CHALMERS

An analysis of maintenance strategies and development of a model for strategy formulation

– A case study

Master of Science Thesis in the Master Degree Programme, Production Engineering

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Göteborg, Sweden, 2012

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ABSTRACT

Maintenance has during a long period of time mostly been associated with costs and stoppages and has, of this reason, acquired a connotation of being something necessary evil. Nowadays, availability, reliability and safety in the production plants are more emphasized. An increasingly number of companies replaces the current reactive, fire-fighting, maintenance strategy with proactive strategies such as predictive and preventive maintenance and also with aggressive strategies such as Total Productive Maintenance (TPM) in order to achieve world-class performance.

This master thesis is aimed to address these issues for Volvo Trucks. Volvo is today working with maintenance in a reactive manner, where events and failures choose the direction. Although, there are at present ongoing changes in order to become more preventive and proactive in the work. This master thesis should serve as a basis for developing their strategy which will guide them towards a preventive and proactive maintenance environment.

A number of different methods have been used in this master thesis, i.e. a literature study; an internship with maintenance craftsmen on the shop-floor; a visit at the maintenance fair; an improvement meeting with a cross-functional group and interviews with maintenance craftsmen; benchmarking of Volvo Trucks Tuve and three other companies. A maintenance department analysis (MDA), which is a tool for benchmarking, has also been made. The MDA is a form with 45 questions, whose intent is to review and score the maintenance organization within a company.

The thesis provides results showing that a highly reactive approach is used by the maintenance department. The average score from the MDA, with a value of 2.2, placed Volvo Trucks maintenance department last among the benchmarked companies. There is room for improvements in cooperation and communication between the maintenance department and production department, and this will contribute to a more preventive working environment.
The maintenance department is often left out of projects and seen as a separate supporting function. The benchmarking has proven that successful companies have changed that approach and the communication between departments is integrated. These methods later formed the basis for the Customer Focused Model which has been developed, to guide Volvo Trucks in developing a maintenance strategy.

The Customer Focused Model has been developed primarily from the factors the authors found to obstruct the maintenance department from achieving the desired state and thus, it is a guidance to achieve the desired state. Together with Volvo's expertise and experience within the own organization and the area of maintenance it is hoped that the model will function as a bridge when developing and improving the organization to reach the vision.

Keywords: Maintenance strategy, reactive maintenance, preventive maintenance, proactive maintenance, reliability, life cycle costing, change management, human factors.

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We would also like to thank the organization Sustainability and Maintenance Global Center, SMGC, and Filip Adielsson for the contributions made via knowledge, experience and contacts provided which enabled the benchmarking studies we've performed. An organization whose future we hope to be successful, as they highlights a very important, but also interesting, area that we believe will be an important factor for companies from now on.

Finally, we want to spend the last word to thank our supervisor Torbjörn Ylipää, for his eternal commitment to our work. Torbjörn has provided us with his extensive knowledge and experience which have contributed a great support to this thesis, and we are eternally grateful for that.

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Gustav Fredriksson
Hanna Larsson

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ABBREVIATIONS

BCM	Business Centered Model
CFM	Customer Focused Model
CM	Corrective maintenance
CMMS	Computerized maintenance management system
CNA	Client Needs Analysis
DoD	Department of Defense
EEM	Early Equipment Management
EWO	Emergency Work Order
FMEA	Failure Mode and Effects Analysis
JIPM	Japan institute of plant maintenance
JMA	Japan management association
KPI	Key Performance Indicator
LCC	Life Cycle Cost
LCP	Life Cycle Profit
LTA	Logic tree analysis
MDA	Maintenance department analysis
MTBF	Mean time between failures
MTTF	Mean time to failure
OEE	Overall equipment efficiency
PDCA	Plan-Do-Check-Act
PdM	Predictive maintenance
PM	Preventive maintenance
RCA	Root-cause analysis
RCM	Reliability centered maintenance
ROI	Return on investment
SWOT	Strengths-Weaknesses-Opportunities-Threats
SMGC	Sustainability and Maintenance Global Center
TPM	Total productive maintenance
WCM	World class manufacturing

1 INTRODUCTION

Below is the background, purpose, delimitations and research questions, with the intention to highlight the cause of this work. It is hoped that the reader is presented with the subject and in the end can connect with the conclusions of the work.

1.1 Background

Before World War II there was no maintenance as much. Parts were mostly menial and they would break so they were changed thus removed. An error, therefor, had little effect and was in many cases thus ignored. That changed during the war. Demand for production and production increased, but with a lack of manpower it led to more mechanized industry and more complex production (Alsyouf, 2007). Cost, longevity and availability were topics that aroused interest, and thus arose maintenance departments. The new found state had maintenance departments to develop periodic maintenance, planned maintenance and preventive maintenance (Kister and Hawking, 2006).

A production system consists of different types of equipment; all equipment must have a high availability and reliability in order to ensure a stable process. The maintenance department is responsible for keeping the equipment in the condition it initially was procured for and also to ensure that it can deliver according to the specification. This is an important role in a production system and if it is performed successfully it can facilitate the journey towards becoming sustainable through high asset utilization, thus providing to the overall profitability

Successful companies of today have often a distinct expressed business idea connected to a strategy that explains it and also, how to reach it.

It is widely known that the maintenance currently is viewed by management as a big expense. And it is not an unusual opinion since maintenance does not include any value adding activities. But this is about to change. It is increasingly common for enterprises to work with maintenance as a center point of profit. A greater knowledge of maintenance and its ability for long term profiting have increased the interest in the topic. It is all based on minimizing the downtime and the key to success is to ensure that proactive maintenance is properly being used. Hence, by leaving the firefighting perspective and striving to use proactive maintenance there is a lot to gain. Less failure, minimized downtime, lowered stress and higher quality, all working in the favor of profit.

1.2 Purpose

As Volvo trucks are trying to achieve a maintenance strategy where preventive maintenance accounts for as large part as possible, one has now developed a clear vision for where to be within a reasonable time. Furthermore, to achieve this vision one need to have a strategy which connects present time and the mission describing what to achieve, with the visions future state and where one wants to go. A commonly used metaphor describes it as a road which will take Volvo from the present state to the visions state. Recently Volvo trucks developed a vision of their maintenance; however, they have at this point no strategy for how to reach it. Hence, the purpose of this master thesis is to develop a model for the formulation of a strategy which will support reaching this vision.

Besides the development of an model for the strategy, the thesis has been intended to benchmark other companies in order to get an understanding of how maintenance work are performed outside Volvo Trucks. Benchmarking is a robust method to distinguish if the work performed today lies within the frames of the means, thus, the benchmarking also where intended to highlight where the means are performing and where Volvo stands in comparison.

1.3 Research questions

To summarize the above mentioned purpose, this work should through several methods; including literature review, benchmarking and a status report on Volvo maintenance organization's present state, develop a model that form the basis for the formulation of the maintenance department's future strategy. In order to develop the model, three research questions have been formulated. These three questions are aimed at grasping the key objectives of the thesis and also to function as guidance along the way of developing the model.

The three research questions are the following:

1. *What is the present state of the maintenance department at Volvo Trucks, and what is the desired state?*
2. *Where do Volvo Trucks maintenance department stand in comparison with companies within similar industry segment, and what can Volvo Trucks learn from these companies?*
3. *What obstructs the maintenance department from achieving the desired state?*

1.4 Delimitations

This master thesis is aimed to the maintenance department and will thus not focus or take into account the work or decision-making process related to production.
The master thesis will not include literature studies on the operational level of a maintenance organization; it will not include theory of how tools and techniques are used. The master thesis does not regard the time frames for executing the steps in the model.

2 METHOD

The methodology used in this project aims at gain knowledge about the area of maintenance from a strategic perspective, to understand the present state at Volvo Trucks maintenance department, as well as maintenance departments at other companies. This is, to finally present a model for the formulation of a maintenance strategy. This thesis is intended to generate a result and discussion useful for Volvo Trucks maintenance department. Therefore, the authors have continuously moved between performing literature studies of theoretical framework and documentation of their own observations, respectively collection of opinions from maintenance employees' within the industry. That is, to gather a strong foundation of knowledge to present a broad and useful result and discussion.

The collection of information consisted mainly of interviews and observations, i.e. a qualitative methodology. An extensive literature study, internship at the shop-floor, benchmarking, a visit to the maintenance fair, a workshop and participation during a seminar, have also been performed in order to collect information and to create an understanding of the subject.

The problem in the thesis is characterized by factors such as human, culture, technology and economy. Therefore, in order to clarify and to understand the significance of the problem a qualitative methodology was used, which follows the interactive model of research design presented by Maxwell (2005). Qualitative approaches, compared to quantitative approach, emphasize words rather than numbers when data are collected and analyzed, and are intended to clarify the character or properties of a phenomena rather than determining quantities (Bryman and Bell, 2003; Widerberg, 2002). When performing qualitative research questions such as; "What does the phenomena mean?" and "What is it about?" are to be asked (Widerberg, 2002).

The interactive model of research design presented by Maxwell (2005) is intended to facilitate the understanding of the actual structure of the study, as well as to plan and perform the study. When to design a qualitative study, a logical strategy cannot, according to (Maxwell, 2005), be developed in advance and then faithfully be implemented. Thus, it is an ongoing process rather than a process proceeding through a fixed sequence of steps. Hence, the design components interactions and interconnections with one another demands the design to be changed and adjusted so that the study accomplishes what it is intended to (Maxwell, 2005).

The interactive model of research design the different parts form an interacting and integrating whole, and each component is tied closely to several others. The most important connections among the five components (goals, conceptual framework, research questions, methods and validity) included in the model presented in (Maxwell, 2005) can be obtained from Figure 1 below.

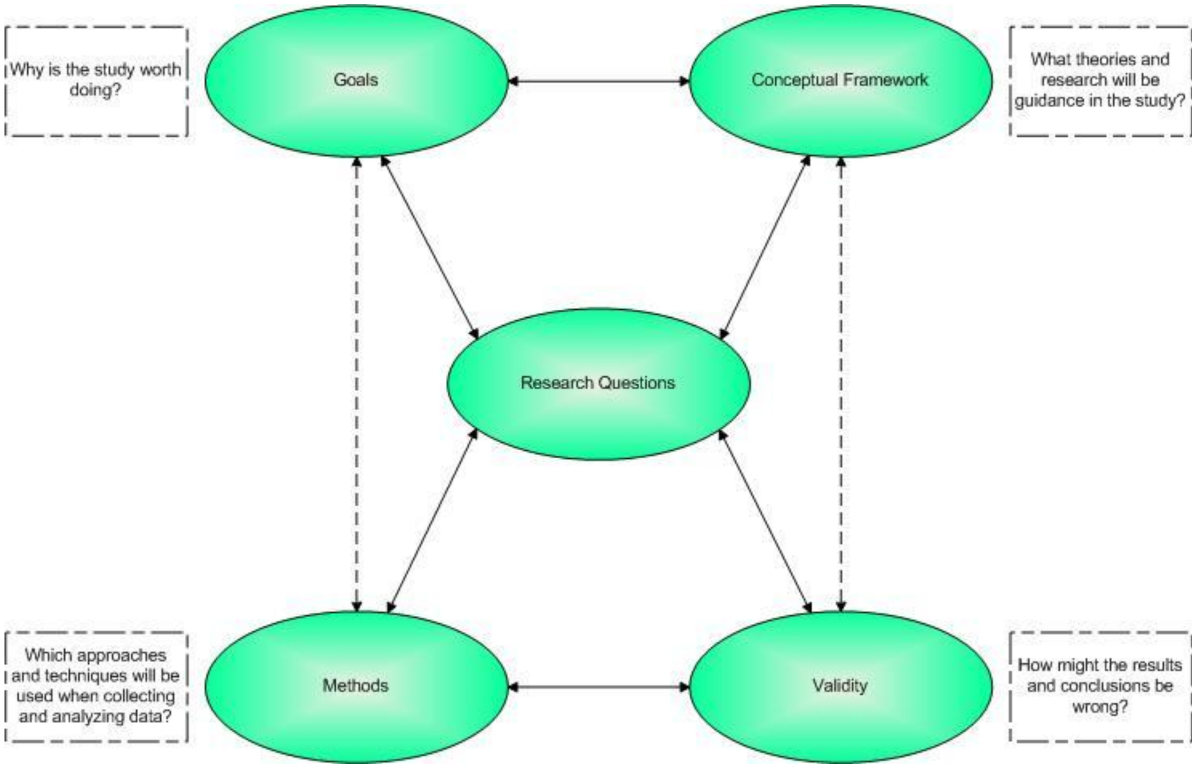

Figure 1. An interactive model for research design (Maxwell, 2005)

2.1 Literature study

To gain knowledge about the role of a maintenance organization within an enterprise and the various maintenance concepts presented by researchers, the master thesis work began with an extensive literature study. Areas such as maintenance strategy, maintenance management and change management were studied in order to understand the strategic level of maintenance and the management's role. The main goal of the literature study was to create a strong foundation of which the result is to be based upon.

A Maintenance Department Analysis (MDA) has been developed based on the literature study. The MDA consist of 45 questions within 13 areas concerning a maintenance organization. Each question is justified based on published literature. The MDA has been used as a benchmarking tool in order to perform an accurate comparison between companies, present the results clearly and visually, and also to truly gain the relevant information.

2.2 Internship on the shop-floor

In order to create a network within the maintenance department and to understand the maintenance function at Volvo Trucks Tuve, four days was spent on the shop-floor, working together with maintenance craftsmen. Three days was divided equally between three different maintenance divisions at Volvo Trucks, where the maintenance craftsmen's workday was observed, the fourth day was spent by observing maintenance technician's workday. The first day was spent at the start of the production, the frame factory, the second at preassembly, then the third day at the final stage of the production and ending the week by working next to a technician related to the frame factory. The internship has also provided the thesis with data concerning human factors and change management. First, by understanding how a change may affect the role and perception of the organization, but also by the individual approach to their work, as this were able to be observed.

2.3 Visit at the maintenance fair

Visits to the maintenance fair were made to discuss maintenance with various companies. The focus was mainly on two well-known consultancy companies; Idhammar AB and Coor Service Management. The work performed during the maintenance fair was based on non-structured interviews.

2.4 Benchmarking

Benchmarking is a method and procedures to develop oneself by analyzing internal and / or external process counterparts (Berggren, 1992). Robert C. Camp (1989) defines it as: "*an approach for establishing operating goals and productivity projects based on best-industry practices".* The aim is to obtain a better understanding of how others might do the same processing in a more efficient way, and thus increase the likelihood of improving their own productivity and competitiveness (Bergman and Klefsjö, 2010).

The outcome of a benchmark exercise depends on three fundamental aspects: Make sure to know your own operation, its strengths and weaknesses. Also, know the industry leader, and finally, make sure to incorporate best available methods (Camp, 1989).

Furthermore, benchmarking can be divided into four variants; internal, competitor, functional and generic. Internal benchmarking, when comparing different departments within the own company, can be advantages in the sense that data can easily be collected. Hidden factors are also easier to check (Wireman, 2010). Functional benchmarking aim to, in addition to comparison with competitors, compares organizations in similar fields. Generic benchmarking is when comparing to the best known to exist today (Bergman and Klefsjö, 2010), sometimes also called Best practices benchmarking (Wireman, 2010).

Various models for benchmarking has been developed. Xerox uses a ten-pace plan (Camp, 1993), while Bergman and Klefsjö (2010) presents a benchmarking process that linked the various steps to the PDCA, Plan-Do-Check-Act, cycle. They describe this model along what they refer to Watson presented in 1992. See below Figure 2.

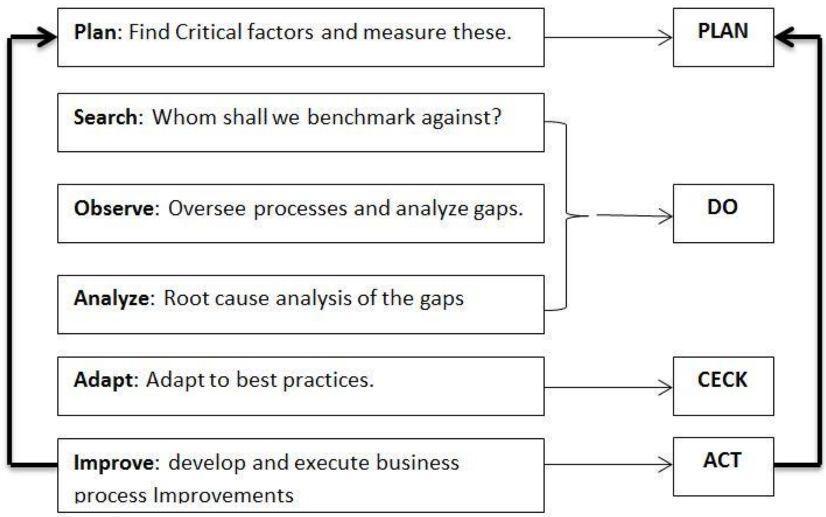

Figure 2. The benchmarking process connected to the PDSA-cycle (Bergman et al., 2010).

Benchmarking has become a popular exercise and is used diligent of companies. However, it have also received portion of criticism. Wireman (2010) believes for example that there are some fundamental problems with the method. Wireman (2010) considers, among other things, that few parameters can really indicate what defines your position in the market. At the same time Wireman (2010) wonders whether a comparison with a company in another industry can really produce significant benefits. The failure to analyze companies and their processes in a more complete and better way, can lead to embracing methods which can be serious for one's own processes. In turn to competitor benchmarking, the issue of benchmarking is if it really represent their true values and solutions, because why would a competitor be willing to support its own competitor with solutions. Finally Wireman (2010) is critical to how to adapt to the benchmark values, if unlikely, the comparison succeeds obtain valuable comparisons. What instead is advocated is to embrace the best practices, where you learn how one works according to methods that really work. Most often, it may then even be enough to look to their own companies and the various departments. The problem is that many departments within the same company can be doubtful about solutions they haven't come up with themselves (Wireman, 2010).

Results of the work consist, in part, of a benchmarking exercise which aimed to compare Volvo Trucks with companies in the same type of manufacturing. Since it is difficult to determine best in the business, and hence perform a generic benchmarking, a functional benchmarking has instead been performed. The work has developed a benchmarking form, maintenance department analysis, MDA, consisting of 45 questions in different areas of the maintenance organization. In addition, the thesis work has visited three companies and performed on-site analysis according to the MDA.

SKF has their own developed analysis tool named Client Needs Analysis (CNA), which through connection with the company was consigned to the authors. This tool was used on Volvo Trucks to compare Volvo Trucks with its industry segment. The CNA was not performed as SKF performs it. When SKF performs a CNA analysis it's done by an experienced maintenance specialist who based on the 40 questions performs the interview with personnel from maintenance and production. In these interviews the people from the customer site is interviewed together and the interviews take 3-4 hours. The result from the CNA analysis is during a second meeting presented to the customer together with a report with recommended actions. The CNA was in this thesis sent to Volvo Trucks maintenance department and the questions were answered under the responsibility of the maintenance manager.

2.5 Workshop at Volvo Trucks Tuve

Workshop is a term used for meetings with a purpose, and it is commonly viewed at as a meeting with a distinct structure and held by someone experienced within workshops techniques (Forsberg, 2012). By the use of the right tools and techniques during a meeting is the groups combined skills and experienced maximum utilized. A group can accomplish more together than the individuals can accomplish in their own directions (Forsberg, 2012). The increased rate of change demand meetings in order to debate and ventilate complex and difficult questions (Forsberg, 2012). It is important to consider the employees' as well as the managers' opinions and views in the master thesis, due to their experiences of the maintenance organization. Therefore, a cross-functional group was gathered to participate in a workshop focused on improvements by the use of a tool, a so called fishbone diagram. The problem highlighted was that the maintenance organization does not work proactively. To allure ideas and causes to the problem was a question asked: "What obstructs the organization to work proactively?" The authors handed out post-its on which the participants wrote plausible causes. When the causes were written down, the authors collected them and categorized them into main causes, i.e. "main bones" and placed them on the fishbone diagram which was drawn on a whiteboard. When the participants were finished with the writing was the fishbone complete and visual on the whiteboard, and a discussion concerning each cause was held. The execution of the workshop took 1.5 hours.

2.6 Interviews with maintenance craftsmen

Interview is a data collection method in which thoughts and opinions is gathered. It is a relatively simple procedure to obtain knowledge about a person's experience, experiences, values and opinions (Osvalder, A.L., 2008). Depending on the interview structure, it is possible to collect quantitative information but also qualitative. It is customary to divide the interview into three categories, namely; Unstructured, semi-structured and structured interview. Depending on what is sought through the interview is selected to which is believed to be most preferable. Structured interviews are best suited to quantitative studies, while unstructured is more suited to qualitative (Osvalder, A.L., 2008).

What distinguishes an unstructured interview is that interviewer asks open questions which are then discussed freely. The interviewed person may thus be controlled since every reference to the desired area can be controlled. The aim is that unstructured interview is preferable when the interviewer in advance is unsure of the areas applied for, or has less knowledge about the subject (Osvalder, A.L., 2008). Unstructured interviews provide for this reason qualitative data. Additional advantages of an unstructured interview are deepening the ability of the issues that seem important to the respondent. The summary of the interview is complicated, however, rated value and the method is not suitable for larger scales.

In a structured interview, questionnaires where the respondent may, either independently or through the predefined response options, answer questions. To make a structured interview it requires good knowledge of the subject and a pre-desirable area to study. A structured interview is quantitative. Finally, in a semi-structured interview a priori structure of the areas that are sought in the interview has been made but the order is less operative and follow-up questions are also possible. Thus, the respondent is easier to be involved in the layout during the interview and answer in a more free way. A semi-structured interview provides both quantitative and qualitative responses (Osvalder, A.L., 2008).

As described, interviewing as a data collection method has both advantages and disadvantages. Advantages are usually mentioned to be that an interview is a subjective and flexible approach with the possibility of a deeper analysis of what the interviewed person really feels about a certain area. It's easy to ask the person to develop and explain their reasoning. This will also minimize the risk of misinterpretation. A further advantage which may also prove to be disadvantageous is that it is possible to influence the sample. The disadvantages are that the interviewee must be present throughout the operation. This may affect the interviewing person adversely. In addition, in an interview, allow the respondent to adjust their responses along what he thinks the interviewer are looking for, and thus influence the outcome. Interviews may also be seen as self-reporting data, that is, they do not give a far-reaching conclusion of what an audience likes but convey only what the respondent thinks (Osvalder, A.L., 2008).

The authors have formulated a number of questions concerning the maintenance organization which have been asked to maintenance craftsmen. This was performed to gain knowledge about the craftsmen’s opinions on their own work. This interview method is seen to be semi-structured. It was in advance known what topics that would be interesting and the respondent was seen to be allowed to answer each question freely. The data was collected via three respondents from each of the areas in the factory. They all had the same title and were considered to have similar skills. In addition, they have been employed for a long time. The questions which have been used can be found in Appendix I.

2.7 Maintenance Conference

A conference for the maintenance department was help, which the authors participated in. The conference was a starting point towards becoming more preventive in the work performed. It was on own initiative from the maintenance department and containing a present state review. An inspiring speech on the importance of maintenance and how the view of maintenance should be changed for the better took place by the company cluster, SMGC, Sustainability and Maintenance Global Center. The financial manager went through the importance of effective maintenance with a focus on the company. Onwards, a interactive group assignment was conducted with emphasis on how the employees look at the vision stated by the maintenance department and what employees believe may become obstacles as well as success factors. In aspects for the thesis, the conference supported opinions, both by the financial manager as well as the feedback from the employees.

2.8 Presentation at Volvo Trucks

The work has halfway presented then results to validate that the problem found were justified and correct approach has been used. The aim was to early announce the direction and progress of the work and obtain feedback on the chosen path. In the final stage of the presentation is also given the opportunity to ask questions targeted to the listeners and embrace their approach in the subject. The questions asked were:

1. Which are the prerequisites to succeed change the organization?
2. Why were not the TPM implementation completed and what knowledge was gained?
3. Which are the critical success factors for the future implementation work?

2.9 Presentation at SKF – Validation

In a final stage, the thesis presented its approach and main results for the strategy group within SMGC. SMGC is a cluster of companies and was founded by the fact that it generally is a problem that businesses are reactive in their maintenance organizations. The strategy group within SMGC is a project that raises the question of maintenance strategies. Since Volvo also is a member of this company cluster, the thesis was offered the opportunity to present at one of their meetings, which appeared at SKF. The work therefore took advantage of the opportunity to obtain feedback from persons within the area of maintenance, and possesses considerable experience and knowledge. The presentation was aimed at highlighting the conclusions made on the subject of maintenance strategies. On the occasion developed model, to illustrate the establishment of a maintenance strategy, was presented and received useful feedback. Participants at the presentation were both researchers in the field of maintenance and simulation, maintenance managers, corporate CEO and strategy consultants. The feedback has been shown to be essential for the work, but have also shown that the work, at this stage, formed good results with a solid background to the topic.

2.10 Reliability and validity

Different methods has previously been discussed, both which is theoretically possible to perform in a similar study and also the methods practically carried out in this work. Onwards, it is logical to talk about the validity and reliability of the methods.

