rather than only machine level. Obsolescence should not come as a surprise for customers when requesting a new spare part. Instead, the case company should be more proactive in giving notice well in advance so that the customers would have more time to create plans for the possible obsolete components. This would require co-operation between the case unit and product factories from which the component level life cycle data should come in the first place.

Like it was mentioned before, development of the inventory management guidelines was not in the scope of this study. However, spare part sales related data was studied and it was noticed that the actual emergency spare part sales figures are relatively low and random and therefore, setting up a customer’s own inventory can be seen difficult from the financial point of view. As the case company has service centres all over the world, global inventory in some central location would be one possibility to reduce quotation lead times, delivery times and improve service level while keeping the operational costs low. However, it is worth studying would that bring any extra revenue for the case company. There are generic products that can be bought through multiple suppliers, and then supplier specific products that are available only from one supplier.

It can be that the sales would not improve despite the central inventory as the customers might continue using the provider who has the lowest prices. And same thing with the supplier specific products which cannot be bought anywhere else and if there is a real need for the product then there is no alternatives than to just withstand the long delivery time.

To summarize the results, the classification approach needs to be presented to the management and modified based on feedback before the demand forecasting can be carried out which can be seen as a next step in improving spare parts management. When starting to define guidelines for the inventory, not only technical department should take part as the spare part inventory influences also logistics and financial departments. During this point, earlier discussed criteria such as life cycle, MTTF and price should be taken into account.

7.3 Validation of the references and research methods

The study is divided into literature review and empirical case study. The literature part provides an overlook to the most common spare parts classification models and recent academic studies in the field of the after sales environment. Academic studies and publications were the most used sources of information and attention was also paid to the publication dates and authors. From the publications, the most recent ones which were published in industrial management journals were favored although, basic principles in the inventory management for example have been the same over the decades. Some older academic studies were used when mapping how the criticality definition has evolved over time. The empirical part of the study was carried out as a case study for a vessel that was built in Finland between 1999 and 2000. Component lists have over 1000 items and when the duplicates have been removed, the list still has around 500 items. In this part of the study, the considered classification criteria were tested with the subject case cruise vessel.

During the study, meetings were held with the instructors where the classification related questions were discussed. Also the meetings with maintenance and commissioning engineers gave important aspects in to what should be considered when classifying spare parts, for example that the port authority might not give permission to continue the voyage if some machine failure affects the operation but does not prevent it. For being able to get external opinions, two semi-structured interviews were held. Semi-structured interviews were seen as the most suitable approach for this kind of study. Questionnaires would had been easier to send to larger group but as the questions and the problems which needed external opinions were not possible to put into unambiguous format, the semi-structured interviews were seen to be the most suitable method. The semi-structured interviews allowed the customers also to express themselves freely as the structure of the interview was not strict. The interviews confirmed that there is a real need for spare parts classification and that the developed model was easy to understand regardless of the customers' technical skills. The number of interviews is relatively low and there is a possibility that the results would be different if more interviews were held and therefore, generalization of the received answers cannot be done. However, the interviews gave enough input so that it is possible to visit the customers in person and present the idea without fearing a total rejection towards the idea.

The developed classification model is seen to be generic and therefore, it can be adopted in the other organizations operating in the marine industry as well. With a little adjusting, the model is suitable also for other industries. The main problem arises with the time component that was used to specify the storage location. By excluding that or redefining the time definition, the criticality classification can be used in other industries as well. Unlike the classification models presented in academic literature, the developed model in this study takes two criteria: machine –and system criticalities into account which can be seen as relatively low in terms of different criteria. However, when the number of criteria is increased the model becomes difficult to use and understand. From that perspective the applied spare parts classification model provides an easy to understand approach to classify critical parts which can be seen as the first step in improving spare parts management.

8 Summary

The goal of this study was to provide an outlook on the most recent spare part classification models and how those could be utilized in the case company. The research was started by presenting academic publications related to the after-sales environment from the spare parts point of view. In this part, the most common classification models, different classification criteria and the basics of inventory management were presented. The case company does not have an active spare parts inventory at the moment and from the inventory management point of view, spare parts classification can be seen as the first step for setting inventory management guidelines. As the spare parts can have different features such as criticality, life cycle phase, commonality and delivery time, it is important to recognize these features for being able to manage them better. As the marine industry is very capital intensive where machine failures can cause downtime resulting in great losses, long delivery times can cause trouble for the vessels' operation and therefore, are not favourable. Also when the case company prepares recommended spare part lists for the new build vessels, customers in some cases have had difficulties in understanding the importance of the recommended parts. This set up works as the basis for this study where different classification models and criteria are discussed instead of developing guidelines for inventory management.