2.10.1 Reliability

Reliability in this context deals with the issue of consistency of measures performed (Bryman, A. and Bell, E. 2007). Furthermore Bryman, A. and Bell, E. (2007) believes that there are three areas explaining whether a measure is reliable, namely: Stability, Internal reliability and Inter-observer consistency.

- *Stability* is about the ability to obtain the same answer, and values through time. To be sure that the result does not fluctuate. Would thereof measurement or procedure is performed again, the result should prove to be the same. Would the correlation between the measurements deviate, it would imply that the respondents' answers are unreliable (Bryman, A. and Bell, E. 2007). However, if it were to be a long time span between the measurements, the results of the respondents may very well be influenced by, for instance, living standards of the respondent.
- *Internal reliability* concerns, according to Bryman, A., and Bell, E. (2007), the issue of the procedure that the indicator for an answer even to affect the respondent's answer to another question. A multi- form is compiled into a final score, of which there are risks that the answer does not give a consistent picture (Bryman, A. and Bell, E. 2007).
- *Inter-observed consistency* deals with procedures were subjective judgment is involved in the categorization of responses or observations; it is thus possible that lack of consistency is present. Especially in the case where there is more than one observer who compiles the answers. This reflects most often in contexts in which issues, objects, answers, observations, to classify an individual's behavior (Bryman, A. and Bell, E. 2007).

2.10.2 Validity

Validity highlights the question whether an indicator actually measures what it is looking for. There are multiple approaches to pursue the validity of a concept and its data, below some, who Bryman and Bell (2007) highlights, briefly are clarified.

- *Face validity* – Here the validity are evaluated by looking to see how developed readings and reflections seems to be true. This may for example be done by experts in the field sharing their thoughts about the results and whether the measure reflects the concept concerned (Bryman, A. and Bell, E. 2007).
- *Concurrent validity* - In this case one seeks to validate whether the data measures the concurrent factors. It is then useful to use the criteria for their testimony and see the validity to this (Bryman, A. and Bell, E. 2007).
- *Predictive validity* - this validation differs for the concurrent in the means that predictive validity uses a future criterion measure for the concept (Bryman, A. and Bell, E. 2007).
- *Construct validity* - a means of determining the validity by deriving hypotheses from the theory that is relevant to the concept (Bryman, A. and Bell, E. 2007).
- *Convergent validity* - The validation is made possible by the data of the concept compared with other methods for the same concept (Bryman, A. and Bell, E. 2007).

3 THEORETICAL FRAMEWORK

The theoretical framework made is aimed to introduce maintenance and corresponding methodologies and philosophies within maintenance. It should also be used as a foundation of knowledge within the area of maintenance in order to develop a model for the formulation of a maintenance strategy.

3.1 The development of Maintenance

Definition maintenance

Maintenance is defined as: “Combination of all technical, administrative and managerial actions during the life cycle of an item intended to retain it in, or restore it to, a state in which it can perform a required function.” (prEN 13306, 1998)

History

The industry did not have a high mechanical level before the Second World War, that is, most of the equipment was over-designed and simple. The consequences of failure did not have a strong influence and the effect was neglected (Alsyouf, 2007). Due to this, the industrial equipment was running until failure occurred, and when it did it was either replaced or repaired. Thus the mentality was: “fix it when it breaks”. In the first approach of maintenance no actions were taken to detect the onset of failure neither to prevent failures, this approach can be described as reactive maintenance (Alsyouf, 2007).

The Second World War turned things around and everything changed dramatically during the war. This is due to shortage of manufacturing manpower and an increasing demand on production (Kister and Hawkins). As a result, the mechanization increased and the manufacturing facilities changed to be more complex (Alsyouf, 2007). To meet the growing demand for war materials, customer goods and to compensate to the manpower shortages, the technology within manufacturing was forced to develop more mechanization (Kister and Hawkins, 2006). Cost, longevity and availability were now regarded as important factors to achieve the business objectives and therefore, maintenance was considered as a technical manner and became a task of the maintenance department (Alsyouf, 2007). The equipment reliability was now important and production downtime became everybody’s concern. The newfound stature of maintenance allowed the maintenance organization to develop and implement periodic, planned and preventive programs (Kister and Hawkins, 2006).

The manufacturing facilities became even more automated and complex during the 1970s (Alsyouf, 2007). Reliability, availability and maintainability, as well as quality, safety, environment and multi-skilling were now considered very important. Condition monitoring, condition based maintenance and maintenance management information systems began to be used in the industry. Condition based monitoring became easier to use in industry due to automation and development in information technology, and maintenance became more integrated and was no longer an isolated function (Alsyouf, 2007).

In the beginning of the 1980s had many systematic concepts been proposed, such as Total Productive Maintenance (TPM) and Reliability Centered Maintenance (RCM) (Alsyouf, 2007).
The middle and corporate level management have until recently, ignored the impact of the maintenance operation on production costs, bottom-line profit and product quality. The general opinion has been that "nothing can be done to impact maintenance costs" or "maintenance is a necessary evil". The developments of computer-based instrumentation or microprocessors have provided the means to manage the maintenance operation due to that it can be used to monitor the operating condition of plant equipment and systems. Unnecessary repairs can with this technique be reduced or even eliminated, catastrophic machine failures can be prevented and the negative impact of the maintenance operation on the profitability can be reduced (Mobley, 2004).

Today

It was not until recently that maintenance has gained recognition as potential profit generator. This is, despite the fact that in many industries maintenance amounts for a substantial sum and the maintenance personnel sometimes comprises a significant number of the total work force (Waeyenbergh and Pintelon, 2002).

The focus today is, due to globalization, to create internal and external partnership between maintenance and other elements in the supply chain, for example are maintenance involved when designing and improving the production process, and helping the purchasing department to select the original equipment manufacturer. Monitoring the deviations in both the quality of the product and the machine condition are now more emphasized (Alsyouf, 2007).

Maintenance becomes more and more part of the integrated business concept and there is a growing trend towards outsourcing, also a shift from failure-based to use-based maintenance and increasingly towards condition-based maintenance. Availability, reliability and safety in the production plants are now more emphasized (Waeyenbergh and Pintelon, 2002).

An increasingly number of companies replace the current reactive, "fire-fighting" maintenance strategy with proactive strategies such as predictive and preventive maintenance and also with aggressive strategies such as TPM in order to achieve world-class performance (Swanson, 2001).

Companies undertake efforts to reduce costs and at the same time improve quality and productivity, a part of these efforts commonly includes an examination of the maintenance function. For many operations within a producing company are effective maintenance critical due to the fact that it extends equipment life, increase equipment availability and retains equipment in proper condition. Poorly maintained equipment may conversely lead to more frequent failures of the equipment, low utilization rate of the equipment and delayed production schedules. Equipment that is malfunctioning or misaligned may cause a higher scrap rate or produce products with a questionable quality. In addition does the equipment need to be replaced more often due to shorter life-cycles, which also is a consequence of poor maintenance (Swanson, 2001). Maintenance has traditionally been considered as a necessary evil, but it is in fact rather a centre of profit than just unavoidable and unpredictable expense (Alsyouf, 2007). If effective maintenance policies are used, failures can be reduced to a minimum level which can result in great savings. Therefore, due to its role in the corporate long-term profitability, more and more significance is put on maintenance. The production and its operational aspects such as quality, costs, capacity, safety and environment are influenced by maintenance of the equipment. But, due to the fact that maintenance is considered to be a support process for production it is difficult to mark its impacts. The perceived maintenance performance level depends on the applied perspective (Alsyouf, 2007). Different departments within the organization have according to (Alsyouf, 2007) different views:

Accountants - The maintenance performed is considered in terms of costs
Top management - Only interested in budget performance
Engineers - Focus on techniques
Production - Sees the maintenance performance in terms of equipment availability and support responsiveness.
Thus, there is a lack of common language (Alsyouf, 2007).

3.2 Maintenance strategy

Definition of Maintenance Strategy
Management method used in order to achieve the maintenance objectives (prEN 13306, 1998).

Definition of Maintenance Objectives
The targets assigned to or accepted by the management and maintenance department (prEN 13306, 1998). These targets may include availability, cost reduction, product quality, environment preservation, safety (prEN 13306, 1998).

A strategy is the idea of how to reach the objectives which means to take different steps or performing activities. The overall direction, a plan which describes the activities to be performed is described by the strategy (Campbell and Reyes-Picknell, 2006; Bergman and Klefsjö, 2010).

The content in the maintenance strategy is a mix of techniques and/or policies which depends on factors such as the nature of the plant, the maintenance goals or the equipment that will be maintained, the work environment and the work flow patterns (product focus, process focus) (Alsyouf, 2007).

In a competitive strategy are the firm's goals and the means needed to reach the goals combined (Salonen, 2011).

A number of maintenance strategies and concepts have been suggested by intellectuals or implemented by practitioners. Researching, identification and execution of many inspect, repair and replace decisions (maintenance actions) are involved in the maintenance strategy, and the strategy describes which events (e.g. condition, passing of time, failure) that trigger which type of maintenance action. The concern is about formulating the facility's optimal maintenance schedule, and also the best life plan for each unit of the facility, which should be done in co-ordination with production and other concerned functions (Alsyouf, 2007).

3.2.1 The importance of a maintenance strategy

Industry today is forced to increase production efficiency continuously in order to be competitive. The maintenance of production equipment is one important factor of this (Salonen, 2009).

A strategy (direction) is always followed, either consciously or unconsciously. When a strategy is not stated, only followed unconsciously, the result is often a reactive approach, which causes events and others to choose the direction. If a company does not work proactive to avoid failures or the consequences of failures, then the maintenance is operating on a run-to-failure strategy (Campbell and Reyes-Picknell, 2006).

If there is a well-developed and defined maintenance strategy which is known to everyone then new problems instead of old recurrence ones will be solved. If one is not, measurable time will be earned from develop and define a maintenance strategy, communicate it, and last focusing on the tactical choices for how to achieve it. Tactics are the actual activities needed to implement the strategy, which concerns the management of processes, people, and physical asset infrastructure (Campbell and Reyes-Picknell, 2006).

The strategy are developed to create a direction of how to meet the objectives of maximum availability/reliability and gaining thorough knowledge in the technical systems with an easy to use and structured approach (Waeyenbergh and Pintelon, 2002). The objectives may appear to be intuitive, but not until they are written down can the importance of a proactive maintenance and reliability organization of a company and its assets be highlighted. The effectiveness of a company will always be sub-optimized unless the reliability and maintenance organization works with a proactive list of objectives. Thus, reliability and maintenance is more than a "fix it when it breaks" function (Wireman, 2010). The objectives must be realized in accordance with safety and environmental regulations and also in a cost effective way. The integration of machines, men, methods and means into a well-designed strategy requires indispensable managerial capacity (Waeyenbergh and Pintelon, 2002).

(Waeyenbergh and Pintelon, 2002) points out three critical success factors:

1) The direct production personnel and the maintenance craftsmen and technicians need thorough knowledge of maintenance technology and competence to prevent disruptions early in the production process.
2) Management skills regarding maintenance planning and control tasks as well as human resources management are of major importance.
3) Flexibility to exploit trends and opportunities.

When developing a sound performance management system a fundamental step is to develop a comprehensive reliability and a maintenance organization (Wireman, 2010). Without the business defined it is not clear what the performance management system measure, therefore, proper resources need to be dedicated to ensure a well- defined and approved reliability and maintenance strategy. Until then, performance indicators for reliability and maintenance business should not be developed (Wireman, 2010).

Salonen (2009) performed a case study where the industry's view on maintenance strategy was investigated. Six companies were included in the study and four of these companies had no maintenance strategy, nor did they use measures relevant for maintenance control. Salonen (2009) has presented another case study where stakeholder involvement in one company was tested. One important conclusion from this study was that stakeholder involvement may lead to a unanimous view on the maintenance department expected deliveries to the production department, which may contribute to higher cooperation between these departments. Thus the company's productivity will in turn benefit from this (Salonen, 2009). Also (Bergman and Klefsjö, 2010) points out that both the internal and external customers, i.e. all stakeholders, need to be satisfied. In this case are maintenance technicians and craftsmen the internal customers which, as internal customers, according to (Bergman and Klefsjö, 2010) need to be satisfied in order for them to do a good work. There are several external customers, one of them is the production department, who is the customer which actually utilizes the service and thus, need to be satisfied with the service provided by the maintenance department. Other external customers pointed out by (Bergman and Klefsjö, 2010) are the people who live in the environment that is influenced by the organization and also the society at large. According to (Bergman and Klefsjö, 2010) does the customer who utilizes the service often play an active role in creating the service. It is argued that stakeholders of an organization have the following two characteristics (Salonen, 2009):

1. The ability of an organization to achieve its objectives is affected by them.
2. For helping the organization to achieve its objectives they require something in return.

3.2.2 Formulation of a maintenance strategy

In order to formulate a competitive strategy is it of important to consider the following key factors (Salonen, 2009):

1. The company's strengths and weaknesses
2. The key implementers personal values
3. Opportunities and threats from the industry

4. Expectations from the society

Number one and two above are internal to company while number three and four are external (Salonen, 2009).

The strategy needs to be supported by tactical plans which must be executed, without tactical plans consisting activities won't the idea of what to do or how to do it, be clear (Campbell and Reyes-Picknell, 2006). Industrial systems evolve rapidly, to keep up with the changing systems and environment the maintenance strategy therefore needs to be reviewed periodically (Waeyenbergh and Pintelon, 2002). This requires not only a structured but also a flexible maintenance strategy which allows feedback, improvement and responds to requirement changes (Waeyenbergh and Pintelon, 2002; Campbell and Reyes-Picknell, 2006). Furthermore, the strategy should be customized, which implies that it should consider all relevant factors of the situation on-hand. As such, the needs of the company will be tailored in the maintenance strategy. By that, the maintenance strategy will be unique for each company but the underlying structure needed to develop such strategy may be very comparable. The expectations of a structured framework for maintenance concept development are very comparable in almost every case (Waeyenbergh and Pintelon, 2002).

When to develop a strategy for maintenance it needs to be considered as a holistic (Waeyenbergh and Pintelon, 2002). A strategy can be built on many ways and if the company knows the current state, i.e. where the company is today, then an overall vision can be created and a good way to do this is by brainstorming for ideas after a seminar or workshop on successful practices (Campbell and Reyes-Picknell, 2006). The vision is the end result of what to achieve, an idealized picture of a future state which is desired for the organization. When the vision is formulated it is important to be innovative and encourage the employees to think new and big, and also that it is understandable to everyone (Campbell and Reyes-Picknell, 2006; Bergman and Klefsjö, 2010; Thomas, 2005). When the vision is created then the company states what to do to achieve it (Campbell and Reyes-Picknell, 2006). If the current state is not well known it is preferable to perform detailed analyses of this, a review of what is done and how it is done, before stating the vision and the strategy (Campbell and Reyes-Picknell, 2006).

Kelly (2006) has presented a business-centered model (BCM) for the formulation of a maintenance strategy, see figure BCM below. The approach is called business-centered because it is derived from, and driven by, the business objectives identification, which then are translated into maintenance objectives and support the formulation of the maintenance strategy (Kelly, 2006). When to formulate a maintenance strategy it is important to understand how the plant operates, the relationship between the plant and its market and the maintenance function within this context (Kelly, 2006).

According to Kelly (2006) does the maintenance objectives need to be established in relation with the production and business objectives, and before this is done it need to be understood how the maintenance function will be affected by its dynamic relation with the production function. When to set the objectives it need to be done in conjunction with the production department, this is, due to the fact that the production and maintenance objectives are inseparable (Kelly, 2006). The production and maintenance objectives also need to be compatible with the business objectives which can be obtained in Figure 3 below.

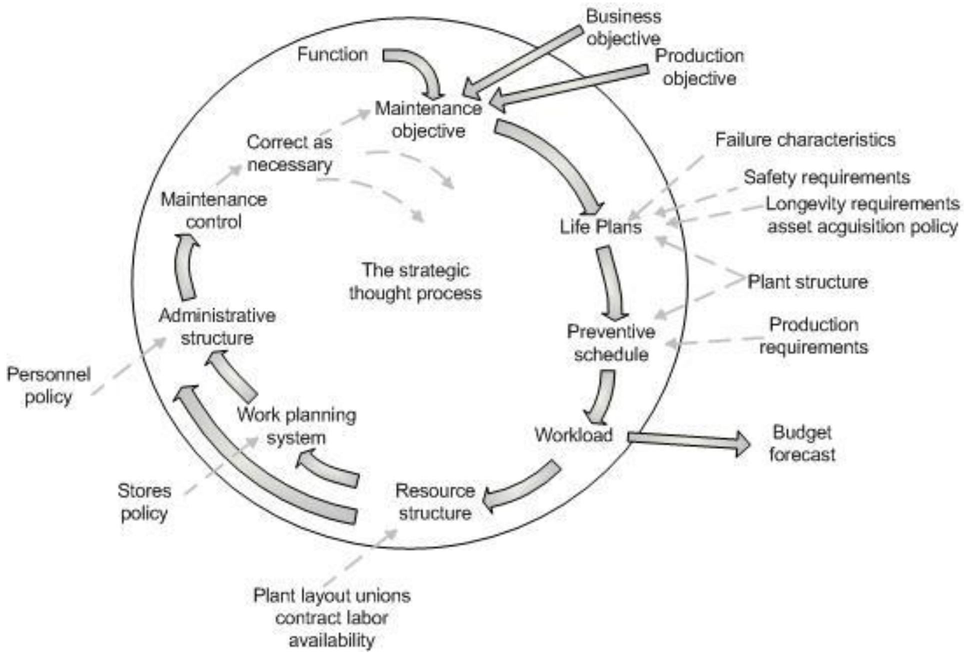

Figure 3. A business-centered model (BCM) for the formulation of a maintenance strategy (Kelly, 2006)

The large circle in Figure 3 above illustrates the strategic thought process of the maintenance manager which starts with the maintenance objective of the plant (Kelly, 2006).

McAllister (1999) has also presented a model for the formulation and review of a maintenance strategy. It is pointed out that maintenance should be considered as a partner within the business with the shared overall aim, that is, to produce and sell products at an acceptable margin of profit. In order for this to be achieved it must be understood that all functions within the business contributes to profitability. Thus, the maintenance function should align with the overall business goals. McAllister (1999) also points out that the before developing a maintenance strategy the need for change should be established. In the maintenance philosophy should change be embraced as a major expectation and constituent (McAllister, 1999). The maintenance strategy development process starts with stating the maintenance philosophy which is an expression of the maintenance function's role within the company and the chosen approach for how to fulfill it. The next step is to consider the aims and objectives of the maintenance function. The aims can be at corporate, production and maintenance levels and the objectives must respond to the driving forces from production. The third step is to assess and evaluate the maintenance practices and issues. Figure 4 below represents the range of maintenance policy sectors and corresponding practices to consider for this assessment which, after completion, may be used to develop a maintenance program. Then should tactics, for how to integrate existing practices with new ones, be developed. The last step is to determine the implementation plan (McAllister, 1999).

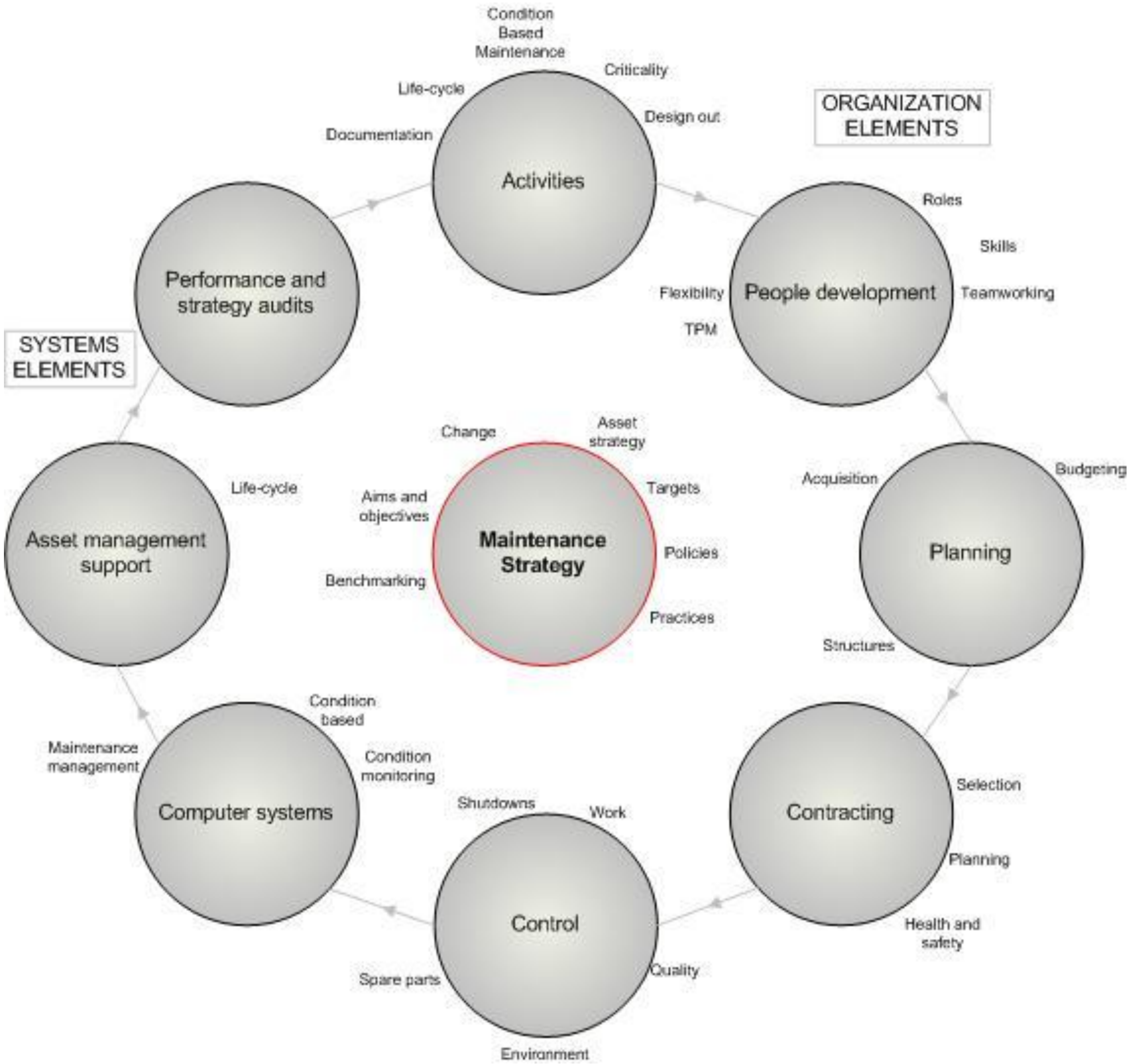

Figure 4. The range of maintenance policy sectors and corresponding practices (McAllister, 1999)

Factors that describe the general organizational structure, technically describe each system to maintain, as well as factors that describe interrelations between the different systems should be addressed. The maintenance concept will not reach its full potential if some of the required aspects are not included in the development of the strategy. A careless analysis, lost data or lack of knowledge might be reasons for an inadequate strategy. Due to the operational impact that maintenance may have on the equipment's performance and the involvement of high direct as well as indirect cost, for both in-house and outsourcing maintenance, the development of the maintenance strategy should be done in a structured way (Waeyenbergh and Pintelon, 2002).

Concerning the formulation of a maintenance strategy a model proposed by Salonen (2009) will also be presented in this thesis. This model is a schematic view of the work-process when formulating a maintenance strategy and is presented in Figure 5 below.

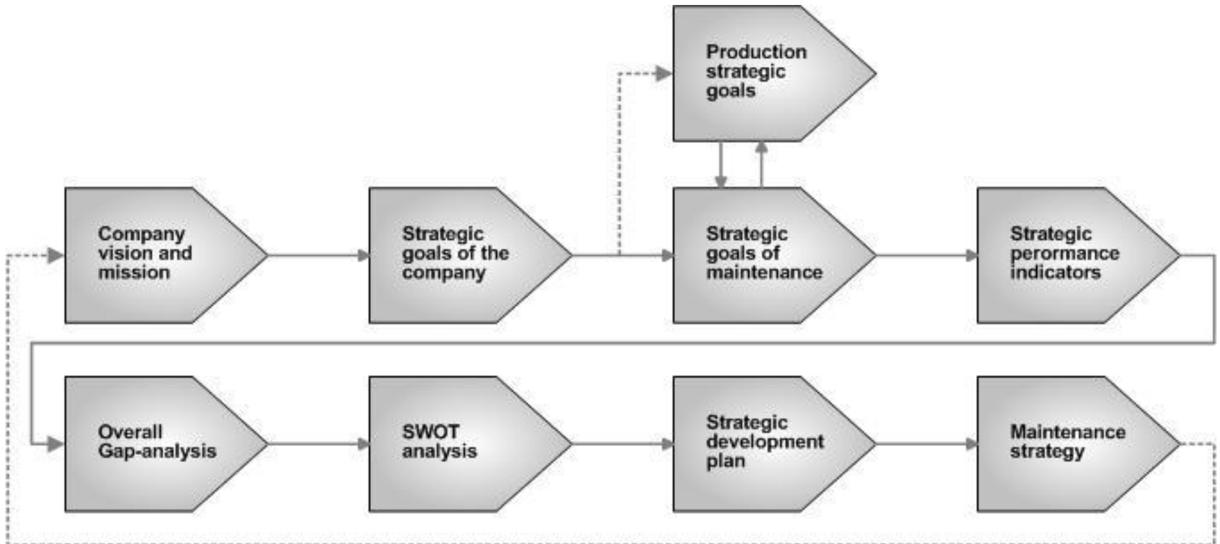

Figure 5. A schematic view of the work-process when formulating a maintenance strategy (Salonen, 2009)

Salonen (2011) describes the different parts within the model as follows:

1. ***Company vision and mission –*** The strategy should be based on the company vision and the mission.
2. ***Formulation of the strategic goals of the company –*** These goals should be supported by all functional strategies. Regarding the maintenance strategy it is essential to consider not only the overall strategic goals of the company, but also the goals of the production which is the customer to the maintenance organisation.
3. ***Define the strategic goals of maintenance –*** The strategic goals of both the production department and the company should be considered and the goals should reflect both effectiveness and efficiency. This is, in order to satisfy all stakeholders.
4. ***Tie the strategic goals to strategic performance indicators –*** The performance indicators are measured in order to evaluate the fulfillment of the strategic goals. All stakeholders, such as the production department and the owners, should preferrably be involved when choosing the performance indicators. The acceptance of the strategy among the stakeholders will with that approach increase. In order to avoid misinterpretations, the indicators need to be well-defined. Responsibilities, data collection methods and sources of data may also be defined in the strategy formulation.
5. ***Perform the overall GAP – analysis –*** Adress current or potential gaps in maintenance performance and when this is done, identify factors which potentially may influence the gap between current and desired levels.
6. ***Perform a SWOT (Strengths, Weaknesses, Opportunities, Threats) analysis –*** Adress the identified gaps in relation to factors considered strategic for the development of the

maintenance function. From the result of the SWOT analysis may a list of actions be identified.

7. ***Determine a strategic development plan –*** This plan can be set up by prioritizing the actions identified from the SWOT analysis.
8. ***Formulate the maintenance strategy –*** When the strategic development plan is in place may the maintenance strategy be formulated (Salonen, 2011).

In order to formulate a maintenance strategy and produce a maintenance plan, following questions need to be answered (Gupta, 2009):

- What should be done?
- Which are the most important items?
- What are the legal requirements to be considered?
- When can the work be performed in order to avoid loss of production?
- In which frequency should surveys, inspections, works and tests be carried out?
- From where does the money come?

Salonen (2011) propose a structure to follow when to formulate the maintenance strategy, see Figure 6 below.

Figure 6. A structure to follow when to formulate the maintenance strategy (Salonen, 2011)

A maintenance strategy should function as a road map which allows and includes alternatives, it is not meant to go in just one direction. The maintenance strategy must remain flexible in order for it to change with the company's situation. The road map can be created based on results from benchmarking and from observations of the company's own best plants as well as others already do. The vision is the description of desired excellence regardless from where the direction originates. The already existing practices need to be changed if they don't match the vision, and this is regardless if it is good or bad. The plans need to be more or less detailed dependent on how much change desired (Campbell and Reyes-Picknell, 2006).

3.2.3 Implementation of a maintenance strategy

There are many opinions on how the strategy should be implemented, but something that characterizes most is that there is no standard for how the implementation to take place. Rubenowitz believe that every organization has its own problems and will face its own problems. The conditions of which will vary greatly, which makes it difficult to use standards. Below are some approaches.

According to Campbell and Reynes-Picknell (2006) the implementation on the tactical level is based on the strategy and the following components are to be included, see Figure 7 below:

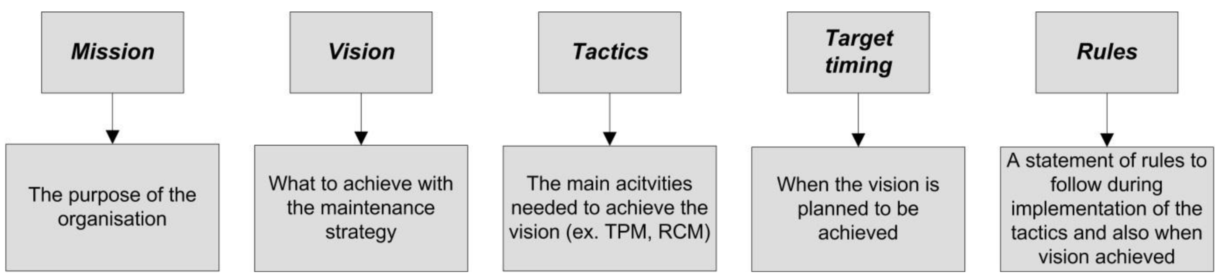

Figure 7. Components included in the strategy (Campbell and Reyes-Picknell, 2006).

Supply chain, finance, accounting, training departments, operations, and plant management will all be affected by the maintenance strategy therefore, it should not only be the maintenance department's responsible for putting the strategy together. Thus, it is a team effort. The details in the implementation plan do not need to be included in the document or statement of the strategy, those can be managed separately, the strategy should not be too complicated with excessive details – it should be simple. The detailed implementation plans should preferably start to be developed first when the strategy is stated, and move forward with the implementation details and execution of them step by step. Figure 8 below illustrates the development process of the maintenance strategy which is highly effective: Plan – Do – Check – Act (PDCA cycle).

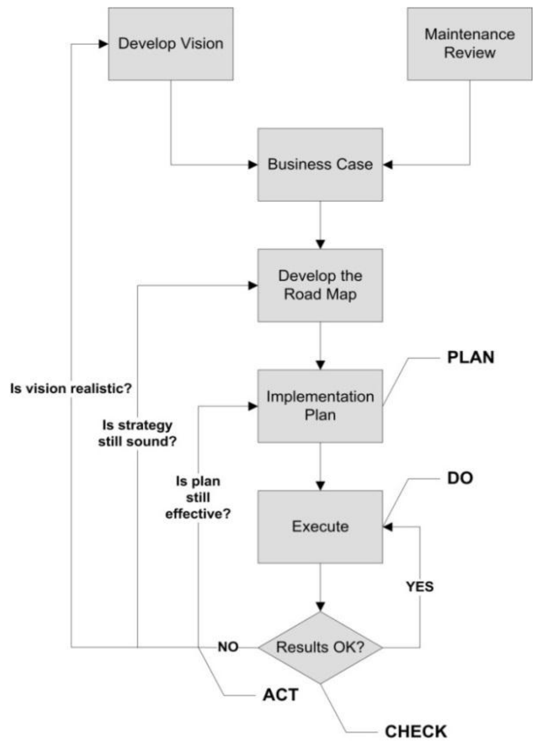

Figure 8. Strategy Development Process using the PDCA cycle (Campbell and Reyes-Picknell, 2006).

The entire transition to the point where the vision is attained should be covered in the strategy. The implementation plan, a description of who will do what in specified time frames, is developed from the road map. From each part of the vision a work stream will be formed (Campbell and Reyes-Picknell, 2006). When developing an implementation plan the following should be considered:

- The task and its key activities
- Prioritize the initiatives. If there are several ongoing improvement projects, how much senior management time should be spent on each?
- Estimate needed resources and level of effort
- Appoint the “champion” which assignment is to ensure successful completion and the “sponsor” which tasks are to provide the resources
- Establish start date, completion date, and milestones along the road
- Define the goal to be achieved on successful completion, and the parameters to measure to determine if the project is on the right track
- Define and evaluate the challenges along the way that can derail the efforts or cause a lose focus

The implementation of the plans is far more than a technical project. Human change is involved, which is the hard part. It is crucial not to ignore change management on every level within the organization (Campbell and Reyes-Picknell, 2006).

As described, Rubenowitz (2004) states that there are no standard solutions for implementing an organizational change since all companies suffer from issues specific for their company. However Rubenowitz (2004) also states that the most essential when implementing a change in an organization is the level of ambition. The most successful changes have been found in situation where the initial step is made in small areas. A change process is an ongoing project and should be performed in smaller processes which are then spread over the organization (Rubenowitz, 2004).

Slack and Lewis (2008) views a implementation as all activities involved in making the strategy work as intended. It is advocated to uses, the five Ps, which are the following: Purpose, Point of entry, Process, Project management and participation. To a large extent Slack and Lewis (2008) focuses on operations, and hence the work will not go into detail on all steps, however, a few areas are highlighted below.

Purpose – in this context the purpose covers the strategic context. In which the connection the organizations resource capabilities is linked and fit to the requirements of its market. It also includes the perception of, understanding of, and cope with risk involved with change. These are all to be included in the implementation plan (Slack and Lewis, 2008). Important aspects here are how to manage risks. Slack and Lewis, describes *prevention strategies*, where the aim is to prevent a problem arises, *mitigating strategies* where the event causing the risk is isolated from causing negative consequences. Also, *recovery strategies* where the operation accepts the consequence from the event happening but actions are undertaken to minimize or compensate them.

Point of entry – This aspect highlights different organizational structures ability to change, it should be noted however, that each has its strengths and weaknesses and to propose an organizational structure is therefore difficult to do. Further, also it is important to heed the fact that an implementation process can be politically sensitive within the organization or company. For this reason, also support from the hierarchy is central to the success of the change (Slack and Lewis, 2008).

Process- This step covers the methodology of implementing formulation of the strategy. That is, the means and methods and the approach which are to be taken to formulate the strategy (Slack and Lewis, 2008). This focus area should also take into account the cost of implementation. A change may affect the process negatively in an initial stage, this influence may have economic effect, which Slack and Lewis (2008) categorizes the adjustment cost.

Project management - implementing a strategy is a big project and need to be treated as such. Slack and Lewis means that it is more of a program than a project. A project has a defined start and end point, a goal and defined resources. A program does not; rather it is an ongoing process. It should include documentation of stakeholders, resource and time planning, controls, communication and reviews. One area that in many cases may need a special focus is just stakeholders, which in some cases have the power to affect change, hence they should never be ignored, and above all they should be kept informed (Slack and Lewis, 2008), see also Figure 9, showing the interest in stakeholders.

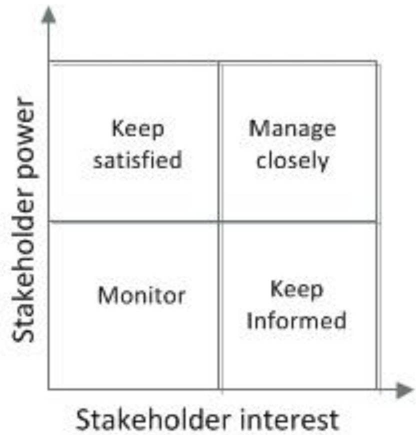

Figure 9. Stakeholder interest and how to include the stakeholder

Participation - Dedicated employees are obtained if those affected by the change also may be part of the process to develop the implementation stage. Bringing in too many staff may however have the effect that the change resemble today's situation too much as many may be limited by current experience.

3.3 Maintenance Management

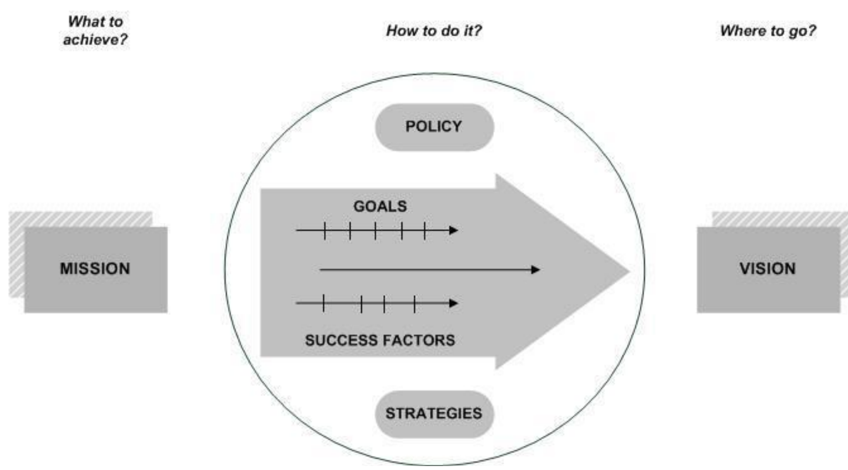

Figure 10. An illustration of the management organization's main tasks (Bergman and Klefsjö, 2010).

Maintenance management is a support organization, in a world-class organization the mission of maintenance is to achieve and sustain optimum availability of the business productive assets (plant, equipment, vehicles etc.). The product that maintenance delivers is uptime, i.e. availability (Mobley, 2004; Campbell and Reyes-Picknell, 2006). See also Figure 10, explaining the connection between mission – what to achieve, vision – where to go and the policies, goals and strategies – the how to do it.

Definition Maintenance Management

"*All activities of the management that determines the maintenance objectives, strategies, and responsibilities and implement them by means such as maintenance planning, maintenance control and supervision, improvement of methods in the organization including economic aspects*." (prEN 13306, 1998)

Gupta (2009) defines Maintenance management as:

"*A combination of different skills, including the experience and technical knowledge necessary to specify remedies and to identify the needs of maintenance*."

The elements to the management of any physical asset that are important from an engineering viewpoint is according to Moubray (1997) that the asset must be maintained and that it need to be modified from time to time.

Maintenance management generally consists of the following basic concepts (Gupta, 2009):

1. Setting aims and objectives
2. Providing the means of attaining those aims and objectives
3. Decision making

The maintenance function must integrate five major factors in order to achieve optimum costs for upkeep and repair, and those factors are (Gupta, 2009):

1. People
2. Policies
3. Equipment
4. Practices
5. Performance evaluation

3.3.1 The role of Maintenance Organization

Many maintenance organizations are pride of how fast they can react to production disturbances or catastrophic failure instead of their ability to prevent such events. Most plants continue to operate in this breakdown mode while few admit their continued adherence to this mentality. The role of the maintenance organization is in contrary to the popular belief; it is to maintain the equipment of the plant i.e. to be proactive and not to repair it after failure i.e. reactive. However, all catastrophic failures cannot be avoided and maintenance must therefore continue to react quickly to unexpected failures (Mobley, 2004). Optimum reliability is one part which determines the production capacity of the plant. Maintenance organization primary function is to ensure that all equipment and systems always are in good operating condition and on line, in other words to reduce disturbances (Mobley, 2004).

Production Disturbances

Production disturbances are a concept which is differently defined dependent on from which perspective the disturbances are regarded;

- *Maintenance perspective* – Disturbances seen as technical errors or interruption.
- *Production perspective* – Disturbances seen from the aspect of efficiency.
- *Security perspective* – Disturbances seen from the aspect of risks and consequences.
- *Quality perspective* – Variation in product quality is the focus.

The prerequisite of finding the best way to handle disturbances, are increased when regarding all these perspectives. Among other things, disturbances can be regarded as losses (Bellgran and Säfsten, 2010).

Production disturbances can be defined as a discrete or decreasing, unplanned or planned change or disruption during production time, which might affect operational performance, product quality, availability, work conditions, environment, safety etc. (Bellgran and Säfsten, 2010). Thus, the disturbances occurring should be distinguished from desirable, planned conditions.
Some examples of production disturbances are shown in Figure 11:

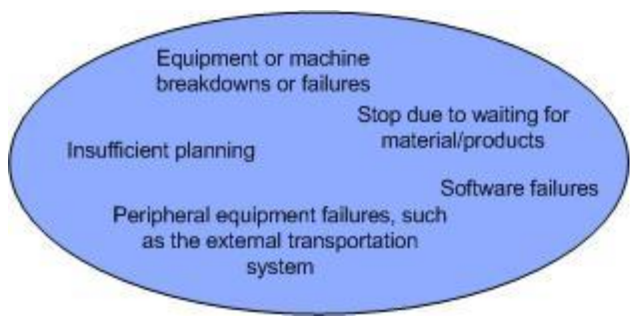

Figure 11. Examples of production disturbances (Bellgran and Säfsten, 2010)

A result from a study of 80 companies (Bellgran and Säfsten, 2010) showed that the idea concerning what a production disturbance is varies in the various functions within a company.

Figure 12 below shows an illustration of the different views regarding production disturbances between the maintenance function and production function.

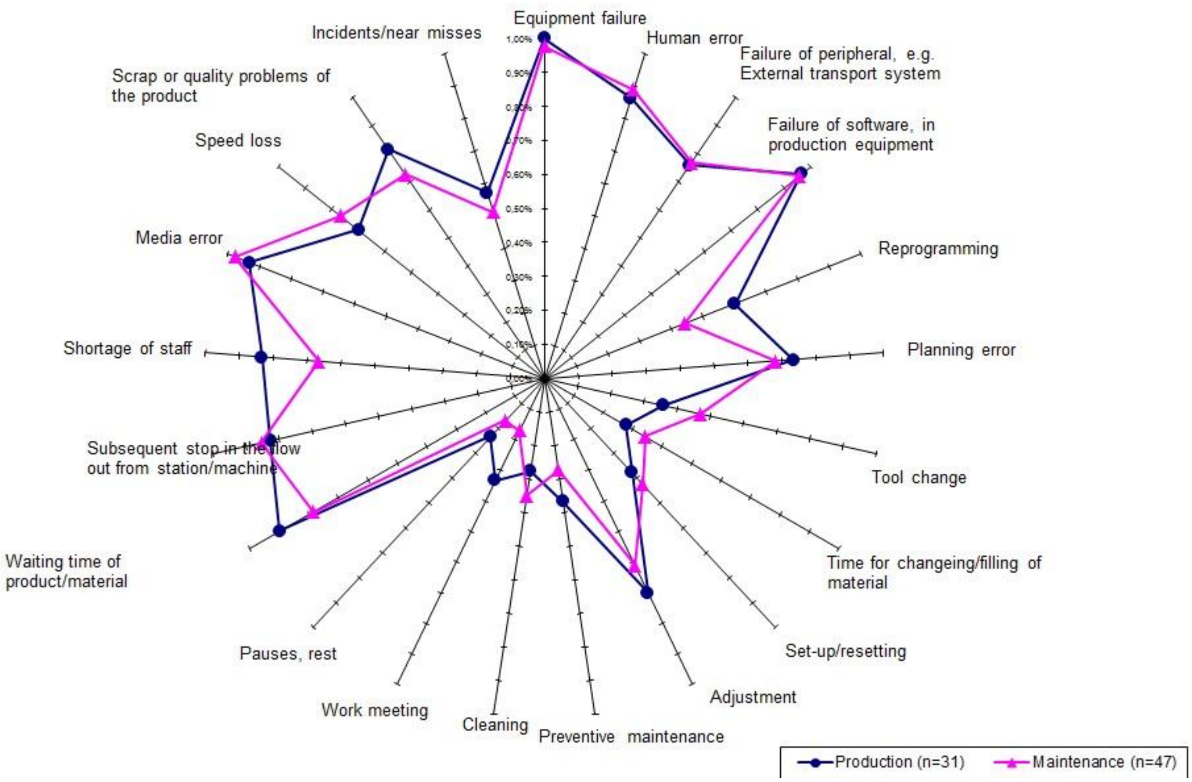

Figure 12. Similarities and differences regarding what production disturbances are, between the maintenance and the production function (Bellgran and Säfsten, 2010 with permission from the authors)

Another dimension of production disturbances relevant to discuss is their extent in time. Minor disturbances which frequently return are equally important to consider as larger disturbances that are more time-consuming, but return with a lower frequency. For minor frequent disturbances is the accumulated time often considerable, which often is longer than for major disturbances. The major disturbances often receive more attention and one reason for this might be that they are often easier to discover and requires often more extensive measures. However, areas to eliminate disturbances and handling of disturbances are receiving an increasingly attention in industry, mainly due to the perspective focusing on continuous improvements and elimination of waste. This contributes to creating prerequisites for a better balance between the handling of minor disturbances and major technical faults (Bellgran and Säfsten, 2010).

The production increase when reducing disturbances

Lack of demand from the market, repairs of equipment and scheduled maintenance are according to (Campbell and Reyes-Picknell, 2006) all counted as downtime, disturbances. This is in contrary to Smith and Hawkins (2004) who do not see scheduled maintenance tasks as downtime, they rather see it as savings. It is pointed out that a task that has been scheduled and planned is at least 50% more efficient in terms of both time to complete and costs. By a transformation of unplanned tasks to planned tasks the possible range of savings can easily be seen (Smith and Hawkins, 2004).

By doing only the right maintenance also the time spent on scheduled maintenance can be minimized, and by being more reliable the time spent on unscheduled maintenance can be minimized. By being more reliable means to perform the right scheduled maintenance consistently and conscientiously. For a company to meet its production targets to meet the demand from the market, the maintenance role need to be fully integrated with marketing and production strategies in order for the company to meet its production targets to meet the demand from the market. This means that the asset capacity for the entire business should be optimized (Campbell and Reyes-Picknell, 2006).

A research project, "TIME-Production efficiency and effectiveness: IT-support and methods", that was carried out 2001-2004, investigated the production effectiveness and efficiency of production equipment and production system (Bellgran and Säfsten, 2010). The research was made from a life-cycle perspective, and therefore brought feedback of information and knowledge about production disturbances in the phases of the production system (design, start-up, operation, and phase-out). The result from the research presented, for instance, a guideline concerning elimination of disturbances already during the development phase. Work carried out to handle disturbances and to reduce disturbances can be performed on several levels of the production system, based on results presented in for example (Ylipää, 2000; through Bellgran and Säfsten, 2010) can a division into strategic, tactic and operative levels be made. The division provides an opportunity to adapt information, activities and improvements to different actors.

Maintenance improvement

Maintenance organizations are often so busy maintaining equipment that efforts to plan and eliminate the need at its source are forgotten. Efforts in reliability engineering should emphasize elimination of failures that require maintenance which is an opportunity to *pre-act* instead of *react.* The first and most valuable digit to eliminate or reduce the need for maintenance is maintenance improvement efforts (Mobley, 2002). In order to work in a systematic and structured way with improvements it is important to define what a production disturbance is. Naturally, it is difficult to control and improve what is not measured and followed-up. It is required to cooperate when working with improvements and it is then important to have a common view of the production disturbances (Bellgran and Säfsten, 2010).

3.3.2 Different types of Maintenance

According to Mobley (2004) are there two types of maintenance management that are typically utilized by industrial and process plants; corrective maintenance and preventive maintenance.

Corrective maintenance

Definition of corrective maintenance according to the standard prEN13306 (1998):
*"*Maintenance carried out after fault recognition and intended to put an item into a state in which it can perform a required function."

This management type is simple and straightforward, "fix it when it breaks" (Mobley, 2004), i.e. the things are fixed either after failure or during failure (Moubray, 1997). This maintenance type is emergency, repair, unscheduled and remedial tasks (Mobley, 2004). This method has been a major part of the maintenance operations since the first manufacturing plant was built, and it sounds reasonable on the surface. But it is actually a no-maintenance approach of management. It is also the most expensive one due to high machine downtime, low production availability, high overtime labor costs and high spare parts inventory cost (Mobley, 2004). The corrective technique does not take any maintenance action until equipment failure. This maintenance management philosophy is rarely used altogether without any preventive tasks (i.e. lubrication and adjustments). Still, in a corrective environment, the equipment are not rebuilt nor repaired in greater extent until it fails to operate (Mobley, 2004).

Analyses has indicated, according to Mobley (2004), that this corrective approach of maintenance cost in average three times more than the same repair in a preventive approach.

Preventive Maintenance

The preventive tasks mean replacing components or overhauling items at fixed intervals (Moubray, 1997) that is, to premature equipment damage and prevent unscheduled downtime that would result in repair or corrective activities. This approach to maintenance management is predominantly recurring or time-driven tasks performed to maintain acceptable levels of availability and reliability (Mobley, 2002).

The definition of preventive maintenance from the European standard (prEN 13306, 1998) is presented as: "*Maintenance carried out at predetermined intervals or according to prescribed criteria and intended to reduce the probability of failure or the degradation of the functioning of an item*."

Preventive maintenance can, according to the standard prEN 13306 (1998) be divided into three divisions:

- ***Scheduled Maintenance***
  Preventive maintenance carried out in accordance with an established time schedule or established number of units of use.
- ***Predetermined Maintenance***
  Preventive maintenance carried out without previously condition investigations and in accordance with established intervals of time or number of units of use.
- ***Condition Based Maintenance***
  Preventive maintenance consisting of performance and parameter monitoring and the subsequent actions. The performance and parameter monitoring may be scheduled, on request or continuously.

Machine rebuilds and repairs are in preventive maintenance scheduled based on MTTF statistic or the bathtub curve (Mobley, 2004). There is a great variety in the actual implementation of preventive maintenance, but one thing which is valid for all preventive maintenance programs is that they are time driven. This means that the tasks are based on hours of operation or elapsed time (Mobley, 2004). Comprehensive preventive maintenance programs schedule repairs, adjustments machine rebuilds for all critical equipment while more limited programs only consist of minor adjustments and lubrication. The scheduling guideline for these programs is the common denominator due to that all preventive maintenance management programs assume that equipment will degrade within a certain period of time (Mobley, 2004). The problem with the preventive approach to maintenance is that the operation mode and plant-specific variables have a direct impact on the normal operating life of equipment. For example does the mean time between failures (MTBF) vary between a pump handling water and one handling abrasives (Mobley, 2004).

Predictive Maintenance and Operator Maintenance

There are two additional types of maintenance types which are important to emphasize; Operator maintenance and Predictive maintenance.