When the spare part classification models and criteria were compared, the focus was put on to customers and considered classification criteria that are seen important from the customer point of view. The model needed to be also easy to implement and understand for a person regardless of his/her technical knowledge. Taking the previous mentioned requirements into account, a decision tree based VED-analysis was introduced in the study. In this approach, spare parts are classified based on their criticality which is divided into two phases: machine and system criticalities. The customer point of view was taken into account by considering how much there is time to repair the suddenly occurred machine failure. Based on the component criticality and the available time frame, suggestions for the storage location can be given. The more critical the spare part is, the closer to the vessel it needs to be stored. The customer interviews supported this approach as it was seen as an understandable and systematic way to classify spare parts. Delivery times and life cycle phase related questions were raised by the customers but as those criteria are seen to be related to actual inventory management, the developed classification approach does not take those into account at this stage.

The applied classification model provides answers to questions such as what to stock and where to stock. But when it comes to stocking quantities, further research needs to be carried out. It was studied that the subject case service unit does not have enough vast sales figures and therefore implementing a cost effective local inventory is difficult and hence, global co-operation could be one possibility to keep both costs and delivery times low. The applied classification model can be used when providing recommended spare part lists for the customers and even if it is later decided not to go further with developing their own inventory, the information provided in this this study can still be utilized by offering more detailed information to the customers regarding spare parts.

References

Ala-Risku, T. 2009. Installed Base Information: Ensuring Customer Value and Profitability after the Sale. Espoo. Yliopistopaino. pp. 1-203, ISBN: 978-952-248-005-7

Almeida, A., Cavalcante, C., Alencar, M., Ferreira, R., Almeida-Filho, A. & Garcez, T. 2015. Multicriteria and Multiobjective Models for Risk, Reliability and Maintenance Decision Analysis. International Series in Operations Research & Management Science Volume 231, pp. 1-417, ISBN 978-3-319-17968-1

Altay, N. & Litteral, L. 2011. Service Parts management – Demand Forecasting and Inventory Control. London. Springer, pp. 1-315, ISBN 978-0-85729-038-0

Bacchetti, A. & Saccani, N. 2011. Spare parts classification and demand forecasting for stock control: Investigating the gap between research and practice. Omega vol. 40, no. 6, pp. 722-737

Behfard, F., Heijden, M., Hanbali, A. & Zijm, W. 2013. Last time buy and repair decisions for spare parts, p. 498-510

Bosnjakovic, M. 2010. Multicriteria Inventory Model for Spare Parts, pp. 499-504

Botter, R. & Fortuin, L. 2000. Stocking strategy for service parts – a case study. International Journal of Operations & Production Management Vol. 20 Iss 6, pp. 656-674

Braglia, M., Grassi, A. & Montanari, R. 2004. Multi-attribute classification method for spare parts inventory management. Journal of Quality in Maintenance Engineering Vol. 10 Iss 1, pp. 55-65

Bundschuh, R. & Dezvane, T. 2003. How to Make After-Sales Services Payoff, The McKinsey Quarterly, 4 2003

Cavalieri, S. Garetti, M., Macchi, & Pinto, R. 2008, A decision-making framework for managing maintenance spare parts. Production Planning & Control Vol. 19, No. 4 pp 380-396

Carpentieri, M., Guglielmini, A. & Mangione, F. 2007, A Life Cycle Framework for the Management of Spare Parts. Advances in Life Cycle Engineering for Sustainable Manufacturing Businesses, pp. 473-478.

Celebi, D., Bayraktar, D. & Aykac, D. 2008. Multi Criteria Classification for Spare Parts Inventory. Computers & Industrial Engineering, pp. 1780-1787

Chen, Y., Kevin, W., Levy, J., Hipel, K. & Kilgour, M. 2008. A Rough Set Approach to Multiple Criteria ABC Analysis, pp. 35-52

Cohen, M., Agrawal, N. & Agrawal, V. 2006. Winning in the Aftermarket, pp. 129-138

Dekker, R., Kleijn, M.J. & Rooij, P.J. 1996. A Spare Parts Stocking Policy Based on Equipment Criticality. International Journal of Production Economics vol. 56-57, pp. 69-77

Duffuaa, S. & Raouf, A. Planning and Control of Maintenance Systems, Chapter 11. Reliability-Centered Maintenance 2015. Switzerland. Springer, pp. 245-260, ISBN 978-3-319-19802-6

Flores, B. Olson, D. & Dorai, V. 1992. Management of Multicriteria Inventory Classification. Mathl. Comput. Modelling Vol. 16, No. 12, pp. 71-82

Fortuin, L. & Martin, H. 1999. Control of Service Parts. International Journal of Operations & Production Management, Vol. 19 Iss 9, pp. 950-968

GL-Group, [WWW-document]. [Accessed May 11th 2016]. Available: http://www.gl-group.com/infoServices/rules/pdfs/gl_i-1-3_e.pdf

Goffin, K. & Colin, N. 2011. Customer support and new product development – An exploratory study. International Journal of Operations & Production Management, Vol. 21 Iss 3, pp. 275-301

Gummesson, E. 1994. Service Management: An Evaluation and the Future. International Journal of Service Industry Management Vol. 5 Iss 1, pp. 77-96

Guvenir, H. & Erel, E. 1998. Multicriteria inventory classification using a genetic algorithm. European Journal of Operational Research vol. 105, no. 1, pp. 29-37

Hirsjärvi, S., Remes, P. & Sajavaara, P. 2008. Tutki ja Kirjoita. Helsinki. Otavan kirjapaino Oy. pp. 1-448

Holmström, J. & Ala-Risku, T. 2010 Business Process Management Systems – Enabling Continuous Improvement in Industrial Services, pp. 636-643

Huiskonen, J. 2001. Maintenance of spare parts logistics: Special characteristics and strategic choices. International Journal of Production Economics vol. 71, no. 1-3, pp. 125-133

IMO 2016, [WWW-document], [Accessed May 11th 2016]. Available: http://www.imo.org/en/About/Conventions/ListOfConventions/Pages/International-Convention-for-the-Prevention-of-Pollution-from-Ships-%28MARPOL%29.aspx

Inderfurth, K. & Mukherjee, M. 2008. Decision support for spare parts acquisition in post product life cycle. Central European Journal of Operations Research, pp. 17-42

Johns, N. 2001. “What is this thing called service?”. European Journal of Marketing, Vol. 33 Iss 9/10, pp. 958-974

Kotler, P. & Keller, K. 2012. Marketing Management. New Jersey. Pearson. pp 812, ISBN 978-0-13-210292-6

Krikke, H. & van der Laan, E. 2011. Last Time Buy and control policies with phase-out returns: a case study in plant control systems, pp. 5183-5206

Li, X., Dekker, R., Heij, C. & Hekimoglu, M. 2016. Assessing End-Of-Supply Risk of Spare Parts Using the Proportional Hazard Model, pp. 373-394

Macchi, M., Fumagalli, L., Pinto, R. & Cavalieri, S. 2011. A Decision Making Framework for Managing Maintenance Spare Parts in Case of Lumpy Demand: Action Research in the Avionic Sector. Service Parts Management, pp. 171-202

Marquez, A. 2007. The Maintenance Managament Framework, pp 341, ISBN: 978-1-84628-821-0

Molenaers, A., Baets, H., Pintelon, L. & Wayenbergh, G. 2011. Criticality classification of spare parts: A case study. International Journal of Production Economics vol. 140, no. 2, pp. 570-578

Natarajan, K. & Tarannum, N. 2012. Spare Parts Pricing Optimization, pp 1-10

Olhager, J. 2007. Advances in Production Management Systems, pp. 1-422, ISBN: 9780387741567

Person A. 2016. Manager, Project Management and Retrofit. Company A. Interview. 13.6.2016

Person B. 2016. Senior Superintendent, Propulsion Systems. Company B. Interview. 16.6.2016

Person X. 2016. Global Marketing & Sales Manager Medium Voltage Service. Company X. E-mail interview. 16.3.2016

Person Y. 2016. Service Product Manager. Company X. E-mail interview. 16.3.2016

Person Z. 2016. Service Product Manager. Company X. E-mail interview. 16.3.2016

Petrovic, D. & Petrovic, R, 1992. SPARTA II: Further Development in an Expert System for Advising on Stocks of Spare Parts, pp. 291-300