Operator Maintenance is defined as (prEN 13306, 1998):

> "Maintenance carried out by qualified user or operator."

Predictive Maintenance is defined as (prEN 13306, 1998):

> "Condition based maintenance carried out following a forecast derived from the analysis and evaluation of significant parameters of the degradation of the item."

According to (Moubray, 1997) is predictive maintenance basically to check if something is failing or about to fail. Predictive maintenance is, according to (Daley, 2008), maintenance intended for optimists, it is based on the belief that it is possible to find failures and take action before it occurs. Predictive maintenance is therefore proactive, i.e. the tasks are performed before a failure occurred and thereby the failure is prevented. Conditions that can cause deterioration and lead to failure are searched for in predictive maintenance (Daley, 2008).

Tasks designed to find potential failures are known as *on-condition* tasks (Moubray, 1997). They are called on-condition tasks because the items which are inspected are left to perform operation *on the condition* that they continue to meet the specified performance standard (Moubray, 1997).
Predictive maintenance is the means of improving product quality, productivity, and overall effectiveness in production and manufacturing plants (Mobley, 2004). Predictive maintenance is an attitude or philosophy which uses the actual operating condition of equipment and systems within a plant to optimize total operation of the plant. Equipment is used to monitor the condition of other equipment, for example changes in vibration characteristics or changes in temperature, and these techniques are known as *condition monitoring* (Moubray, 1997). A predictive maintenance management program which is comprehensive utilizes the most cost-effective techniques in a combination to obtain the condition of critical equipment. Maintenance activities are then scheduled based on the data obtained on an as-needed basis. This will reduce the

maintenance cost and also provide the ability to optimize the equipment availability (Mobley, 2004).

Proactive Maintenance

Moubray (1997) defines proactive tasks as: "The tasks undertaken before a failure occurs, in order to prevent the item from getting into a failed state. These tasks embrace what is traditionally known as 'predictive' and 'preventive' maintenance." This is in contrary to corrective tasks which deal with the already failed state. Proactive maintenance is based on theoretical risk analyses. Proper countermeasures are taken to avoid failures (WCM overview). The characteristics of proactive maintenance are a control over the maintenance resources. With the advent of correct maintenance scheduling and planning procedures the understanding of what is required of the maintenance resources weekly often change vast and rapid. The weekly planning period can often later extend to monthly planning periods (Smith and Hawkins, 2004).

According to Moubray (1997) are there a whole family of maintenance tasks which do not belong to either of the above categories. One example of this is a periodically activation of a fire alarm which simply is a check of if it works. Tasks like this are known as functional checks or failure-finding tasks.

Maintenance management comprises several aspects. In Figure 13 below are 16 different aspects presented which contribute to an understanding of the maintenance function within a company.

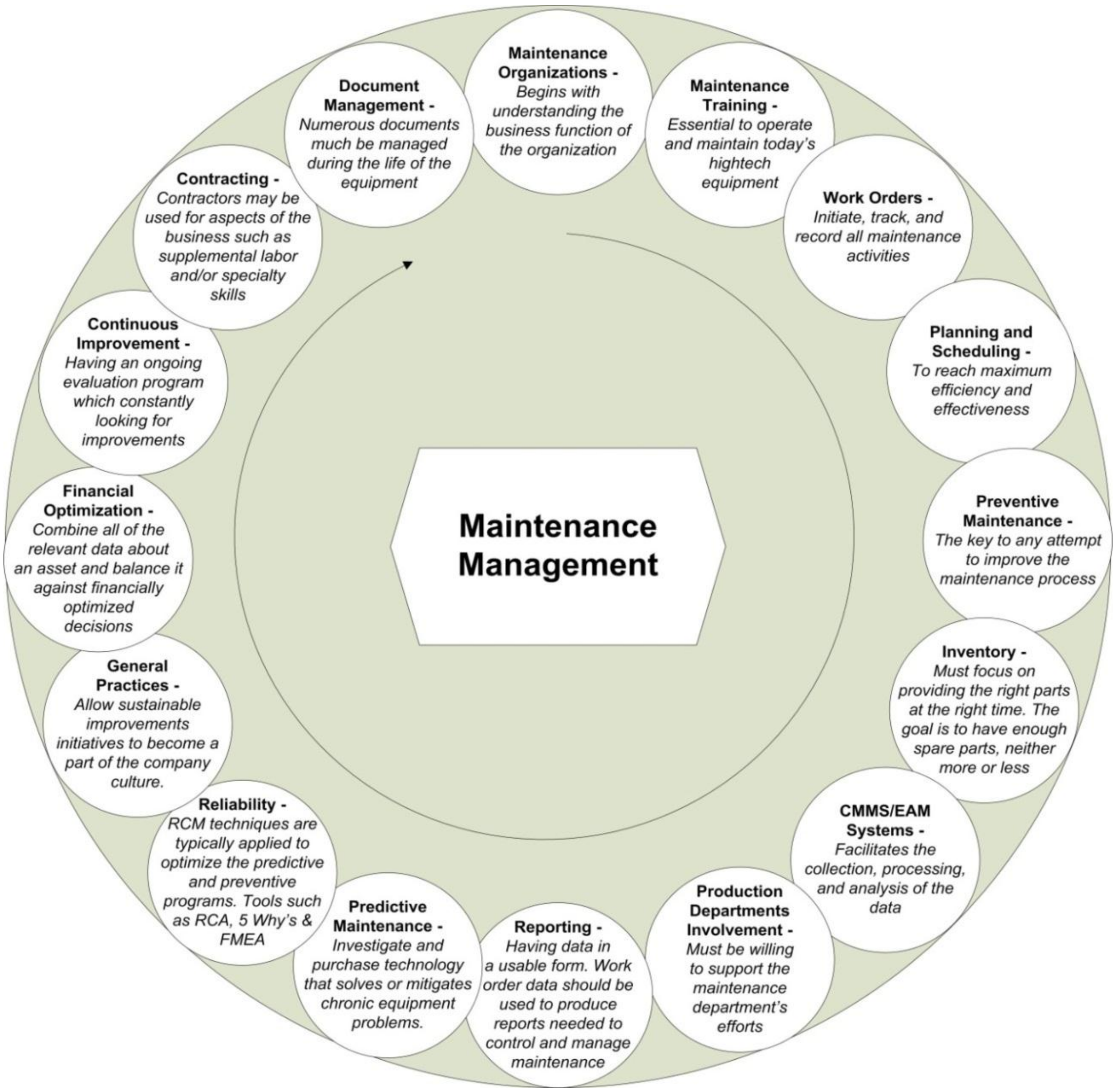

Figure 13. A presentation of 16 different aspects important to gain understanding of maintenance management (Wireman, 2010).

3.3.3 Criticality Classification

Resources are limited and it is therefore necessary to determine how to distribute them. This is to ensure that no important equipment is neglected and that more resources are concentrated on the items which are the most critical. It is therefore necessary to classify equipment according to its importance (Gómez de León Hijes and Cartagena, 2006). Availability of spare parts is a major factor that leads to a reduction of downtime duration when a breakdown occurs. Stocking is on the other hand limited by cost and space. Therefore, by designing the availability of spare parts in an optimal way is of significant importance (Braglia et al., 2004).

3.3.3.1 Equipment

According to Börjesson and Svensson (2011), determination of the equipment criticality should be based on the cost of past events. This type of foundation for prioritization guarantees that maintenance resources are continuously focused on equipment which causing the most harm to the organization. A more robust production will be obtained by continuously improving the most critical equipment. Börjesson and Svensson (2011) have proposed a classification methodology which forces the organization to react upon failures, this methodology provide a systematic way to learn from the past. The classification model constitutes of three blocks; knowledge foundation – Competence, knowledge and data, cost model for failures – prioritize with regard to cost which is a uniform measure, and stratification and prioritization – help to prioritize, stratifying costs to find the most critical equipment. To support the classification method are work methods such as data collection, operator maintenance, proper performance measures and improvement projects. Another method to use for classification of equipment is the Always Better Control (ABC) classification of equipment is used in order to assess the need of maintenance and to optimize the maintenance activities (Ylipää, 2012). The classification is made with regard to six factors (Ylipää, 2012):

1. Safety risk associated with breakdowns – **S**
2. Quality problems, customer complaints or scrap – **Q**
3. The extent of time during which the equipment are used for production – **T**
4. Obstacles that arise in the production process, which affect the lead time, due to the equipment breakdown - **O**
5. Failure frequency – **F**
6. Mean Time To Repair (MTTR) - **M**

In Figure 14 below are the rules for ABC classification presented and the ABC equipment classification process is presented in Figure 15.

S	High risk	Low risk	Insignificant risk
Q	High risk	Low risk	Insignificant risk
T	24 hours/day	8- 24 hours/day	8 hours/day
O	Cause a stop in the whole process	Don't stop the process but cause losses	Don't stop the process
F	F > 1 failure / 2 months	1 failure / 2 months – 1 failure / 6 months	F < 1 failure / 6 months
M	MTTR > 2 hours	0.5 < MTTR < 2 hours	MTTR < 0.5 hours

Figure 14. Rules for the classification of equipment (Ylipää, 2012)

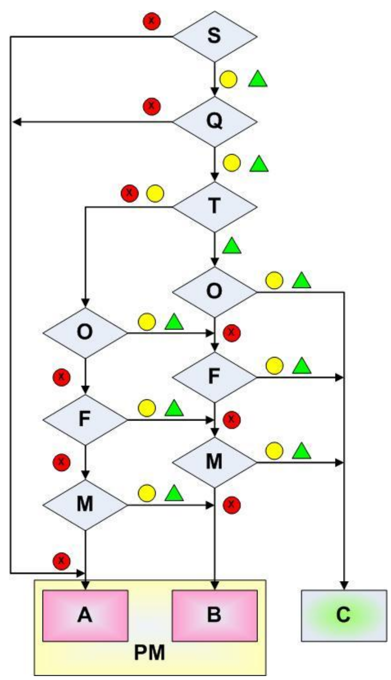

Figure 15. A flowchart which represents the process of classifying equipment (Ylipää, 2012)

As can be obtained in Figure 14 and Figure 15 above the process consist of answering the following questions for the equipment:

1. How high is the safety risk?
2. How high is the quality risk?
3. How many hours per day is the equipment used for production?
4. How is the production process affected by the equipment breakdown?
5. What is the failure frequency?
6. What is the mean time to repair?

According to Figure 14 is a preventive maintenance program developed for equipment classified as 'A' or 'B'. For equipment classified as 'C' is no effort made to prevent failures, those failures are allowed to occur and then repaired, i.e. a corrective maintenance program
(Ylipää, 2012; Moubray, 1997).

3.3.3.2 Spare parts

According to (Wireman, 2010) do the inventory and purchasing employees have a great impact on maintenance productivity and the management on spare parts must be controlled in a profitable and effective manner; the right parts must be provided at the right time and the goal is to have enough spare parts, neither more or less. This can also be obtained in Figure 13. Spare parts management routines should, according to Börjesson and Svensson (2011), be based on the consequences of shortage of a certain component. It is also pointed out that it is important to consider the cost of keeping the component in storage versus the cost of a shortage in terms of production loss. The probability of a shortage must be included when determining the cost of a shortage. In order to establish is a certain spare part is beneficial to keep in storage must the shortage cost be greater than the cost of purchasing, ordering and carrying the part (Börjesson and Svensson, 2011). A spare parts model are developed, by Börjesson and Svensson (2011), for performing this analysis. ABC analysis can be used also for spare parts control (it has already been described, but for classification of equipment). It separates the inventory items into three categories, namely A, B, C with respect to their annual cost volume consumption: unit cost x annual consumption (Gupta, 2009). Items categorized as 'A' require special managerial attention, 'B' items are not so costly as to require special managerial attention but overstocking should not be ignored, and 'C' items can be managed more casual and the quantities ordered can be relatively large without incurring excessive costs (Gupta, 2009). According to (Wireman, 2010), items categorized as 'A' are 20 % of the stock items and 80 % of the total inventory value, 'B' items are 30 % of the stock items and 15 % of the total inventory value and finally, items categorized as 'C' are 50 % of the stock items and 5 % of the total inventory value.

3.3.4 Reliability Engineering

According to Hinchcliffe and Smith (2004) a general accepted formal definition of reliability is: "*Reliability is the probability that a device will satisfactorily perform a specified function for a specified period of time under given operating conditions*."

The purpose of reliability engineering is to develop tools and methods to demonstrate and evaluate reliability, maintainability, availability, and safety component, systems and equipment, as well as to support production and development engineers in order for them to build in these characteristics. Equipment and systems are becoming more and more complex, and the cost incurred by loss of operation due to failures is rapidly increasing, this has highlighted the aspects of reliability, maintainability, availability and safety (Birolini, 2010).

Every physical asset is put into service because there is a need for a specific function or functions, and this asset is expected to fulfill this need (Moubray, 1997). Reliability focuses on the assets ability to perform this function under certain specified condition during a stated period of time (Gulati and Smith, 2009). According to Gulati and Smith (2009) are there three key elements of asset reliability:

1. Asset function
2. The conditions under which the asset operates
3. Mission time

Reliability is a design attribute and should therefore be “designed in” when the asset is designed and built. Maintainability is another design attribute, and it goes hand in hand with reliability. Both reliability and maintainability are therefore strategic tasks. Maintainability reflects the ease of maintenance and thus, the objective is to insure that maintenance tasks can be performed safely, easily, and effectively (Gulati and Smith, 2009). Reliability is measured by Mean Time Between Failure – MTBF and maintainability is measured by Mean Time To Repair – MTTR (Gulati and Smith, 2009).

Maintainability is closely related to maintenance prevention, which focus on the initial design of equipment to reduce the need for maintenance, thus it is the designed ability to maintain the asset. Issues such as: accessibility, serviceability, safety, component standardization, interchangeability and modularization are addressed by maintainability. The overall maintenance cost during the operational phase of the equipment’s life cycle is dramatically reduced when these issues are addressed during the design phase of the equipment (Wireman, 2000).

Companies search for methods of reducing maintenance cost and one part of the solution is the type of equipment they design or purchase. The overall maintenance cost for the equipment’s life cycle will be lowered if the maintenance requirements can be minimized during the design phase of the life cycle. Many companies are concerned about their current assets and this maintenance prevention design principle can still be applied to these assets. Analyses of the assets historical records concerning trends of types of failures, frequency of component failures, or root causes of failures should then be made. The information gained from the analyses can be examined further in order to determine how to eliminate the problem and reduce maintenance by changing a process or changing the design (Wireman, 2000).

Both reliability and maintainability are designed into the assets to minimize maintenance needs and thus, the maintenance cost, this is done by using reliable components, simplify replacements and ease inspections (Gulati and Smith, 2009). As already mentioned, these issues can also be addressed on existing equipment to reduce the maintenance cost. By reducing the amount of money that is spent on maintenance the profitability increases (Wireman, 2000).

Maintenance is a tactical task, it sustains the assets reliability and thus, it does not improve the reliability (Gulati and Smith, 2009). The asset is maintained to ensure that it will continue to fulfill the specific function or functions, i.e. to retain the inherent reliability in order to preserve the state where it performs as the user wants it to (Moubray, 1997).

Reliability specifications and requirements are necessary in order to develop a reliable asset. The specifications need to address the conditions in which the asset has to operate, mission time, usage limitations and operating environment. This often requires a detailed description of how the asset is expected to perform from the perspective of reliability. Also financial aspects need to be taken into consideration when the reliability specifications are formulated. Questions such as; how many failures are acceptable? What reliability can we afford? Thus, it is necessary to balance the financial constraints with realistic asset reliability performance expectations (Gulati and Smith, 2009).

According to Gulati and Smith (2009) has it been found that as much as 60 % of failures and safety issues are possible to prevent by making design changes. Assets must be designed to fail safely, designed for fault tolerance, designed with early warning to the user of the failure, have a built in diagnostic system to identify the location of the failure and if possible also designed to eliminate all or critical failure modes cost effectively. Gulati and Smith (2009) recommend that the following analyses are performed during the design phase of an asset:

- ***Reliability Analysis –*** Lowers asset and system failures long term.
    - The asset and system reliability depend on robustness of design, and also on quality and reliability of its components.
- ***Maintainability Analysis –*** Reduces the cost of maintenance and minimizes downtime since the time for repair is reduced.
- ***System Safety and Hazard Analysis –*** Identifies, reduce, or even eliminate safety-related risks throughout its life cycle.
- ***Human Factors Engineering Analysis –*** Prevents human-induced errors or mishaps and mitigates the risks to humans.
- ***Logistics Analysis –*** Reduces field support cost resulting from reliability, maintainability, poor quality and safety. It also insures availability of all documentation including spare parts, PM plan and training needs.

3.4 Maintenance concepts with fundamental ideas

Presented in this chapter are the concepts existing within maintenance that are believed to serve this thesis a good base of knowledge, both for the reader, to understand, but also as fundamental aspects to the Customer Focused Model, CFM.

3.4.1 Total Productive Maintenance

Maintenance has for a long time been a major area in the industry but more recently has its importance and value increased as more and more companies are realizing its value, and perhaps above all, the consequences of downtime.

Maintenance departments have since 1900 gone from being responsible only for repairs to in 1960-1970 take over responsibility for maintenance and preventive maintenance (Ljungberg, 2000). It was also during this time that the Japanese companies, and to a large extent, associations Japan Management Association, JMA, and its daughter organization Japan institute of Plant Maintenance, JIPM, became interested in the American corporate procedure, preventive maintenance. Preventive maintenance was embraced, and when the Japanese company Nippondenso, which at that time had problems with an increasingly higher degree of automation, developed Preventive Maintenance for Autonomous maintenance began the elaboration of what is now known as Total Productive Maintenance (Ventakesh, 2009).

Total productive maintenance is a concept in which the purpose is to maximize the overall equipment efficiency, OEE, (Ljungberg, 2000), thus creating a system free from interference. By concentrating on preventive techniques and involvement of operators, downtime can be minimized, and thus increasing the OEE.

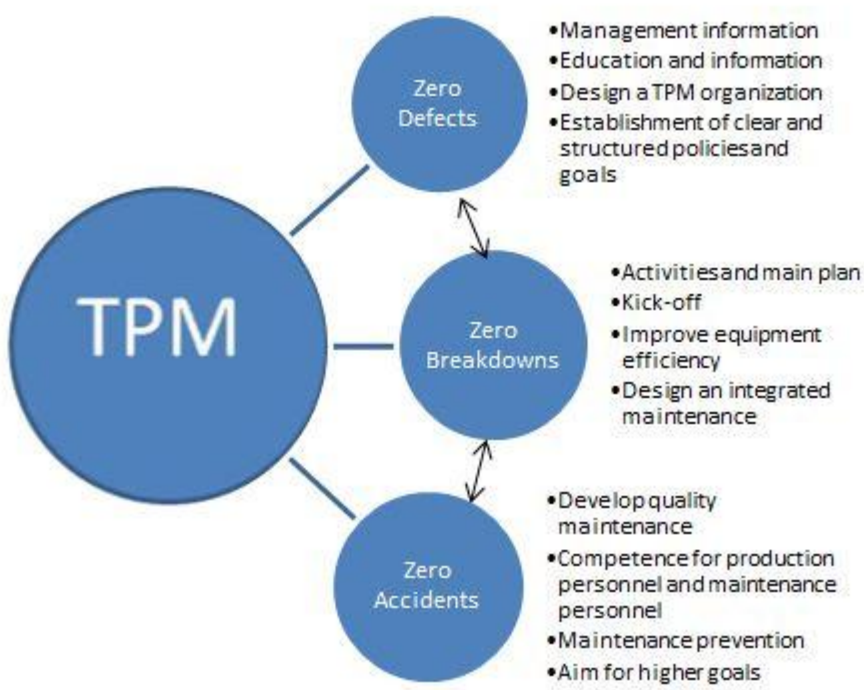

Figure 16. TPM consists of three basic goals; Zero product defects, Zero breakdowns and Zero Accidents. Furthermore TPM have 12 activities coupled to the basic goals.

Working with TPM gives rise to direct and indirect benefits. Direct benefits in this context are; Increased OEE, Reduced customer complaints, reduced manufacturing costs, increased delivery reliability and decreased amount of injuries with less severity. Indirect benefits may in turn be; More self-confident employees, clean workplaces, better attitude among employees, group feeling among employees, lower hierarchy feeling and a more personal feeling towards the equipment (Hagberg and Henriksson 1996).

In order to sustain and improve the TPM processes for companies, JIPM develop a 12-step procedure, describing how it is to be implemented, see Figure 16.

Step 1 - Management information

Companies working continuously with TPM have proven to show good results. This includes reducing interference times up to 90 %, reduced scrap rate and sick leave due to injury (Hagberg and Henriksson 1996). TPM have proven to be a concern for companies, it motivates and drives the workers and in top management levels it has proven to be of strategic matters as it facilitates the work concerned with competitiveness. For this reason, attitude for change is of great importance and also superior everyone. The fact that there is a possibility to perform better should, and have to, be the single most important thing.

It should also be noted that work cultures of this magnitude may have an implementation phase up to two to three years, thus demanding an open attitude from everyone and especially the top management involvement. Furthermore, purposeful efforts are needed to reduce, what in TPM is called “the six sources of loss”, this due to affection on the OEE. “The six sources of loss” are; equipment failures, adjustments, idle running, excessive cycle time, process losses and reduced exchange. To meet the specification for the award “PM Excellent Plant Award” it is required to perform with no less than 85% in OEE. Something Volvos production facility in Gent achieved in 1991 (Hagberg and Henriksson 1996). As of this moment, working with pilot projects, study visits and attending presentations and seminars is of great importance since the management’s understanding is crucial for success (Nord and Pettersson, 1997).

Step 2 - Education and information

When managements have understood the message of TPM and its meanings, it is time to pass the information to the rest of the company. Those who are to participate in pilot projects needs to be educated in order to understand the reasons behind TPM, its meaning and what the purpose of the pilot project are (Nord and Pettersson, 1997). Further, a large part of the education is to start a discussion among the workers, where everyone can share their view of possible problems and solutions.

It is important that the flow of information about the pilot projects reach remaining workers so that interest in TPM and its impact on daily work increase. This information may also be of value to share with suppliers and customers (Hagberg and Henriksson 1996).

Step 3 - Design a TPM organization

A well-structured TPM organization is of paramount importance. The organization should provide a comprehensive decision making and to some extent also be represented in senior management to safeguard the long-term of TPM work (Hagberg and Henriksson 1996).

Step 4 - Establishment of clear and structured goals and policies

Concrete objectives and policies should be designed and be available for everyone to take part of. This should also be based on the current situation for the company, thereby making it clear what to measure but also showing realistic goals.

A policy is the next step after the goals have been developed. The policies are to describe the role of different steps in the corresponding long term goals (Slack and Lewis, 2008). Thus acting as a guiding principle for all activities and taking into account both external, internal customers as well as suppliers. A policy may reflect the methods and values of the company, showing how the company is to achieve its vision (Bergman and Klefsjö, 2010).

It has previously been pointed out the importance of vision and goals, and that they are informed as to all employees but also that they are accepted by all. To simplify this process, it is common to use policy deployment, which means that all who become involved in the cases also have the right to take part in the development of these (Bergman and Klefsjö, 2010). Thus it is possible that the "what" comes from the vision, while "how" comes from those who participate in the execution of the change (Bergman and Klefsjö, 2010).

Step 5 - Activities and main plan

A master plan reaching far into the future and covering the adoption to TPM are to be designed. This is to prevent time and resource activities to be misjudged. All activities are to presented in a clear and simply time table, i.e. a Gantt—schedule.

Step 6 - Kick-off

The pilot projects may at this point be sufficient far advanced with the TPM work that the ability for analysis and evaluation is appropriate. Hopefully also proving that the TPM work can be expended further within the company.

Step 7 - Improve equipment efficiency

This step can be further divided into sub tasks, however, what it comes down to are continuously measure and improve. There are several methods and procedures to do this, however most common are to use either the seven improvement tools or the seven management tools. Each describing a method to measure, analyze and improve the process.

The seven improvement tools are a set of tools to handle large amount of data. Since, involvement and participation are constantly advocated, it is therefore also vital that these tools are easy to understand but also to use (Bergman and Klefsjö, 2010).The following methods are included in the seven improvement tools: Control chart, Pareto chart, Scatter plot, Data collection, Histogram, Stratification and Cause-and-effect diagram.

Supplementary to the seven improvement tools are the seven management tools. Their intention is to deal with verbal data. They are particularly effective tools when it comes to identify problems and to prioritize solutions for these (Bergman and Klefsjö, 2010). The seven management tools are: Tree diagram, Affinity diagram, Matrix data analysis, Matrix diagram, Interrelation diagraph, Activity network diagram and Process decision program chart. In addition to these there are also special KPI's generally used in manufacturing and maintenance.

Step 8 - Design an integrated maintenance

The aim and purpose is to increase the cooperation between various professionals in order to reach a better maintenance system. Striving for an "ownership feeling" towards the equipment. However, this demands higher competence of the staff and delegation of responsibility. In order for this to work properly it requires discipline in the production. Operators should not unduly be interrupted, thus tools and equipment should be located at each site. A common method to handle this within Lean production is to use 5S.

As the operator learns more stations and can take more responsibility, they are also more powers. In this way, operators will soon be able to conduct inspections, failure analysis and find causes for simple errors. Within a reasonable time the operators facilitate the traditional maintenance work (Nord and Pettersson, 1997). To reach operator maintenance Nord and Pettersson (1997) describes a model, seven steps to self-maintenance. See Figure 17 below.

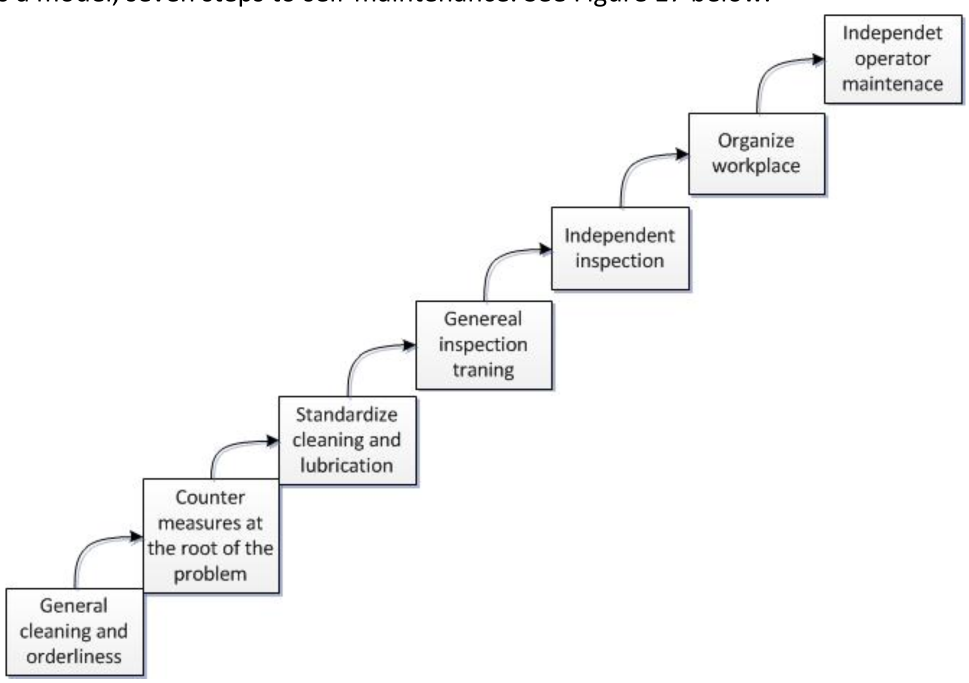

Figure 17. Reaching independent operator maintenance is based on starting with simple tasks and develops as the operator raises the level of competence (Nord, C., Pettersson, B., Johansson, B., 1997)

5S

A method within lean production, which aims to eliminate waste in the sense that it highlights the problems and errors that otherwise would be hidden. The goal is to obtain cleaner and safer workplaces and better organized and more efficient ones. This will save time, with fewer interruptions, and space by getting away unnecessary tools or by moving the tools not used to often, and thus don't need to be at site (Liker. K, 2004). 5S comes from the Japanese words:

Seiri - Sort - Separating frequently used tools from tools not frequently used. Only the frequently used tools, supposed to be directly adjacent to the workplace.
Seiton - Straighten - Every frequently used tool should have its place and be well tagged.
Seiso - Shine - Regularly clean and inspect the workplace.
Seiketsu - Standardize - Develop a procedure to maintain and monitor that the first three rules are followed.
Shitsuke - Sustain - Evaluate regularly and always try to improve.

This is a continuous loop and follow the otherwise well-known concept, kaizen, continuous improvements, therefore, 5S is not intended as a quick fix and made for a limited time, but shall continue to run continuously and constantly trying to improve. See Figure 18, the 5S loop.

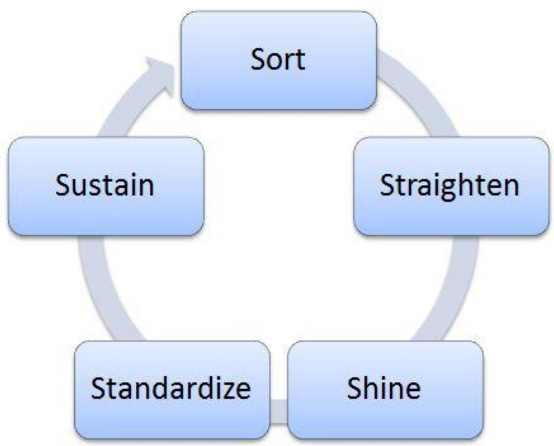

Figure 18. The process-chain for 5S is intended to continue to run continuously and have hence no apparent end. (Liker, J.K, 2004) (pp. 151, Figure-13-1)

Step 9 - Develop quality maintenance

Striving towards planned maintenance and quality maintenance, meaning focus on efforts such as preventive maintenance and Design-out-Maintenance. But it also means that the sources of problems must be analyzed at the source of the problems.

Step 10 - Competence for production personnel and maintenance personnel

An interference free process requires that the production staff and maintenance staff will receive training that is directed against them. Production staff needs to further develop their knowledge and the maintenance staff must be offered the opportunity to develop greater expertise that might be expected of them (Hagberg and Henriksson, 1994). Education and knowledge is a basis in order to perform continuous improvement programs.

Step 11 – Early Equipment Management - Maintenance prevention

Old and new equipment should be examined as efficiently as possible. Hence, it is important that this procedure is being performed correctly. Thus, step 11 is all about making sure that new equipment isn't acquired until is has been treated in the proper manner, the same is valid for old equipment, unnecessary time must not be spent on equipment which is soon to fail. Life cycle cost, can for this reason be used successfully. According to Hagberg and Henriksson (1994) following point may be considered.

- Built in maintenance in new equipment
- Striving for maintenance free constructions
- Maintenance department should be present in purchase
- Effective routines for reversal of new knowledge
- Use of present methods for failure analysis

Step 12 - Aim for higher goals

This step concerns the issue of never stop proceeding new goals. One should strive to get rid of all types of Sporadic and chronic failure and never settle for less.

Description of the losses considered within TPM

One of the first focuses of TPM is major equipment effectiveness losses. Here the largest gains can be realized and in the shortest amount of time. It is common in TPM to talk about these losses, and as described earlier, it is common to talk about six sources of loss in TPM. Smith (2004), however, describes 11 losses, these are:

Planned-shutdown losses which includes:

1. Breaks, Shift Changes and simply no production
2. Planned maintenance

Downtime losses, including:

3. Equipment breakdowns
4. Setups and changeovers
5. Tooling changes
6. Start-up and adjustments

Performance efficiency losses:

7. Minor stops. Described by Smith (2004) to be less than 6 minutes
8. Reduced speed or cycle time.

Quality losses:

9. Scrap products
10. Defects or rework

11. Yield losses

In loss 1, the production might be stopped due to the fact that the company is using a third shift as maintenance shift. It might as well be that there is no production during weekends and break, hence, giving shutdown-losses.

Shutdown losses due to planned maintenance are when major maintenance work has been planned and thus needs to stop the production. In many cases the production might be stopped for an appreciable amount of time, which in many cases might be needlessly long. Smith (2004) makes a comparison with pit-stops in Nascar during 1950 and pit-stops today. In 1950 a pit-stop would take about 4 minutes, in which changing tiers, fuel the car, make adjustment to the chassis and wipe windshield and radiator. This is today done in less than 22 seconds, without having more mechanics but simply by doing the maintenance work smarter. The same drastic change is believed to be possible within many industries, meaning that one should look over the planned maintenance program. It can, in some cases, not be as satisfying as first believed (Smith, 2004).

Downtime losses are in many vies considered to be breakdowns of equipment, and this is one, but in downtime losses also includes the time for changing from one lot to another, as well as set-up times, tooling changes and start-ups. The time until production produces at normal tact is considered to be a loss and should thus be known. This is also reflected in performance efficiency losses, where stops less than 6 minutes often isn't tracked, but in the long run, these 6 minutes will add up and represent a larger number of missed production (Smith, 2004). Finally, Smith (2004) illustrates the issue of quality losses, which aim the issue of producing scrap. This will lead to the need of overproducing in order to compensate for quality losses.

3.4.2 Lean Maintenance

Lean maintenance is a concept making use of the ideas and philosophy from lean manufacturing and combining this with TPM and RCM methods. The idea is exploit the best way, methods and ideas that have been adopted in Lean manufacturing. More precise, using planned and scheduled maintenance activities developed in TPM using the strategies developed from an RCM work, and should be practiced by teams using 5S and Kaizen in their work. Further Smith (2004) highlights the possibility of a CMMS system providing parts and materials just-in-time, and thus shed light on the essential parts of lean associated with maintenance. It is stated that not having an effective approach to maintenance makes it impossible to fully succeed with its Lean philosophy (Smith. R, 2004).

Thus in Lean Maintenance, one wants to achieve, to the greatest extent possible, preventive maintenance. Planned and scheduled activities will form the major part of any maintenance. Consequently, it is noted that Lean Maintenance is defined by its internal parts and their definition, including, Lean, TPM and RCM, among others. See Figure 19, Lean Maintenance pyramid, in which Smith illustrates the relative parts.

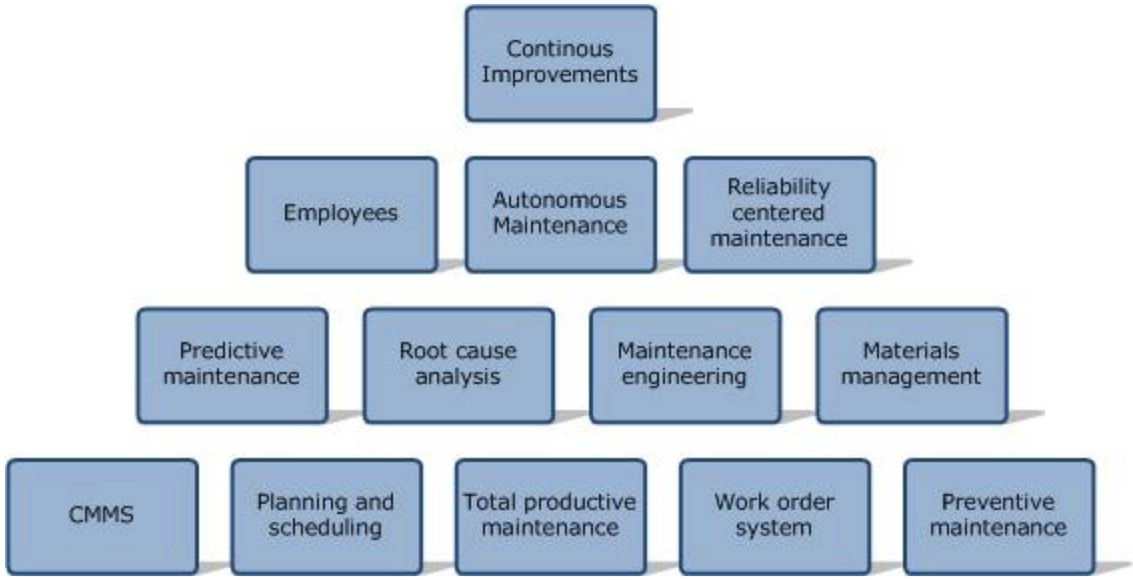

Figure 19. Maintenance management pyramid, according to Smith (2004). Each internal part makes up the concept of lean maintenance.

According to Smith (2004) working with lean maintenance will prove successful in following aspects; improved inventory control as a result from better planning and scheduling which also will decrease the wastes; increased accuracy in maintenance budgeting, also a factor due to improved equipment reliability; and also, reduced maintenance costs, which has, according to Smith (2004) been prove to show a return on investment increase to a factor of 10:1 within three year and also a reduction between 30-50% in maintenance spending within 3-5 years.

Smith (2004) highlights another interesting method to be embraced by lean production, value stream mapping. The aim is to see the value-added flow, and should, according to Smith done in 8 steps. The first step is to choose which part of the process to be analyzed, study the process and understand it. Then in step two is the time to map the process to continue in step three, analyze the process hoping to go deeper into detail on how the value adding process is proceeding. This step is performed until all participants agree that all the pieces have been covered. The end-result from these three steps is the present state for the process.

Onwards, step four will cover re-analyzing the present map in order to identify all activities which are considered not to be value adding. These are in step 5 to be removed, or if not possible to remove, facilitate the ability work around these, thus creating a list of all activities needed to be removed. In step six, the team is to reanalyze the map to verify that the process still is workable and sustainable. When this step is performed, a future map has been developed and the action plan is to be presented for the management for approval. Finally in step 8 the actions are to be implemented (Smith, 2004).

3.4.3 Reliability Centered Maintenance

Originally, Reliability- Centered Maintenance (RCM) was designed for the aircraft industry and the so-called RCM II concept was designed for use in general industry (Waeyenbergh and Pintelon 2002). The RCM approach is a maintenance process based on system functions, consequences of failure, and failure modes (NASA, 2008).

In some fundamental aspects RCM is very different from what the norm among maintenance practitioners is today and it requires very basic changes in our mindset. The basic concept of RCM is quite simple, and might be viewed as organized common sense (Hinchcliffe and Smith, 2004).

The process is named RCM to emphasize the importance of reliability when focusing (or centering) preventive maintenance activities on the retention of inherent design reliability of the equipment. Reliability technology is, as the name implies, at the center of the maintenance planning process and philosophy (Hinchcliffe and Smith, 2004).

According to Moubray (1997) is maintenance performed to ensure that physical assets continue to do what their users wants them to do.
The user's need depends on how and where the asset is used (the operating context) which leads to the following formal definition of Reliability-centered Maintenance (Moubray, 1997):
"A process used to determine what must be done to ensure that any physical asset continues to do what its users want it to do in its present operating context."

The RCM approach has been accepted by the Department of Defense (DoD) and aircraft, spacecraft and nuclear industry for a long time, but it is a relatively new maintenance approach within industries outside these four arenas (NASA, 2008).

An RCM analysis considers the following seven questions about the system or asset under review (Moubray, 1997);

- What are the asset's functions and associated performance standards in its present operating context?
- In what ways does the asset fail to fulfill these functions?
- What are the causes to each of the functional failure?
- What are the consequences of each failure?
- In what way is each failure relevant?
- How can each failure be prevented or predicted?
- What action should be taken if a suitable proactive task cannot be found?

The goal of an RCM approach

Reduce the Life-Cycle Cost (LCC) of equipment to a minimum and at the same time allow the equipment to function as intended with required availability and reliability. A reliability centered approach search for most applicable cost-effective maintenance technique to minimize the risk of impact and failure and to create a healthy working environment while preserving and protecting capital investments and their capability. This is accomplished through identification of failure modes and their consequences for each system. The equipment and system functionality is by this allowed to be maintained in a cost-effective way (NASA, 2008).

What is achieved by the RCM process?

- **Greater maintenance cost-effectiveness:** The activities which have the highest impact on the plant's performance are in focus. This helps to ensure that maintenance resources are spent where it will do the most good.
- **Expensive items will have a longer useful life:** The use of on-condition maintenance techniques is emphasized.
- **Greater safety and environmental integrity:** The safety and environmental influence for each failure mode are considered before its effect on operations.
- **A comprehensive database:** When an RCM review is finished there is a fully documented and comprehensive record of the maintenance requirements of all the significant assets available. Also a clearer view of the skills required to maintain each asset is provided.
- **Improved teamwork:** An easily understood and common language for all maintenance personnel are provided by RCM. This gives maintenance and operations people an increased knowledge of what can or cannot be achieved, as well as how to achieve it, by maintenance.
- **Increased motivation of individuals:** The RCM process and review provides an improved understanding of the assets and also a wider "ownership" of maintenance problems.

Improvement programs are already dealing with these types of issues, and they are also a part of the mainstream of maintenance management. However, an important difference is that RCM provides an effective step-by-step framework for dealing with all the issues at once and also for involving everyone concerned (Moubray, 1997).

The RCM approach

An important question to ask when it comes to reliability is "How is high system reliability to be achieved, and what key elements need to be addressed?" (Hinchcliffe and Smith, 2004). It must first and foremost be recognized that reliability is a design attribute. This means that the reliability of a device is established during the design process and it cannot be tested, inspected or fabricated into a device, i.e. the design is the sole determinant in setting the upper level of reliability that can be achieved. It is during the design and development phase of the device that preventive maintenance tasks are specified initially and the RCM methodology is a highly effective method for developing these initial PM task specifications. PM tasks with a range from simple lubrication to more complex replacement of certain life-limited parts are necessary in order to retain the inherent reliability. Unfortunately, the design process often relegates this aspect to secondary priority, and this leads to that devices are fielded with a less than adequate PM program. Thus, the probability that the device will operate up to the customer expectations for reliability is less than reasonable, and many systems and products in operation today fall into this category. The RCM methodology can, however, still be applied to these systems and equipment, by upgrading their PM programs and ultimately realizing the inherent reliability's full potential (Hinchcliffe and Smith, 2004).

RCM integrates Preventive Maintenance (PM), Predictive Maintenance (PdM), Corrective, and Proactive Maintenance to increase the probability that equipment will function as required over its design life-cycle with a minimum amount of downtime and maintenance. These maintenance strategies are optimally integrated to take advantage of their respective strengths, and maximize the reliability and availability of equipment while minimizing life-cycle costs. Maintenance decisions are required to be supported by sound economic and technical justification by the RCM process.

The six failure patterns in RCM

The frequency of failure is useful when determining maintenance intervals and making cost decisions (NASA, 2008). The traditional view of failure is based on the assumption that most items operate reliably during a period of time and then wear out. The same traditional view suggests that extensive records about failure will enable the possibility to determine that period of time and perform preventive tasks shortly before the item fail. However, equipment is today in general far more complex than that, this has led to changes of that view and resulted in the patterns of failure as shown in Figure 20 below. The curves in the Figure 20 show conditional probability of failure against operating age for a variety of mechanical and electrical items, and the curves fall into six basic types. The overall negative effect that age has on reliability is reflected by the conditional probability of failure (Moubray, 1997; NASA, 2008).

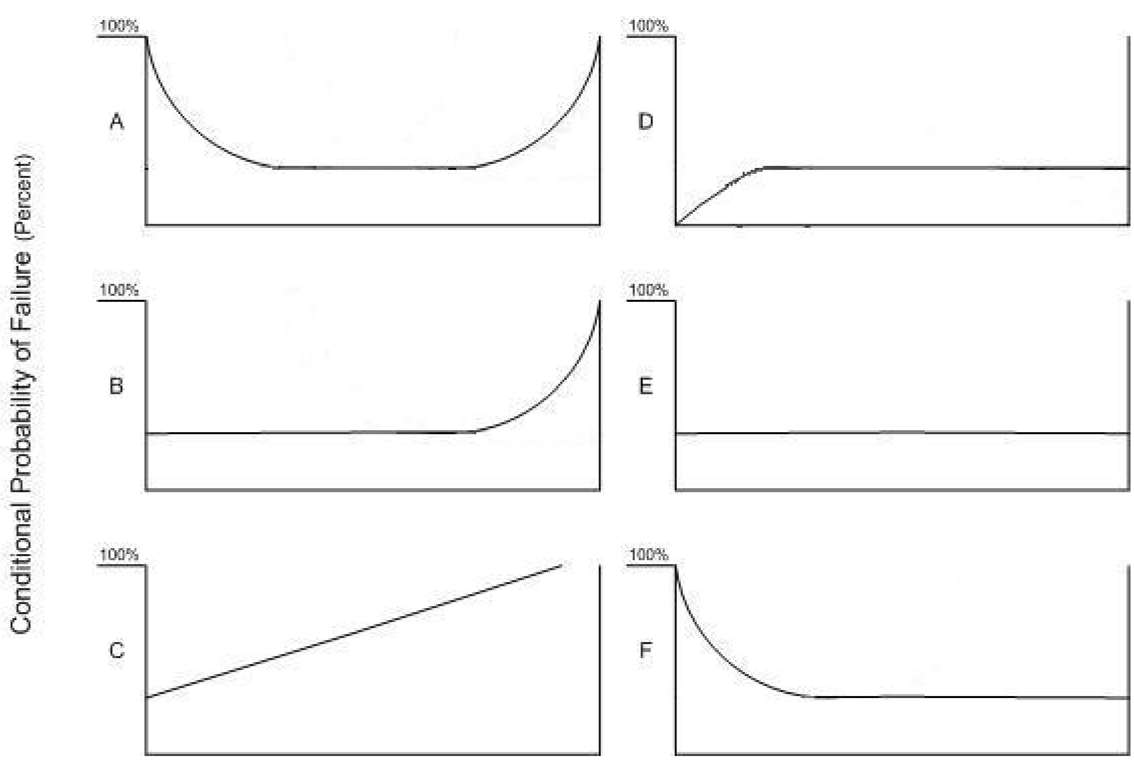

Figure 20. RCM Failure Patterns – The six failure patterns included in RCM methodology, each curve is plotted as probability of failure against age (Moubray, 1997; NASA, 2008).

Failure patterns B and E represents the most widely held views of age-related and random failure. Age-related failures are depicted in pattern B and failure pattern E depicts random failures, in other words, the probability of failures is relatively constant at all ages for pattern E. Pattern A is the bathtub curve which is a combination of two or more different failure patterns, one which depicts infant mortality followed by a constant probability of failure and then a pronounced wear-out region which, i.e. an increasing probability of failure with age. Failure pattern C shows a gradually increasing probability of failure and it is therefore age related, but it has no identifiable wear-out age. Items which follow failure pattern D has a low probability of failure just after overhaul or when it is new, after a period of time is there a quick increase of failure probability to a relatively constant level. Failure pattern F depicts infant mortality, it is the only one where failure probability actually decreases with age and it is also the most common of these different failure patterns (Moubray, 1997; NASA, 2008).

According to Moubray (1997) have studies on civil aircraft been done which showed that 4% of the units follow pattern A, 2% follow pattern B, 5% of the items conformed to pattern C, 7% to D, 14% to E and as many as 68% of the units conformed to pattern F. Moubray (1997) points out that these results are not necessarily the same in industry, although there is certain that assets are becoming more and more complex. Therefore, the fact that units follow pattern E and F are more and more common. This result contradicts the belief that reliability and operating age always are connected. The idea that the more often a unit is overhauled, the more likely it is that it won't fail, has evolved from this belief (Moubray, 1997). This is seldom true at present, due to the complexity of today's units. The mechanisms of failures are still the same, but several simple component parts operate simultaneously and interactively. Therefore, failures do not occur for the same reason at the same age. Unless there is a dominant age-related failure mode contributes age limits little or nothing to improve the complex unit's reliability and unless there are few dominant or critical failure modes it is unlikely that maintenance tasks can be designed. Scheduled overhauls can, in fact, actually increase the overall failure rates by the introduction of infant mortality into units which otherwise are stable (Moubray, 1997; NASA, 2008).

To not schedule maintenance tasks may be the right thing to do for units which do not have age related failures and also if the failures have minor consequences (Moubray, 1997). A no scheduled maintenance, or corrective maintenance, program entails making no efforts to prevent failures, so those failures are allowed to happen and when they do are corrective maintenance tasks performed to repair the unit (Moubray, 1997).

The four features of RCM

RCM is defined and characterized by four features that are set apart from any other maintenance planning process that is used today (Hinchcliffe and Smith, 2004).

Feature 1 - Preserve system function

To "preserve system function" is the first and most important feature of RCM. This is, at first glance, a difficult concept to accept due to that it is in contradiction to our ingrained mindset that

PM is performed to preserve equipment operation. To first address the function of the system, means that it is wished to know the expected output, and that preserving that output (function) is the primary task. This first feature makes it possible to decide systematically later in the process exactly which equipment relate to which specific function, and not assuming that "every item of the equipment is equally important", which is a tendency that seems to pervade the current approach of PM planning (Hinchcliffe and Smith, 2004). An example of the preserve system function concept is presented in Appendix II.

Feature 2 - Identify failure modes that can defeat the functions

The primary objective is to preserve system function; due to this the next item to consider is loss of function or functional failure. Functional failures are not always a simple "have or don't have" situation and it come in many shapes and sizes. There can exist many in-between states that always needs to be examined, these certain states may be of great importance.

The key point in feature 2 is to "identify specific failure modes that potentially caused the unwanted functional failures" (Hinchcliffe and Smith, 2004).

Feature 3 - Prioritize function need (via failure modes)

To preserve system function is the primary objective in the RCM process and in a very systematic way it can be decided just what order or priority to be assigned in allocated budgets and resources. This can be phrased as: "all functions are not equally created", and all functional failures and their failure modes and related components are therefore not created equal. Thus, the importance of failure modes is prioritized (Hinchcliffe and Smith, 2004).

Feature 4 - Select applicable and effective PM tasks for the high priority failure modes

Up to this point is formulating a systematic roadmap that tells the where (component), what (failure mode), and priority. This will now be used to proceed with establish specific PM actions and all of this is driven by the fundamental premise to "preserve function". Thus, we address each failure mode in its prioritized order to identify the candidate PM actions that could be considered, and each one of these candidates must be judged as being "applicable and effective" (Hinchcliffe and Smith, 2004).

According to Hinchcliffe and Smith (2004) is the meaning of applicable respective effective the following:

Applicable – If the task is performed it will accomplish one of the three reasons (discover a hidden failure, detect onset of a failure, or prevent or mitigate failure) for doing PM, irrespective of cost.
Effective – We are willing to spend the needed resources to do it.