Pince, C. & Dekker, R. 2011. An inventory model for slow moving items subject to obsolescence. European Journal of Operational Research Aug 2011, Vol. 213 Issue 1, pp. 83-95

Porras, E. & Dekker, R. 2008, An Inventory Control System for Spare Parts at a Refinery: An Empirical Comparison of Different Re-Order Point Methods. European Journal of Operational Research Jan 2008, Vol. 184 Issue 1, pp. 201-132

Pourakbar, M., den van Laan, E. & Dekker, R. 2013. End-of-Life Inventory Problem with Phaseout Returns. Production and Operations Management Volume 23, Issue 9, pp. 1561-1576

Roda, I., Macchi, L., Fumagalli, L. & Viveros, P. 2014. A review of multi-criteria classification of spare parts: From literature analysis to industrial evidences. Journal of Manufacturing Technology Management, Vol. 25 Iss 4, pp. 528-549

Rolstadaas, A., Hvolby, H. & Falster, P. 2008. Review of After-Sales Service Concepts, pp. 383-391.

Selvik, J.T. & Aven, T. 2015. A framework for reliability and risk centered maintenance. Reliability Engineering & System Safety vol. 96, no. 2, pp. 324-331

Stamboliska, Z., Rusinski, E. & Moczko, P. 2015. Proactive Condition Monitoring of Low Speed Machines, pp. 1-193, ISBN: 978-3-319-10493-5

Stoll, J., Kopf, R., Schneider, J. & Lanza, G. 2015, Criticality analysis of spare parts management: a multi-criteria classification regarding a cross-plant central warehousing strategy. Production Engineering, pp. 225-235

Teunter, R. & Haneveld, W. 1998. The ‘final order’ problem. European Journal of Operational Research vol. 107, no. 1, pp. 35-44

Vrat, P. 2014. Materials Management – An Integrated Systems Approach. pp. 37-49, ISBN 978-81-322-1970-5

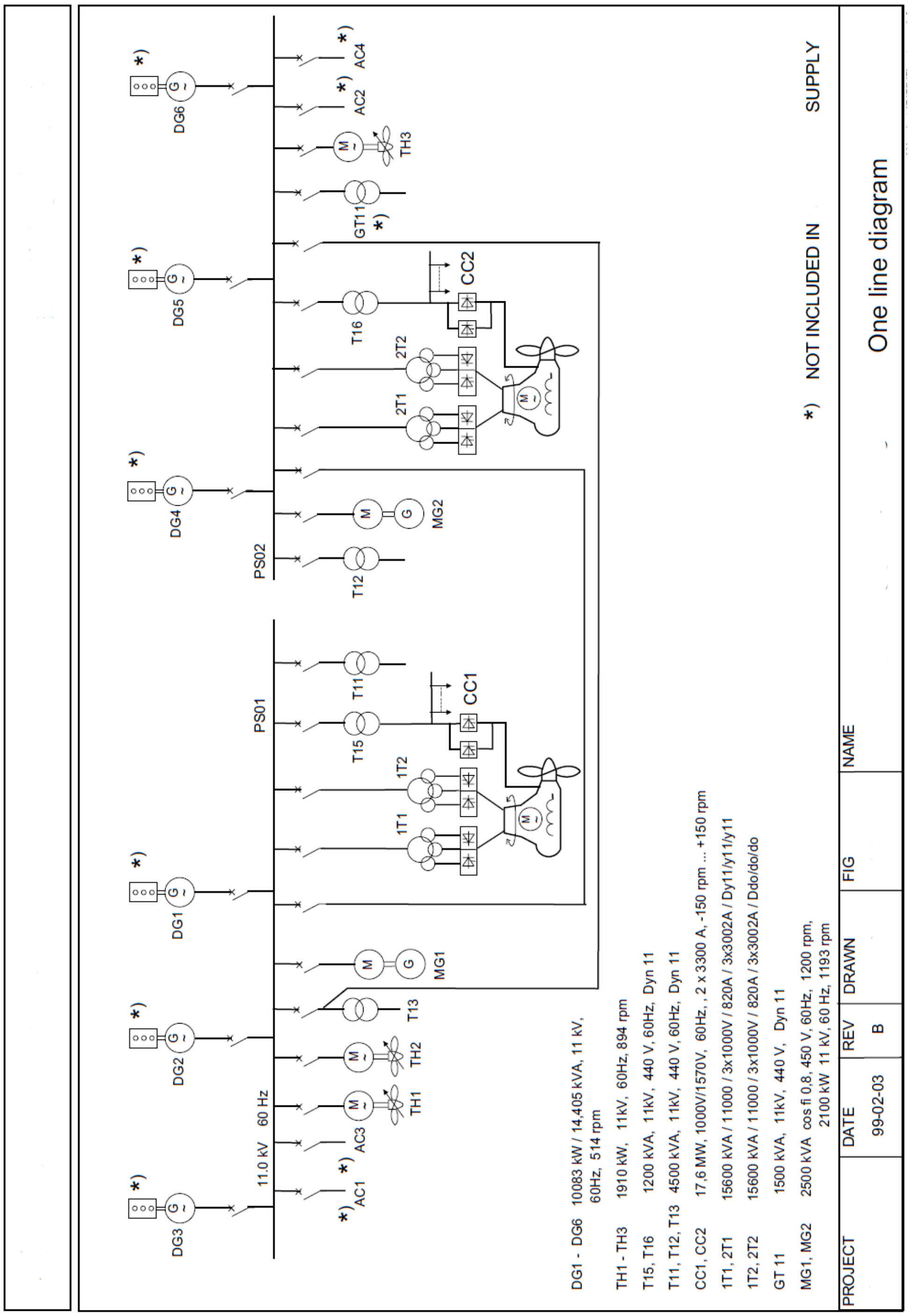
Wagner, S., Jönke, R. & Eisingerich, A. 2012. A Strategic Framework for Spare Parts Logistics. California Management Review Summer 2012, Vol. 54 Issue 4, pp. 69-92