In general if there are more than one candidate PM action that is judged to be applicable we choose the least expensive, i.e. most effective task.

The system analysis process – RCM methodology

The process used to implement the four basic features that defines and characterizes RCM can be discussed in terms of seven steps. These steps are developed from experience as a suitable way to delineate the required information systematically:

Step 1 - Select system and collect information.
Step 2 - Define the system boundary.
Step 3 - Describe the system and draw a functional block diagram.
Step 4 - Define the system functions and functional failures - Preserve functions.
Step 5 - Perform a failure mode and effects analysis (FMEA) - Identify failure modes that can defeat the functions.
Step 6 - Perform a logic (decision) tree analysis (LTA) - Prioritize function need via the failure modes.
Step 7 - Select task - select only applicable and effective PM tasks.

If these seven steps are completed satisfactorily then a baseline definition of the preferred PM tasks will be provided with a well-documented record of exactly how the tasks were selected and why the tasks were considered to be to be the best selections among competitive alternatives. In order to complete a successful RCM program two additional steps are required:

Step 8 - Packaging of the tasks - the recommended RCM tasks will be carried to the floor.
Step 9 - Living the RCM program - the actions necessary to make the beneficial results from step 1-8 sustain over time are comprised in this step (Hinchcliffe and Smith, 2004). An illustrating picture in Figure 21 is presented below.

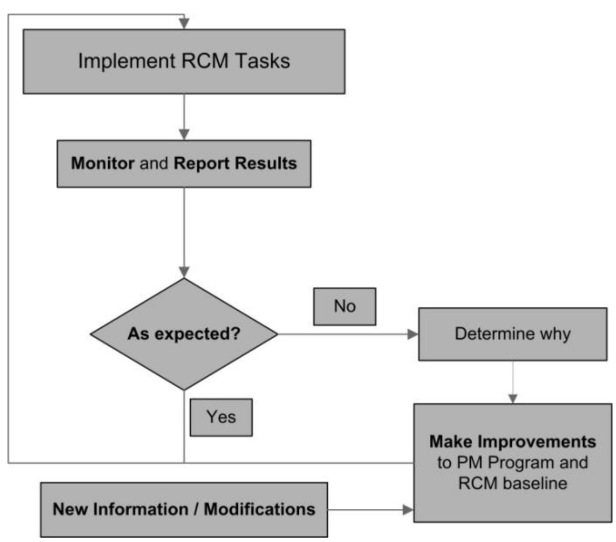

Figure 21. Living the RCM program (Hinchcliffe and Smith, 2004, pp. 229)

3.4.4 World Class Maintenance

World Class Manufacturing (WCM) is a notion used to describe the best way to produce. The fundamental belief on people and people in groups is the heart of the vision (Bellgran and Säfsten, 2010). WCM is a complete management system which is designed to improve the performance of a company by eliminating waste. The resources are focused on improving quality, productivity and customer satisfaction and also on reducing failures. The power of the method comes from the involvement of the WCM team (SB Consultants, 2007).

Companies that achieve the most success of WCM are those continuously that focus on, and making the most of, the potential in people (Bellgran and Säfsten, 2010). It takes time to reach the level of world-class manufacturing and the process need to be carried out step by step (Bellgran and Säfsten, 2010). This master thesis focuses on the maintenance function and therefore is only the theory that concern maintenance included from the concept WCM.

WCM integrates many techniques and tools such as TPM and RCM and others in a way that allows employees and companies to build upon their experience and expertise. It is crucial not to jump in at the top levels techniques and tools, and assume that the company then has become world class. Employees need to be educated about, understand and gain experience in how to use tools and methods before it is expected that they use them properly (Sasaya, 2009).

Manufacturing competitiveness – 15 keywords

1. ***Continuous Improvements*** – as a part of the company culture.
2. ***Having a perspective view*** – from a global to detailed view.
3. ***Zero concept*** – the optimum value can be attained by aiming at zero. *For example: zero machine breakdowns, zero accidents, zero customer complaints, zero defects etc.*
4. ***Perform countermeasures against the root causes of failures*** – the problem can be eliminated to avoid it from occurring again.
5. ***Be detail oriented*** – the real hidden problems can be revealed and highlighted.
6. ***Visualize*** – Standards, Waste and losses, Shop floor, Management commitment etc. must be visible. Visualization creates action to solve problems.
7. ***From reactive → preventive → proactive improvement approaches.***
8. ***Maintenance*** – Utilize equipment optimally with regard to availability and economic aspects.
9. ***Quality focus*** – build in quality in the processes.
10. ***Focus on customer*** – short lead time and zero complaints. Identify and meet the need.
11. ***Time management*** – Value must be produced every minute
12. ***Knowledge management*** – Examine main parts according to standards ("Easy to Manufacture")
13. ***Standardization*** – provide a clear image of the desired condition and make abnormalities immediately obvious so actions can be taken. Link standards to action

14. ***Consciousness of cost*** – Determine Benefit Drivers and Cost Drivers and let a Focus Improvement Team quantify if topic is worth to execute at present.
15. ***Production engineering*** – knowledge about the "how", i.e. tooling, process and layout

Ten pillars towards WCM

If a company has as an objective to achieve World Class standards, improvement activities need to be made. These activities can be categorized into ten different areas, and the temple of WCM illustrates these ten areas, i.e. ten pillars of the temple. All activities included are to support the objective to move towards WCM (Sasaya, 2009). In Figure 22 below is the temple of WCM presented.

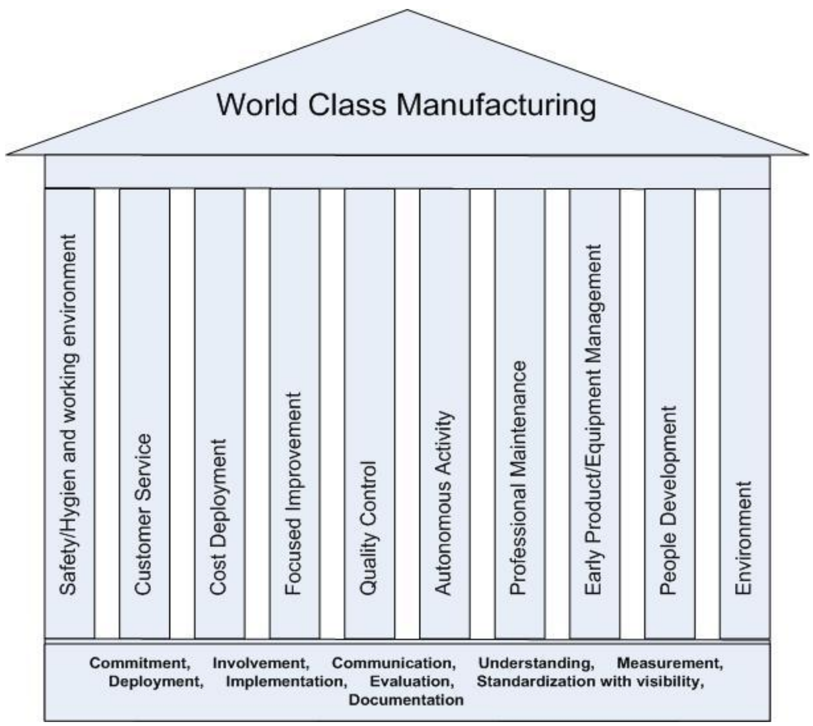

Figure 22. Temple of World Class Manufacturing (Sasaya, 2009)

As can be seen in Figure 22 above it exists ten pillars, these are developed based on the following fundamental enablers: commitment, involvement, communication, understanding, measurement, deployment, implementation, evaluation, standardization with visibility and documentation.
Further description of each pillar is, according to Sasaya (2009), the following:

- ***Pillar number 1 – The Safety Pillar***
  Concern safety/hygiene and working environment, the activities corresponding to this pillar are intended to eliminate accidents.
- ***Pillar number 2 – The Customer Service Pillar***
  The objective with this pillar is to fully satisfy the customers.
- ***Pillar number 3 – The Cost Deployment Pillar***
  Activities are executed in order to identify where the problems are from the cost viewpoint.

- ***Pillar number 4 – The Focused Improvement Pillar***
  By the use of proper methods reduce cost and create important knowhow.
- ***Pillar number 5 – The Quality Control Pillar***
  From the TQC viewpoint, the activities belonging to this pillar are to achieve zero defects.
- ***Pillar number 6 – The Autonomous Activity Pillar***
  Activities are executed meant to raise the shop floor employees' competence. In capital intensive areas adopt autonomous maintenance and in labor intensive areas organize the workplace.
- ***Pillar number 7 – The Professional Maintenance Pillar***
  Zero breakdowns are meant to be achieved with maintenance employees.
- ***Pillar number 8 – The Early Product/Equipment Management Pillar***
  New products and equipment should be launched smoothly into the production.
- ***Pillar number 9 – The People Development Pillar***
  The success of WCM depends on the people and it is therefore crucial to nurture, educate and train people to materialize WCM.
- ***Pillar number 10 – The Environment Pillar***
  From the viewpoint of environment is this pillar meant to make respectable existence for the community.

The approaches for each one of these pillars consist of seven steps to execute and sustain before it is fully implemented. The approaches involve the usage different tools and methods (Plinio).
Essential for the success of WCM is management commitment. Thus, the management must be prepared to challenge the present state, learn the WCM tools and methods, be open minded and also willing to delegate. More power and autonomy is with WCM pushed downwards in the organization. One more essential aspect important to emphasize is clarity of objectives. Weak problem identification and lack of visions is a critical success factor (Sasaya, 2009).

WCM – Autonomous Maintenance

The machine or process operator know his/her equipment and can immediately catch information from the equipment and detect symptoms or abnormalities. Before the breakdown occurs there is a symptom, the breakdown is a result from the growth of a minor defect. It is not possible for the maintenance craftsmen to detect and cover all the breakdown symptoms. The equipment need to be checked for symptoms to eliminate breakdowns. The operators cannot help maintaining equipment unless they know how to do it (Sasaya, 2009).

WCM – Professional Maintenance

Professional is to understand why failures occur, what the problem is and to gain understanding of maintenance issues. The aims and objectives of professional maintenance are to optimize equipment with respect to availability, reliability and financial aspects. Unplanned maintenance activities should be minimized and the organization should strive towards zero failure and breakdown losses (Sasaya, 2009).

3.4.5 Asset Management

Asset Management is a concept designed to examine the assets over its entire life cycle. It is hoped that through a better awareness of the assets value, reviewing the assets in a more satisfactorily way and perform best possible service and standards, will increase profitability through a longer period of time (Schneider et al, 2006). Common used application areas are financial, equipment maintenance and software vendors and infrastructure. Financial, wherein the term must be seen as best recognized, it is viewed to get the best growth and security for investment portfolio.

In equipment maintenance, the aim is to increase the creditability for certain activities. Maintenance has for a long time been seen as pure cost driver and thus been getting a low financial roof. Asset management can here help raise the awareness and importance of the tied up capital and finally in infrastructure where asset management are intended to help describing their role in life (Woodhouse, 2007).

Asset management can, if broaden, be seen as asset care and asset exploitation. Asset care where the aim is to entertain and risk manage assets currently in ownership. Asset exploitation one is striving to achieve certain goals and needs. Hence, asset management must be seen in a time perspective and over the whole life cycle, thus including original investment, maintaining, disposal and modification (Woodhouse, 2007).

Aging of an asset has major impact on the reliability of performance, and thus production. Age is usually divided into three phases for the assets, reliable, degenerated and unreliable (Schneider et al, 2006), see Figure 23 for example model. An effective maintenance will minimize the aging process and thereby prevent it to forfeit all too quickly. Eventually, however, the asset has passed the three states and a decision on renewal is crucial. It is therefore important to know the decisions and calculations for each of the states.

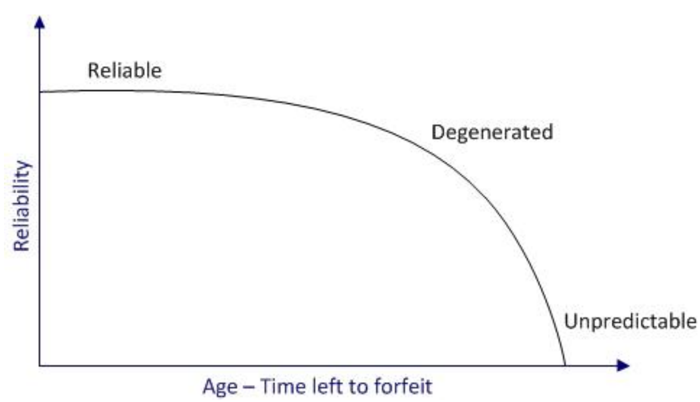

Figure 23. With increased age the reliability will be decreased, and finally the asset will have passed the three phases, reliable, degenerated and unpredictable.

3.4.6 Data management – CMMS

Many industries today are focusing their attention on the maintenance business function. There is a continual focus on cost reduction to attain an increased revenue generation. Cost reduction within the maintenance organization does not concern to reduce the quality or the level of service. It concerns an increased control of the maintenance organization and also related areas. In order to control the maintenance organization properly information about occurring events are needed (Wireman, 2009). Data is the foundation for conclusions and decisions, without effective data gathering cannot incidents be truly investigated and defined (Vanden Heuvel, 2008). To gather and analyze data manually requires a tremendous amount of both time and effort. Due to this, many companies develop and use computer programs concentrated on this. These programs, or systems, are called computerized maintenance management systems (CMMS) and they are designed to gather all data related to maintenance and to file it in the history of corresponding asset (Wireman, 2009). To control and manage maintenance tasks is one of the main functions of a maintenance management system (Ylipää and Harlin, 2007). These systems functions basically the same, they all use the work order systems but can be more or less detailed also the terminology may differ (Wireman, 2009).

The development of test equipment and computerized maintenance management systems (CMMS) has according to NASA (2008) made it possible to:

- Track and analyze the history of equipment as an aid of determining life-cycle cost and failure patterns.
- Determine the actual condition of equipment without time-based techniques which base the probability of failure on appearance and age instead of the equipment's condition.

Applications of CMMS Systems

Speed is one major advantage that CMMS have compared to manual systems. Other disadvantages with manual systems are communication problems, misplaced data and large file cabinets, which are reduced with CMMS (Wireman, 2009).

In Figure 24 below are some advantages which are provided by the features included in CMMS presented.

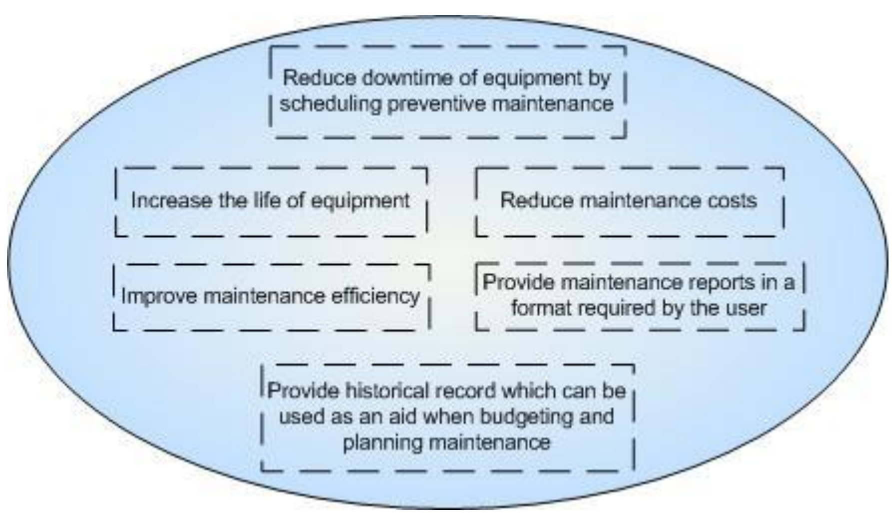

Figure 24. A presentation of some advantages which are provided by the features included in CMMS.

3.4.7 Key performance indicators

KPI has for a long time discussed, defined and refined and often when talking about KPI, measuring is what comes to mind (Smith, 2004). However, key performance indicators are to combine metrics and indicators for critical or key processes in order to yield as an assessment, and thus to indicate the maintenance performance. In order to reach the overall maintenance goals, and thus tracking where the organization is headed, it is important to be able to monitor the performance. Important here are that KPIs are unique for every organization, and can also be unique between different departments within the same company, and should therefore be defined specially for the areas one wants to monitor.

It is common to classify the KPIs as lagging or leading. Leading are indicators which measures performance before a possible problem/failure arise, whereas lagging indicator indicates that the problem/failure has arose (Smith, 2004).

In general what characterizes a good metric/indicator is the ability to benefit and add value from it. It should, to the extent possible, be positive, not conflict with other metrics, and noncompliance with the metric/indicators should always be analyzed for root cause and cost impact. Most often, indicators such as overall equipment efficiency (explained below), labor and material costs and ratio between planned and unplanned work are tracked within maintenance, hence indicators to support operational control. According to Smith (2004) these, however, lack the ability to provide information regarding the maintenance department performance and do not further support the prediction of the future abilities for the organization. Smith (2004) here advocates balanced scorecard, which is believed to, in larger extent, link performance with long term objectives and goals. It is also believed to be easier to read and follow for all operational personnel.

A, otherwise good reputable, indicator of the effectiveness of the maintenance functions and of management attitude is the number of maintenance related production disturbances. If delays in production represent more than 30% of total production hours then the dominant management philosophy is reactive. In today’s market this indicator should be less than 1% for the company to be competitive (Mobley, 2004).

Another management effectiveness indicator is the amount of maintenance overtime. Overtime is a major negative cost in a breakdown maintenance environment. If the maintenance department’s overtime represents more than 10% of the total budget for labor then the company qualifies as a breakdown operation. However, some overtime is and will always be required.
An additional key to management effectiveness is manpower utilization. The percentage of maintenance labor should be evaluated in comparison with total available labor hours expended on repairs and prevention tasks. This percentage will be less than 50% in reactive maintenance management and for a well-managed maintenance organization it should be above 90% (Mobley, 2004). See Table 1 below, for commonly used measures.

Table 1. Strategic and operational measures, including objectives to be achieved.

Category	Measure	Data source	Goal
Strategic Measures			
Ratio of maintenance cost to:	Sales	Accounting	<6%
	Total Manufacturing cost	Accounting	12-14%
	Asset value (Total-net)	Accounting	11-12%
Operational performance and budgetary measures			
Analyze budget variance by:	Total budget	Accounting	Minimum
	Performance to volume	Work order system	Minimum
Safety and environment measures			
	Injuries per million hours of maintenance payroll	Personell Records	<5%
Maintenance ability to meet the needs of the customer			
	Work order overdue	Accounting/Engineering	<5%
	Relapse due to unsatisfactory work at initial error	Work order system	<5%
	Backlog status	Work order system	
Organization of work			
Employees working with:	Urgent respons	Work order system	10%
	PPM Inspection	Work order system	30%
	Work Orders	Work order system	60%
Trend:	Planned to unplanned labor hours	Work order system	9 to 1
	Planned work	Work order system	>90%
Maintenance quality measures: Reliability/Maintainability			
	Mean time between failures	Equipment history	Trend and growing
	Failures adressed by RCA	Equipment history	>75%
	Training per mechanic in hours	Personell Records	>100/year
	Overall equipment effectiveness	Work order system	See Chp: 3.4.6.1

3.4.6.1 Overall equipment effectiveness

OEE is a method to understand the performance of the manufacturing area, but also to identify possible limitations (Hansen, 2002). OEE calculates the percentage effectiveness of the manufacturing process. OEE is further a function consisting of the three factors, availability, performance efficiency and quality.

$$OEE = Availability \times Performance\ Efficiency \times Quality \quad (1)$$

Here, availability measures how long time an asset is running out of the total time it would be able to utilize. Performance efficiency is the amount of products produced within a given time compared to the expected amount of products it would have produced. Furthermore, quality describes amount of products not require rework (Gazdziak, 2010). Thus, following equations describe availability, performance efficiency and quality.

$$Availability = \frac{Planned\ production\ time - Unscheduled\ downtime}{Planned\ production\ time} \quad (2)$$

$$Performance\ Efficiency = \frac{Cycle\ time \times Products\ processed}{Production\ time} \quad (3)$$

$$Quality = \frac{Products\ processed - Products\ in\ need\ of\ rework}{Products\ processed} \quad (4)$$

In the first instance OEE should be applied to bottlenecks or other critical equipment. When driven correctly, as a fact of monitoring and improving the OEE, these areas will make significant improvements to the overall performance of the manufacturing line (Hansen, 2002).

When OEE figures for the assets in the process has been established and all personnel are aware of its significance and meaning, OEE rates, according to Robert C. Hansen (2002), as follow:

- <65%, unacceptable. Meaning that assets are poorly being used.
- 65-75%, moderately and acceptable only if the trend is improving.
- 75-85%, acceptable, however, adoption is likely to improve and should therefore be sought to do so.
- 85-90% world-class level and usually for batch type processes.
- Also, Robert C. Hansen (2002) states that: "*> 90% for continuous discrete processes. Continuous on stream process industries should have OEE values of 95% or better.*"

3.4.8 Economic aspects of maintenance development

Maintenance functions are often viewed upon as to have a tactile role for existing assets, thus maintenance are viewed to be a pure expense (Salonen and Delaryd, 2011). It is therefore common that the maintenance departments are suffered from cost reduction. A large part of the organizations operating budget are constituted by maintenance and investments in machinery and equipment (Salonen and Delaryd, 2011). Salonen and Delaryd (2011) further states that maintenance represents 10-40% of the production cost in a company, however it is further argued that some figures believes it might be as much as 15-70% of the total production cost (Salonen and Delaryd, 2011). Onwards, about 30 % of maintenance costs are related to unnecessary expenditures, due to bad planning, overtime, unmet preventive maintenance, etc. to name a few (Salonen and Delaryd, 2011). Having said, both the importance of a well-functional maintenance work and also the importance of the economic aspects with maintenance are evident. However, according to Salonen and Delaryd (2011) the consensus on how to visualize the financial aspects is insufficient.

The meaning of investment is to perform a capital gambling which will lead to payment consequences for duration of time. It is usually a physical product but it might as well be in intangible resources, such as education (Aniander et al, 2007).

The interesting part of an investment for many companies is, how much the company has put out and when it will be paid back and to what extent. There exist different measures to calculate this, but a selection is the Payback method, Return on investment and the life cycle cost.

It is important to distinguish between the economic life of an investment and the technological life. The economic life of the asset is when the investment has reached its maximum profitability. The technological life of an asset involves its productivity length. As long as the asset/equipment can produce, it has a continued technical life (Aniander et al, 2007). The reason for differentiating between them is that the technical life means that the asset still can produce, but at the expense of an increasingly expensive maintenance.

To further illustrate the importance of economics in maintenance below figure by Ahlmann (2002) describing the costs within maintenance in Sweden. According to Ahlmann the mean of the OEE factor in Swedish production plants is about 60 %. If this would be to improve from 60 % to 80 % the net result would be 38-39 billion Swedish kronor/year, which is about 20 % economic improvement. See Figure 25 for illustration of the economic significance in Sweden.

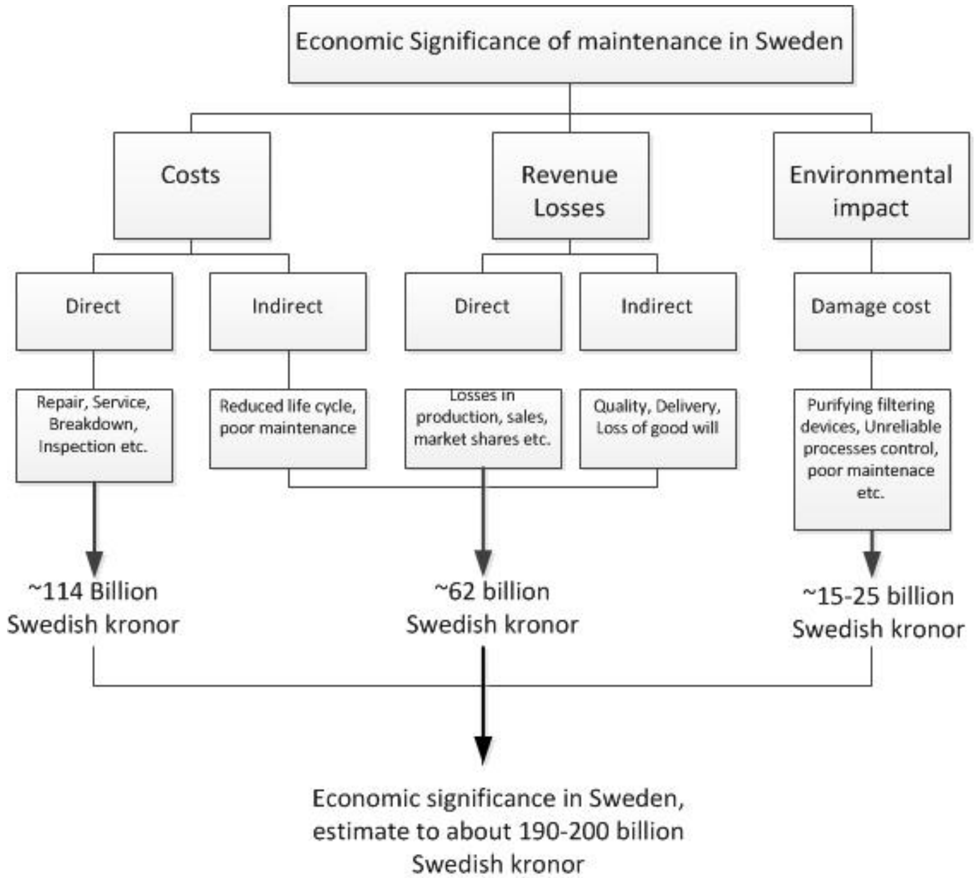

Figure 25. Economic significance of maintenance in Swedish production plants.

3.4.8.1 Life cycle costing

Life cycle cost is the cost of an item in its intended application during its entire life period (New South Wales Treasury, 2004). It involves, acquiring, utilization, maintenance, recycle/scraping of the asset. LCC summarizes the constituents' total estimated costs during its life span and discounting to present day, or time of initial investment. Thus, the objective is to distinguish the best investment alternative, with regards to its total cost during its intended life span. Figure 26 shows the cost driver for an asset during its life span.

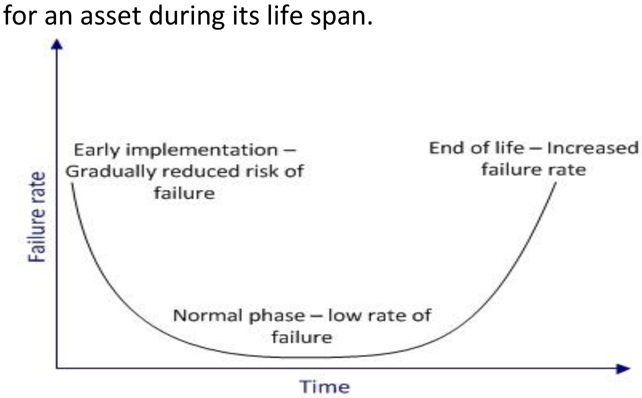

Figure 26. Life cycle cost for an asset. Higher level of failures discloses itself in early implementation phases and in the end of the assets life.

A large extent of the cases, usage, maintenance and disposal of an asset stand for as much as 2-20 times the initial investment (Barringer, 2003). A calculated LCC for equipment's creates a better insight and profitability (Nord and Pettersson, 1996). Another way to view LCC and the comprising cost are through the LCC tree. See Figure 27. The life cycle cost of an asset is here divided, first into the major aspects, acquisition- and sustain costs and later into the underlying cost of each of the acquisition and sustain costs. What is included depends on the intended environment and working condition for the asset (Barringer, 2003). In Figure 27 examples of some of the underlying costs are included.

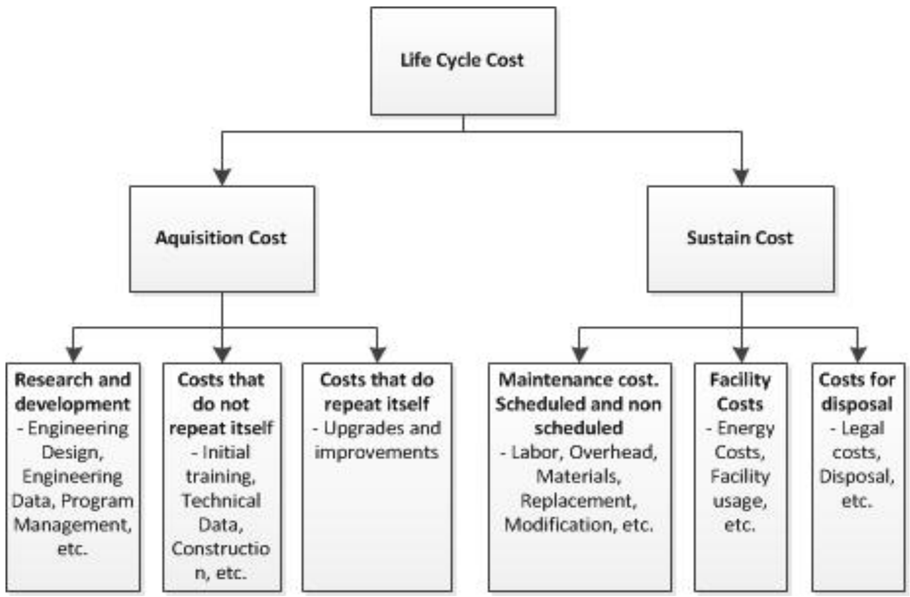

Figure 27. Life cycle cost tree

Different departments of the company have a need to ensure their own interest. For example, the production departments' interest is to maximize the uptime of the process/production, the maintenance departments seek to minimize the repair time and the project engineering department desire to minimize initial investment cost. It is thus necessary for management to merge them and focus on facts, time and money. In the end, money will be the dominating factor, and thus the ability to manage money as efficiently as possible is essential (Barringer, 2003).

Given above illustrations, the LCC concept highlights that: A significant portion of the cost of operating the equipment are linked to decisions of the early stages, such as the planning, projecting and at the design stage (Ahlmann, 2002). It has also been shown that during the operating time, the cost can be as high as 2-20 times the initial investment costs (Barringer, 2003).

Optimum cost and reliability

Smith (2011) describes it in a similar way and describes the total costs that arise during the ownership time of equipment, i.e. the life-cycle costs, as divided as follows:

- *Acquisition:* This is the capital cost and also the expenditures such as transport, installation etc.
- *Ownership:* This is the costs of corrective and preventive maintenance, and also of modifications.
- *Operating:* The costs of energy and materials.
- *Administration:* The analysis and data acquisition costs.

All of the costs mentioned above will be influenced by:

- ***Reliability -*** The loss of revenues, spares and frequency of repair.
- ***Safety -*** These factors affects the operating efficiency, maintainability and liability costs.
- ***Maintainability -*** Affects down time, manpower, test equipment and training.

If the reliability, safety and maintainability are improved the life-cycle costs will clearly be reduced (Smith, 2011). Meanwhile, costs will arise due to the activities needed to achieve them. It is therefore necessary to find the optimal set of parameters that will minimize the total cost. The two figures (Figure 28, Figure 29) below are presented to illustrate this concept and each curve represents the cost against availability.

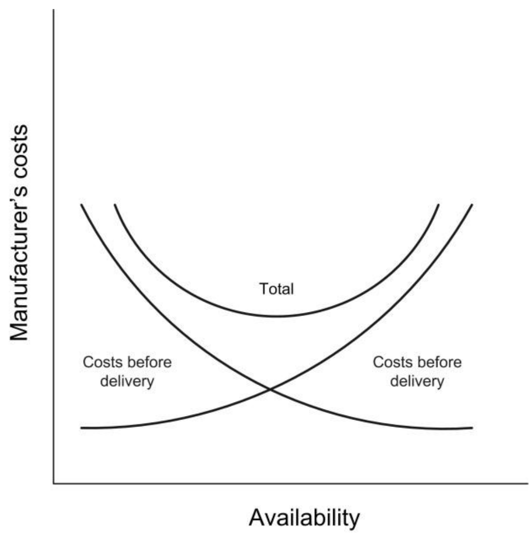

Figure 29. After Smith, 2011, pp 30.

Figure 28. After Smith, 2011, pp 30.

In Figure 28 is the general relationship between availability and cost represented. The curve which shows the total cost indicates some value of availability at where the minimum cost is obtained and the price will be related to this cost. The manufacturer's costs are costs such as:

- Warranty, redesign, loss of reputation and after-delivery (these costs decrease with availability) and
- design, pre-delivery, procurement and manufacture (these costs increase with availability)

The user's cost, which is plotted in Figure 29, represents expenses and losses that arise due to failure which is borne by the user. One curve that shows the optimal availability that gives minimum cost is the result (Smith, 2011).

3.4.8.2 Life cycle profit

As the cost of operating the equipment excess the cost of initial investment, it is inclined to meet requirements and develop the design in a perspective of high reliability and low maintenance cost in the future. However, according to Ahlmann (2002), this concept alone is not sufficient. In regards to investment decision, one should also regard how the asset will generate revenue. The issue is thus, to discuss the ability of the asset to create the higher life cycle profit, LCP. This factor is in many cases even more sensitive to disturbances in the production, as it is affected by capacity utilization, quality and delivery speed. For this reason, it is also advocated, by Ahlmann (2002), take into account the life cycle profit concept. Figure 30 shows the LCP concept, its cost and benefit, in relation to time.

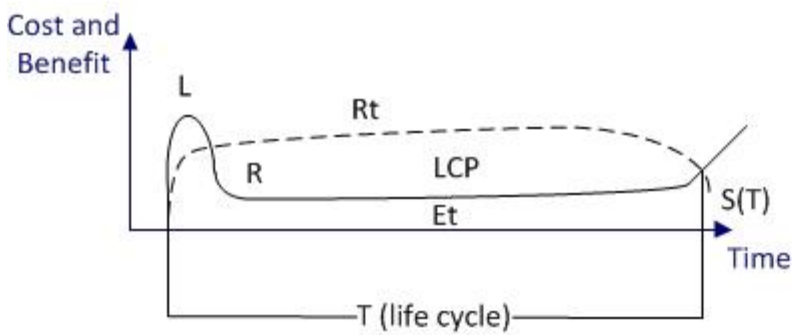

Figure 30. The life cycle profit curve. Rt: Benefit; L: Initial losses; Et: Cost; St surplus value.

According to Ahlmann (2002) the present value, can be calculated by the means of equation 5.

$$V = \int [R(t) - E(t)]e^{-it}dt + S(t)e^{-it} - B0 \quad (5)$$

Here, R(t) is the benefit, E(t) the cost, e^{-it} the discount factor, S(t) the surplus value and B0 the initial investment cost.

The relationship between LCC and LCP is in a great sense depending of the market and area of use. LCC relates better to a stable and predictable market, while the LCP is better in turbulent and dynamic markets. See Figure 31.

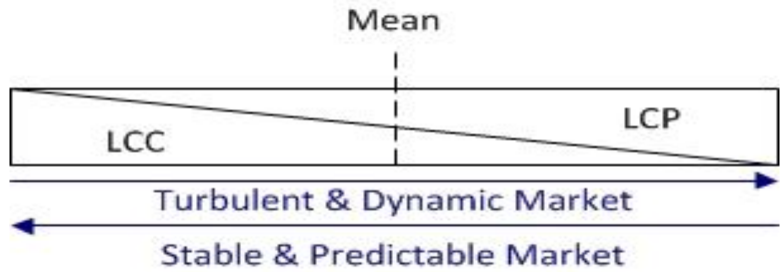

Figure 31. The relation between LCC and LCP

3.4.8.3 Return on investment

Return on investment can be considered when the relation between profit and capital invested are of interest. It is derived from the equivalent annual cost method, which is used to decide investment when comparing investment with different lifespans (Aniander et al., 2007).
Return on investment can be calculated to measure the efficiency of an investment (Investopedia, 2011).

$$ROI = \frac{Gain\ from\ investment - Cost\ of\ investment}{Cost\ of\ investment} \tag{6}$$

ROI will thus show how profitable the company is in using its resources.

3.4.8.4 Payback

The payback method is a means to calculate the time for an investment to repay itself. It cannot say which investment alternative is the best, expect only decide which will repay is initial investment most quickly. The calculation is performed as follows (Investopedia, 2012):

$$\text{Payback} = \frac{\text{Cost of investment}}{\text{Annual cash inflow}} \tag{7}$$

It is a common method often due to its simplicity but also due to the fact that it gives a clear answer on what investment that will repay in the shortest duration of time. Further, indirectly the method takes into consideration the company’s liquidity. The alternative which will repay itself most quickly may also lead to the possibility of new investment, since the company has received capital earlier than the other alternatives would have entailed (Aniander et al., 2007). The downside of the method may also be its simplicity, due to the fact that net present value for future payments isn’t regarded. Also, the method doesn’t take into consideration what might influence when the refund is complete. Different alternatives may have different implications once the payment is complete, hence payback does not measure profitability (Investopedia, 2012).

3.4.9 Approaches to maintenance improvements

There are several techniques and tools that can be used within improvement programs to systematically solve problems (McCormick, 2002), (Bergman and Klefsjö, 2010). Below is the Plan-Do-Check-Act cycle, Failure Mode and Effect Analysis, Fault Tree Analysis, Root Cause Analysis, Five why analysis respectively Fishbone diagram described.

3.4.9.1 Plan-Do-Check-Act Cycle (PDCA)

The “Plan-Do-Check-Act” (PDCA) cycle is a systematic and accurate methodology used for solving problems in continuous improvement work (Larsson, 1993; Bergman and Klefsjö, 2010). Each phase in the PDCA cycle has different objectives:

Planning phase – In this phase are the specific goals and success indicators for the changes to be carried out identified, and methods to perform the changes are established (Larsson, 1993), (Karlöf and Lövingsson, 2005). The causes of the detected problem need to be established and large problems need to be broken down into smaller ones. Concerning the decisions to be made, about what to change, need to be based on facts. Useful tools for working systematically with the decision making and cause finding process, tools such as fishbone diagram, RCA, 5 why’s, FTA or FMEA which is discussed below may be used (Bergman and Klefsjö, 2010).

Do – When one important cause is established are the actual activities carried out by an improvement team (Larsson, 1993; Bergman and Klefsjö, 2010). It is very important that everybody involved have a full awareness of the problem and agrees to the improvement steps (Bergman and Klefsjö, 2010). Measure results during this step and carry out training necessary (Karlöf and Lövingsson, 2005).

Check – Analyze results and evaluate the improvement work, it is important to check if the program was successful (Karlöf and Lövingsson, 2005), (Bergman and Klefsjö, 2010). Compare the results with the goals and success indicators which were identified in the planning phase (Larsson, 1993).

3.4.9.2 Failure Mode and Effect Analysis - FMEA

This analysis is a very useful methodology which in general is recognized as the most fundamental tool that is employed in reliability engineering. Thanks to its practical, qualitative approach, it is also the most widely applied and understood form of reliability analysis that is encountered throughout industry. The FMEA forces an organization to systematically evaluate system and equipment weaknesses, its function, failure modes, failure causes and failure consequences, and also their interrelationships that can lead to product or process unreliability (Hinchcliffe and Smith, 2004; Bergman and Klefsjö, 2010).

FMEA is an analysis method that can be used in several different ways, for example when to investigate the possibility of a future product to fulfill reliability demands and when evaluating the manufacturing process, it facilitates identification of potential problems of a process (Bergman and Klefsjö, 2010; FMEA-FMCA.com, 2012).

Actions are recommended to reduce the likelihood of the problem occurring, and also decrease the risk if it occurs. By a failure mode analysis the team performing the analysis determines the effect of each failure and identifies single failure points which are critical (FMEA-FMCA.com, 2012). The result of an FMEA is printed on a FMEA form which can be designed in various ways dependent on the purpose of the analysis (Bergman and Klefsjö, 2010). Each failure may also be ranked according the criticality of a failure effect and the probability that the failure occur, such analysis is called FMECA (FMEA-FMCA.com, 2012). The main idea with FMECA is to consider the failure modes for every component, quantify the failure frequencies and then rank the failure modes (Bergman and Klefsjö, 2010).

FMEA / FMECA is important and valuable due to many reasons, a few of them are:

- A basis for identifying root failures causes and developing effective corrective actions are provided by a FMEA analysis.
- Reliability / safety critical components are identified by the analysis.
- An investigation of design alternatives at all design stages is facilitated.
- The analysis provides a foundation for other maintainability, safety, logistics and testability analyses (FMEA-FMCA.com, 2012).

3.4.9.3 Fault Tree Analysis - FTA

The fault tree is a logical chart of occurring events which is one of the most effective methodologies when the frequencies of occurrence of events in a probabilistic risk assessment study (Bergman and Klefsjö, 2010;Deshpande, 2011). The method illustrates relations between a non-desired event (on a high system level) and its causes (on a lower system level), the design begins by specifying the non-desired event then is the causes identified and connected with a suitable logical gate, e.g. or-gate or and-gate (Bergman and Klefsjö, 2010). FTA is a top down approach, it starts on a high system level event and are repeated gradually downwards until the events on detailed level on equipment or component are reached (Bergman and Klefsjö, 2010; Deshpande, 2011). There are today several computer software programs to use for performing a FTA (Bergman and Klefsjö, 2010).

3.4.9.4 Root Cause Analysis – RCA

RCA is a methodology used to pinpoint and find the root causes of problems, and the information is then used to avoid reoccurrence of failures (Sharma and Sharma, 2010). To find the root causes or causes of a problem within an organization is the single most important determinant of failure or success of any problem-solving method (Monroe, 2010). All types of problems require an effective root causes analysis and identification to reduce resistance and the risks associated with changing a process (Monroe, 2010).

The goal of a RCA is to understand not only “what” and “how” of a failure but also “why it happened”, it attempts to address all of the underlying causes of the failure and also to learn as much as possible from the occurred failure (Vanden Heuvel, 2008). By finding the root cause of problems will the understanding needed to solve the problems be more easily gained (Pojasek, 2000). This analysis is an aid to establish a foundation of knowledge needed to deal with problems that are related to process/equipment availability, maintainability and reliability by providing a comprehensive classification of causes related to different areas: man, machine, materials and methods which often are referred to as the 4 M's (Sharma and Sharma, 2010). By identifying the root cause of a problem instead of only solve the problem right away by intuition can the problem be avoid from reoccur in the future by the information collected from the root cause analysis (Pojasek, 2000). According to Liker (2004) is it emphasized that in order to solve the true problem identification of the root cause is required rather than the source of the problem – where the problem occur; the root cause is found beyond the source (Liker, 2004).

3.4.9.5 The five why analysis

The five why approach searching for the root cause of a problem by the use of a systematic question form technique. The tool are used by asking "Why?" at least five times, by doing this are the various levels of detail worked through either upstream or downstream in the process (Liker, 2004; Pojasek, 2000). According to Liker (2004) does the process of asking "Why?" five times typically leads to an upstream path through the process. When answering to the question "Why?" becomes difficult the root cause to the problem is probably found (Pojasek, 2000). When the "whys?" are traced back to their root cause issues to confront affect probably not only the original symptom, but also the entire organization (Pojasek, 2000). The answers to the "whys" should not be blaming individuals due to that the only option will be to punish them which do not leave any room for substantive change.

The focus in the search for root causes is on the process of the problems not the individuals involved. Therefore, be careful to not ask "Who?" (Pojasek, 2000).

3.4.9.6 Fishbone diagram

The fishbone diagram, also known as Ishikawa diagram or cause-and-effect diagram, is a systematic analysis which is used to display all the possible causes of a chosen problem – the effect (Bergman and Klefsjö, 2010; McCormick, 2002). The roughly causes to the problem are in the diagram described first, people will by this be helped to get an overview of the whole picture before specific areas are chosen to be investigated further (Bergman and Klefsjö, 2010; McCormick, 2002). When the roughly causes, or main causes, have been described are one of these sorted out and causes to that main cause are investigated and described. Only when all possible causes to that main cause are established the analysis move forward and the same procedure are then made to the next main cause. This is done repeatedly until all main causes are investigated in detail (Bergman and Klefsjö, 2010). The diagram may also be developed in the opposite direction, i.e. all detailed causes are described first and are then grouped into main causes (Bergman and Klefsjö, 2010).

3.5 Human factors and change management

An important part when it comes to organizational development and change is human factors. These areas highlight the factors which influence the commitment and efforts performed by the individual in their work (Rubenowitz, 2004). Below human factors and change management is explained. In addition, the leadership role and how responsibility delegation may relieve the organization and make the decision path simplified.

3.5.1 Human factors and work environment

Productivity can be a result of many things and one of the most significant is the quality on relations between the people performing a certain task and the work they perform. Should the relationship be strong, then the work task is seen as rewording and hence, the employees make an effort to perform well (Lindér, 2006).

It is distinguished between inner desire and work core dimensions. Inner desire comes as a result of the work performed and largely dependent on three things, namely:

- Knowing the result of the work performed.
- Feel a responsibility from the work performed.
- Feel meaningfulness for the work or have a feeling of being challenged.

According to Lindér (2006) it has also been shown that inner motivation and desire has a connection to the work tasks perform, however, here the inner desires cannot influence, thereof it lies to factors which can impacts the work tasks. These are: Task variation, Task identity, Task meaningfulness, autonomy and feedback. These will give rise to experienced meaningfulness, responsibility and knowledge of the result, thus the inner desires. Lindér shows the connection through work knowledge model (see Figure 32), which states the motivational potential, MP:

$$MP = \frac{Task\ variation + Task\ identity + Task\ meningfulness}{3} * Autonomy * Feedback \qquad (8)$$

Here each variable is categorized between 1-7, where higher equals higher motivational affect.

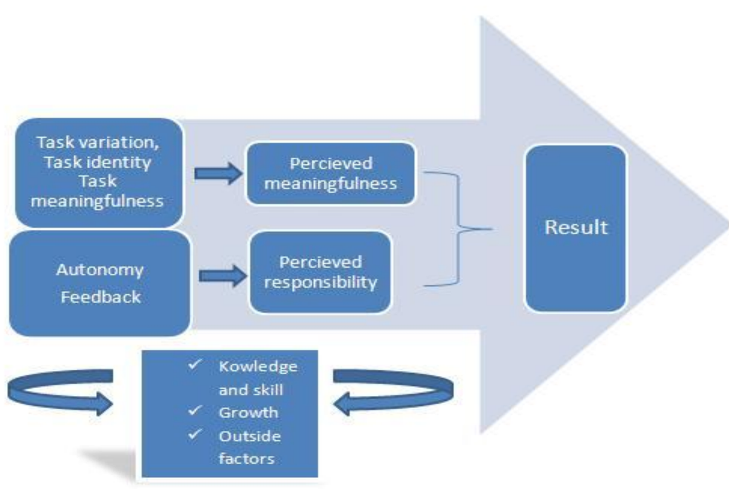

Figure 32. Relationship between work task arrangement and the peer performance of it.

Henceforth, people will react different to the work they perform; some will react in an optimistic manner while some will have a pessimistic attitude. According to Lindér (2006) it comes down to three things, namely: Knowledge and skill of the employee; the individual growth need and satisfactorily factors non-linked to the tasks performed. Another view is through the flow theory first explained by Csikszentmihályi (Bergman and Klefsjö, 2010), see Figure 33

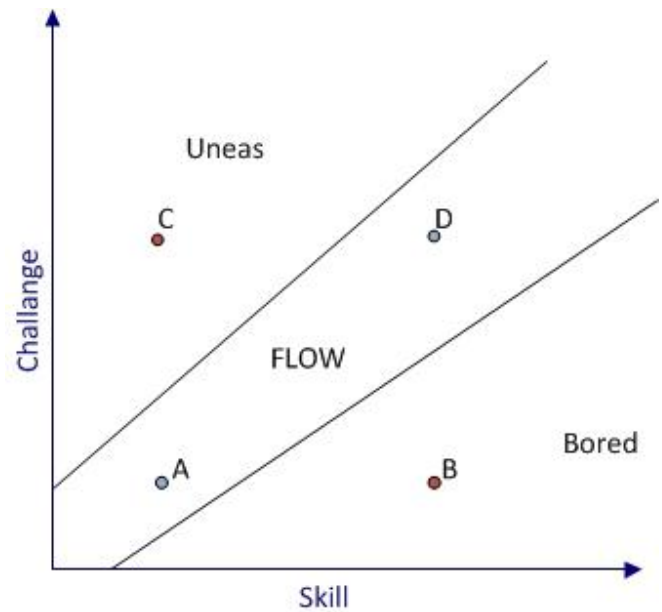

Figure 33. A job well structured so that the employees experience a relation between challenge and skill will perceive flow.

In Figure 33, the flow theory; it is described when a person will feel satisfaction with the work he/she performs. According to Bergman and Klefsjö (2010), this occurs when a person is in the "flow channel" (point A or B in the figure). A person will however not be located in point A for a longer time, except the skill of the work will increase and thus the person will move in the direction towards B where the work will become boring, due to unused creativity and challenge. Furthermore, increasing the challenge to much will result in a feeling of unease and frustration. The perfect combination is when a person is challenge in correct relation to where his skill is at present, point D in Figure 33 (Bergman and Klefsjö, 2010).

3.5.2 Change management

Change management is a continuous improvement process which involves all employees, from the management level to the workshop level, in a total integrated effort dedicated to improve the performance to achieve higher customer value at every level in the company (Berlin, 2004). Organizations that manages and leads their change efforts well improves their competitive standing and positioning. To date have organizations been helped, by major change efforts, to significantly adapt to shifting conditions. Change requires dedication and must be driven by leadership of high quality (Stanleigh, 2008; Kotter, 1996). Globalization, growth, innovation, technology and sense of urgency are some of the drivers of change (Stanleigh, 2008).