Wong, W. 2010. Decision Support Model for Inventory Management using AHP Approach: A Case Study on a Malaysian Semiconductor Firm, pp. 55-71

Zeng, Y.R., Wang, L. & He, J. 2012. A novel approach for evaluating control criticality of spare parts using fuzzy comprehensive evaluation and GRA. International Journal of Fuzzy Systems, Vol. 14, No. 3, pp. 392-401

Appendices

Appendix I: Single line drawing



Appendix II: Customer interview regarding spare parts classification

Customer Interview Regarding Spare Parts Classification

Basic Information

Name:	
Company:	
Position in the company:	
Duration of the interview:	
Date:	

Interview Questions

	Questions	**Marks**
1	Is your company using any spare parts classification models?	
2	How your company has defined critical components? Based on: - Financial aspects: holding costs, price? - Logistics aspects: delivery time, life cycle phase, number of suppliers? - Operational aspects: possible downtime caused by a sudden component failure? - Other criteria?	
3	Regarding the presented classification model. Is the separation between machine and system criticalities seen necessary and beneficial?	
4	Is it confusing that the same component can be vital on the machine level but non-vital on the system level (for example bearing for the generator and generator for the system)?	
5	The difference between operationally critical and non-critical machines in terms of importance (compare propulsion converter and air conditioning system)? Are these both of an equal importance or is for example cyclo machine more important?	
6	Is the customer point of view taken enough into account within the presented model (how critical the	

	component failure is and for how long it can be withstood)?	
7	Would the presented classification model based on component criticality help cruise companies in the spare parts controlling?	

Case Examples

	Case Example	**Questions**
1	Bearings can be seen vital for the generator. However, one generator does not stop the whole process and therefore it is not seen as vital on the system level.	- How the customer sees the situation? Is it “Vital”, “Essential” or “Non-vital” on the system level? - How much there is time to take control of the situation (next port, next planned maintenance, something else)?
2	One phase unit of the Cyclo converter is gone and the torque in one propulsion motor is reduced to half.	- How tolerable the situation is from the customer point of view? - What is the criticality on the system level when using the three alternatives presented previously? - How long the vessel operator is able to withstand the situation?
3	Both phase units of the Cyclo converter are gone and hence, the vessel can be operated only with one propulsion motor.	- How tolerable the situation is from the customer point of view? - What is the criticality on the system level when using the three alternatives presented previously? - How long the vessel operator is able to withstand the situation?
4	Component failure in one of the thruster motor causes a sudden machine failure.	- On the system level, how critical this is from the customer point of view? - How long the vessel operator is able to withstand the situation?