Kotter (1999) presents an action plan consisting of eight steps to go through when leading the change process of an organization:

1- ***Establishing a sense of urgency***
   Examine competition and market realities. Identify and discuss major opportunities, crises or potential crises
2- ***Creating the guiding coalition***
   Gather a group of employees with power enough to lead the change, and urge them to work as a team.
3- ***Developing a vision and a strategy***
   Develop a vision which provides the change effort direction and motivates people. Set goals that are clearly focused but vague enough to allow flexibility and individual initiative, and achievable through great effort.
4- ***Communicating the change vision***
   Use every method possible to communicate the change vision: meetings, newsletters, memos, formal and informal interactions. Use terms to communicate the vision which can be understood in a discussion of five minutes. Ensure that the key players in the change program constantly and consistently reinforce the vision.
5- ***Empowering of employees for taking broad-based action***
   Systems or structures that seriously undermine the vision should be changed. Encourage risk taking, non-traditional ideas, non-traditional activities and non-traditional actions emphatically.
6- ***Generating wins on a short term basis***
   Reward and recognize people who make wins possible. Visible performance improvements and early evidence which shows that sacrifices are worth it should be planned.
7- ***Consolidating gains and producing more change***
   In order to change all structure, systems, and policies which do not fit together and do not match the transformation vision use increased creditability. The process should be reinvigorated with new themes, projects and change agents.
8- ***Institutionalize new approaches in the corporate culture***
   By ensuring that employees see how new approaches to satisfy customers, improving productivity, etc., are linked to improved results changes will firmly be anchored into the culture.

When a change occur the employees move through four phases: denial, resistance, exploration and commitment. Unfortunately, management too often fails to recognize that adjustment to change takes time and thus, they expect employees to move from the denial to the commitment phase very quickly. Also, each individual will move through each phase at different pace, it is never uniform (Stanleigh, 2007).

Rubenowitz (2004) sees the case in a similar manner but with the difference that it exist three cases for change. One is that the individual understands the need for change and believes that it can benefit one's social concerns and needs. The change will be positive in nature; the individual is motivated and is actively involved. The second is that the individual understands the need for change but do not see the possibilities, or it may directly threaten their safety aspects and requirements. A conscious and unconscious resistance occurs. Accordingly, the third option is that the change is assumed absent and hence does not affect the individual's status. Here the individual is either justified or unjustified to support the change. Where senior management and managers see change as an opportunity for technical and managerial effectiveness, the view of the individual employee barriers and consider it more as a question of how this should influence oneself. When the individual in the previous practice has built up a status and skill, change might risk this status and thus the individual feels less valuable. It is therefore natural with reserved opinions to change (Rubenowitz, 2004).

One approach to eliminate, as far as possible, the resistance change can accommodate is to let the most pertinent influence the change process. The earlier the employees involved, are educated and informed, the more the individual will experience the control of the situation and the ability to affect the employment relationship. The probability that the change, then is seen as positive increases markedly thereof.

Furthermore, when changing a company that has in place a very reactive maintenance work culture, i.e. quickly repair failures or breakdowns and get production back on line, there is three steps which is needed to be taken by the maintenance leader (Thomas, 2005):

1. Show the organization that what it is doing, make the organization recognize that the current solution to the maintenance problem is not effective or efficient.
2. Create the vision of the future
3. Provide the plant a tool needed to achieve it, for example via the goal achievement model.

Kotter (1996) and Stanleigh (2007) points out several factors of why firms fail when transforming organizations, some of these factors are: not engaging all employees, allowing too much complacency, permitting obstacles to block the new vision, failing in the creation of a sufficiently powerful guiding coalition, telling people we have to change – we are in a crisis, underestimating the power of vision and failing to create short-term wins.

3.5.3 Leadership, authorities and delegation

A leader has a significant impact on the subordinates commitment, achievement and satisfaction with their work. It has been shown that the leadership, on average, may contribute to as large part as up to a quarter of the profitability for the company (Rubenowitz, 2004). A leader differs from the formal manager role as coach of the minds that optimally utilizes available resources and gets the subordinate staff, as part of the organization, its purpose and goals, to perform. What is sought is thus a leader who can articulate visions and set goals that are realistic and acceptable, which previously has been discussed. This is achieved if the leader possesses the right skills in strategic thinking and economic skills, thus meaning that the leader should be able to emphasize the customer-and market goods (Rubenowitz, 2004).

For a leader to get the employees towards the same goal, it is important to exercise authority in a proper manner. Usually listed five grounds in the exercise of authority, these are: Reward, Coercive Power, Legitimate power, expert power and referent power. Of these, usually Reward, Coercive, and Legitimate characterized as procedural grounds related to administrative aspects. The two latter points are in an informal setting. What has been demonstrated is that the informal has resulted in more positive impact (Rubenowitz, 2004). Thus, for above mentioned properties, it is important that the leader/manager get sufficient education within these areas.

Delegation

In many cases it has been proven that there is a consensus among executives that a substantial degree of delegation is the prerequisite for not locking the leader to routine matters. A further advantage is that the subordinates through delegation is given a more skilled work and are therefore also more challenging tasks (Rubenowitz, 2004). It has however also proved common that delegate to a large extent have some resistance. The reason is often that the leader can doubt the subordinates from having skill enough to handle the task and thus perform it without involvement of the leader himself. What is required of the leader to carry out the delegation of a successful manner is: Time to devote himself ensuring that the subordinate has the right knowledge and the right education by the leader himself in how he will resolve the matters at hand. Furthermore, an open communication between the leader and the subordinate is a perquisite to succeed with the delegation. The leader must be willing to help the subordinate solve issues, however this is not supposed to be a daily briefing, it would counteract the purpose of the delegation. Finally, clear defined goals of the delegation must be provided to the subordinate. It is also important to note that delegation also must be accepted by the part which is to receive the authorities (Rubenowitz, 2004).

4 RESULTS

Below are results from the analyses executed in the work presented. Among other things presented, the current situation at Volvo Trucks maintenance department and the benchmarking where maintenance organizations at other companies are compared is highlighted in this section.

4.1 Present state description

Volvo Trucks are currently in an initial stage of adopting the WCM concept. It has in its sister company, Volvo Powertrain extensive experience of working with WCM, which also seek to exploit. In an initial stage, the idea is to start WCM work by focusing on the AM, PM and Cost deployment pillars of WCM. The following describes the structure, organization and mandate of the maintenance organization at Volvo trucks. In addition, it also describes two parts, internship week and interviews in which the organization along the authors' experience are described.

4.1.1 Production structure Volvo Trucks Tuve

The shop floor in the Volvo Trucks Tuve factory is divided into four main departments; frame factory, LA (pre-assembly line and automatic guided vehicles), LB (final assembly line) and facility (spare parts and facility supply). In the frame factory is there a high level of automation whereas the assembly lines mainly consist of manual work with automatic tools (pneumatic and hydraulic hand tools). The parts that arrive to assembly are transported on a driven line. The maintenance craftsmen are grouped to focus mainly on one of these areas and respective maintenance craftsmen team are located in corresponding department as visualized in the Figure 34 below.

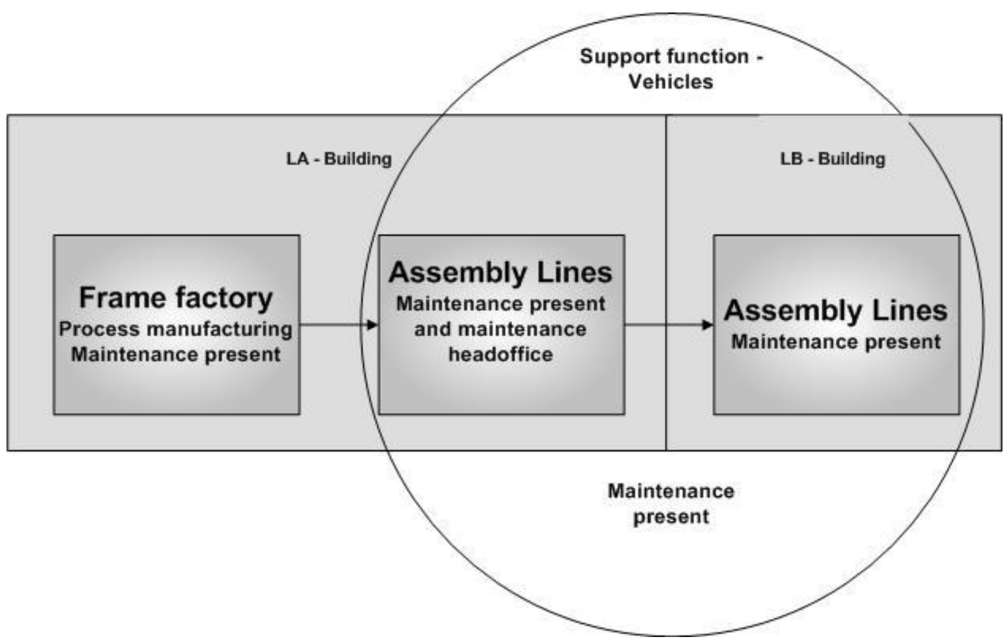

Figure 34. A visualization of maintenance presence at each department.

4.1.2 Organizational layout - Maintenance department

The maintenance department in Volvo trucks Tuve consists of one maintenance manager. Directly reporting to corresponding are the strategist and the administrative managers. In addition, the specialists are also under direct reporting to the maintenance manager; however, these also have an organizational outreach position. Hereunder the maintenance department is divided along the production facilities various areas. Each of these areas, LA, LB, the Frame factory and facility service can be divided into one branch during daytime and one for the shift teams. During shift times the shift team has a group leader, responsible for the administrative work to be done. They have during these times the ultimate responsibility for the work. However, during daytime they are part of the regular organization where the maintenance manager is the highest decision-making position. Furthermore to be noted, the craftsmen respond to alarms and call-outs, if for some reasons they cannot effectively deal with the issue at hand, help is received from the technicians. At times when even those cannot handle the issue, the supplier of the equipment is called in to act as consultants. To be noted, a well-documented job description is missing. See Figure 35 for the organizational chart.

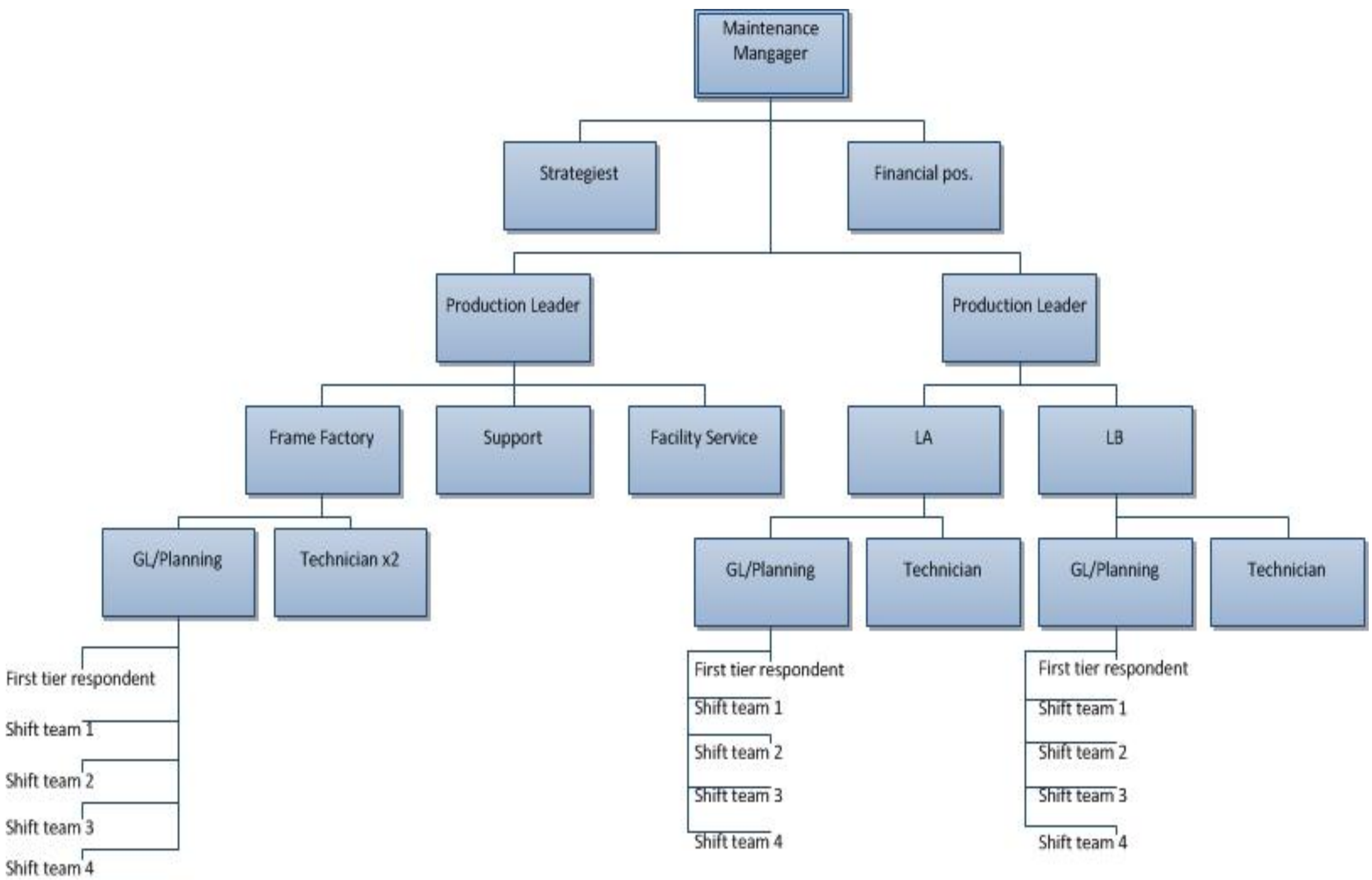

Figure 35. Organizational layout Volvo trucks, Tuve.

4.1.3 Maintenance objectives and responsibility obligations

As any other department, maintenance has a role in developing the organization. Below, maintenance role is explained simply to give a broad picture of the viewpoint of the maintenance department. The production department is the owner of all production equipment. Thus, maintenance does not own any production equipment, but are supposed to support the existing. Making sure that the production can be reliable by eliminating errors in the production equipment. By eliminating errors the journey toward proactive maintenance has begun and as can be explained in Figure 36.

Figure 36. Reactive maintenance comes with low cost investment, but has a high production loss capability. Proactive comes with high investment cost, but lower frequency of production downtime.

Large part of being more proactive comes from being able to root cause analyze your problems. From this the ability to prioritize among the most frequent problems are simplified. Thus, the correct data needs to be gathered. This is to be done by using EWO, Emergency work orders, where cross functional work teams, comprising the maintenance personnel, production personnel and production technicians, deals with information gathering. The role of impawn this information lies on the maintenance department. This is also ought to simplify the role of allocate an owner of the problem, questioning of costs. This will in turn help analyze equipment life cycle cost and thus become a ground for replacement investments.

Besides the above mentioned, maintenance is also responsible for education in autonomous maintenance and supporting the same.

4.1.4 Internship on the shop-floor

Below is the result from the author's internship at Volvo trucks. It is based on what the authors themselves have experienced and observed, and also on discussions with various craftsmen from the maintenance department. Smaller sections originating from document describing methods and assignment are also taken into account and described from the perspective of the authors experiencing it.

Meetings

Action plan meeting short term activities - Maintenance

The maintenance department has meetings on a daily basis (monday - friday) and the personnel present at these meetings are:

- The day maintenance craftsman from each unit
- Day and shift group leader (GL)
- Technician
- Maintenance manager which also are the one who is holding the meeting.

Issues at the meeting are:

- 24 hours activities determined and each activity are assigned to one responsible person
- A follow-up from the last day's 24 hours activities
- Key performance indicators; OEE, number of stoppages and duration of stoppages.

Action plan meeting short term activities – Production

The production units have meetings on a daily basis (monday - friday), in which the corresponding daily maintenance craftsman participate. During this meeting the production units follow up the last 24 hours with regard to OEE, number of stoppages, other problems, crew etc. The following 24 hours are also discussed and 24 hours activities are determined.

The action plan meetings which are held by the production department deviate slightly depending on which production unit holding the meeting, but the overall outcome are likewise. The daily maintenance meetings has in principle the same overall structure as the production meetings, except focus are only and more thoroughly on maintenance performance.

Action plan meeting long term activities - Maintenance

Once a week, the day maintenance craftsmen has a meeting where the five most frequent failures occurred during last week production from each unit are highlighted and discussed. One person from each maintenance unit is held responsible to compile a form regarding these five most frequent failures in which, underlying cause, short and long term action are included. In some cases it is considered that the short-term actions solved the problem and long term actions are not defined. The goal of the meeting is to determine an action plan for the failures that require long term actions. The following day are the action plan and the failures reviewed and discussed in a meeting with technicians, strategists and the maintenance manager, to establish long-term actions and solutions, there are also a follow up of the key performance indicators. The key performance indicators are OEE, number of stoppages and duration of stoppages visualized by diagrams on a spreadsheet.

Both the weekly meetings are held under the supervision of a meeting coach, which are intended to analyze the outcome of the meeting and at the end also point out opinions and suggestions for upcoming meetings.

Deviations between the production units

In the frame factory, the collaboration between production and maintenance works relatively satisfactory. Here, maintenance is a part of the development process of specifications for new equipment to be purchased. Maintenance is also part of the process of working out the best possible solution for investments. However, it should be noted that this stands for maintenance technicians and not the average shop floor maintenance personnel. For the production units LA and LB is the collaboration between production and maintenance at a significant lower level compared to the frame factory.

4.1.5 Interviews with maintenance craftsmen

There are two technicians to each department at Volvo Trucks. The workload varies from day to day. The quality and quantity of tools available for the craftsmen are sufficient and new tools needed an order can be made. Equipment available for failure finding and diagnosis of assets can be updated to be more modern and computerized. Spare parts can to some extent be further revised to secure availability at all times. It is believed that additional education concerning new technologies in the field of maintenance can further streamline maintenance work. The craftsmen's opinion is that they should be involved at an early stage for investment projects; it happens that they are not updated concerning new assets until it is on the shop-floor and is to be assembled. The view of the craftsmen is that they sometimes are forgotten. During the warranty period is the supplier the one who maintain equipment, when the warranty period is over the responsibility is transferred to Volvo and the maintenance department. The craftsmen's opinion is that the supplier should provide further education concerning maintenance of new assets. Sometimes a very general introduction is provided however the perception, from the maintenance point of view, is that this can be further developed. The maintenance department, in some cases, need to figure out and seek knowledge regarding how the machine should be maintained and repaired, by their own. If neither the craftsmen nor the technicians are able to repair equipment, the supplier is contacted for support. The 5S implementation has been successful, it has sustained and it works satisfactory. Maintenance management needs to be committed and require being involved from the production department. See Appendix I for the interview questions.

4.2 Maintenance fair, Gothenburg 2012

Every year is a maintenance fair held in Gothenburg, at Svenska Mässan. A number of companies that were exhibitors at the fair were chosen to be included in this master thesis work.

Idhammar AB

Idhammar AB is a knowledge company which offers education and consultancy within operations safety, maintenance and production safety. The customers are located both in Sweden and internationally.

One interesting result from visiting Idhammar AB is their view of stoppages intended for maintenance. They have developed a concept called “The effective stoppage”. In the Figure 37 below are the basics and advantages with “The effective stoppage” projects presented.

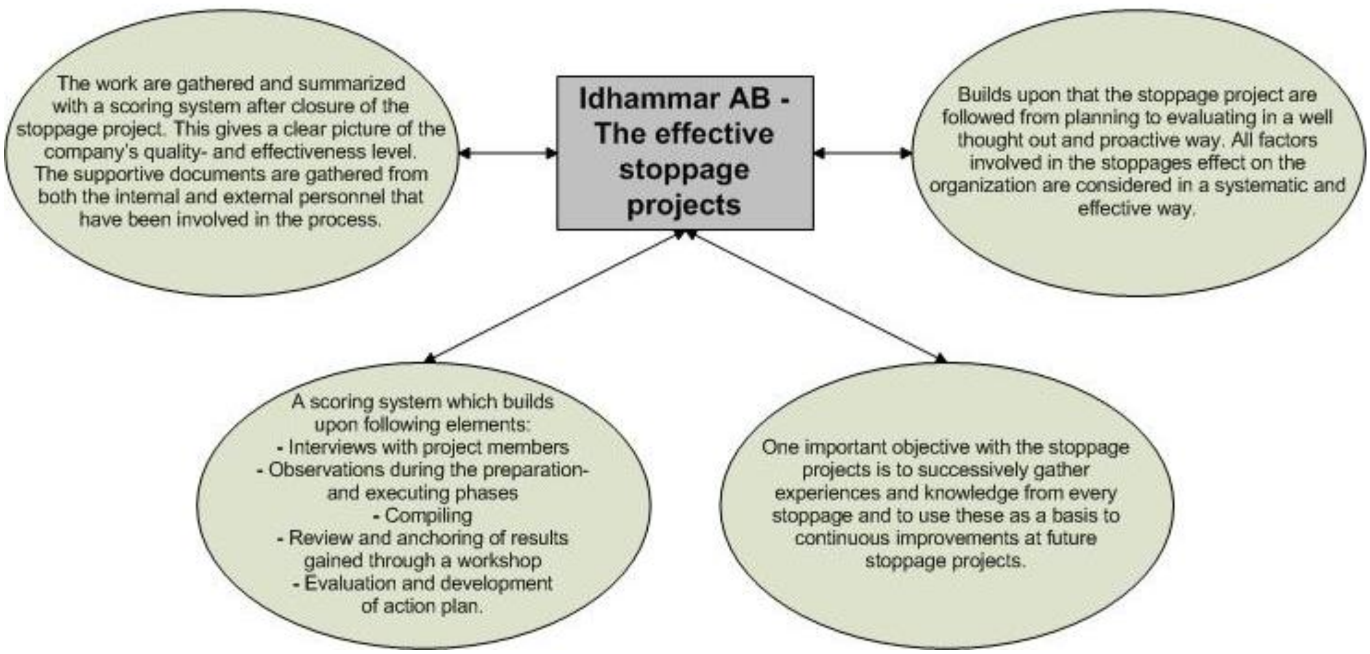

Figure 37. The effective stoppage by Idhammar.

Coor Service Management

Coor Service Management is, with a nation-wide coverage, one of the leading suppliers of industrial services in Sweden. They provide services within workplace and facility maintenance, industrial maintenance and also strategic guidance. In Figure 38 below is Coor’s own developed model for how to work strategic with maintenance presented.

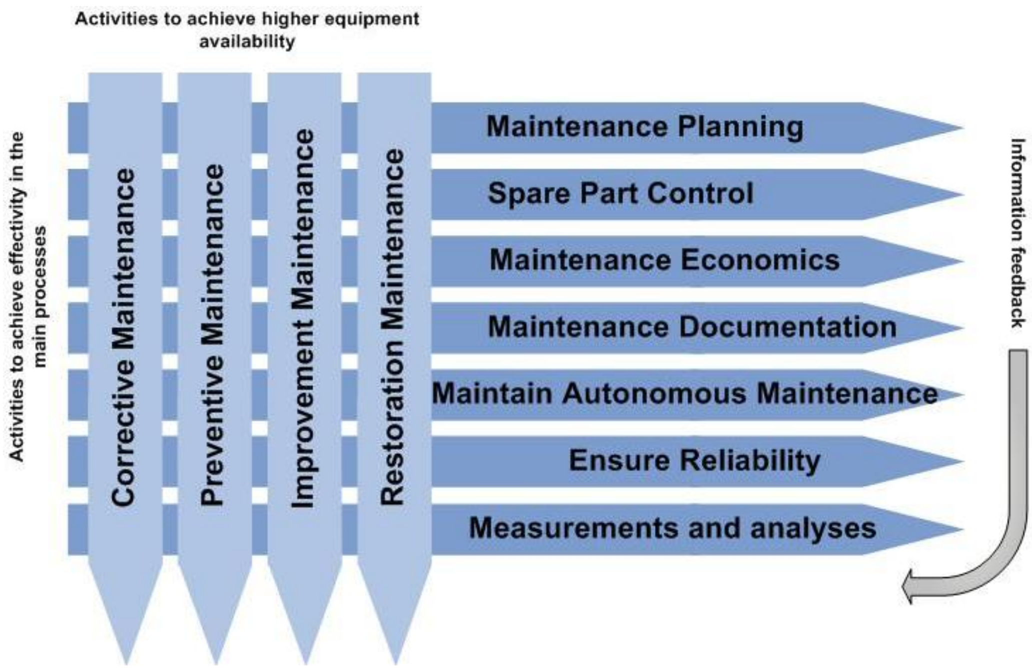

Figure 38. - Coor's platform for a strategic approach to maintenance: "The Coor Way"

4.3 Benchmarking Tools

In order to perform an accurate comparison between companies, present the results clearly and visually, and also to truly gain the relevant information, a benchmarking tool was developed. The tool, named Maintenance Department Analysis (MDA) is presented below.

SKF has their own developed analysis tool named Client Needs Analysis (CNA), which through connection with the company was consigned to the authors. This tool was used on Volvo Trucks.

4.3.1 Maintenance Department Analysis - MDA

The MDA consist of 45 questions, which are presented in Appendix III and justification to the questions in Appendix IV, within the areas of:

1. Maintenance Organization
2. Education Programs within Maintenance
3. Maintenance Work Orders
4. Maintenance Planning and Scheduling
5. Preventive Maintenance
6. Maintenance Inventory and Purchasing
7. Maintenance Automation – Computerized maintenance management system (CMMS)
8. Operator Maintenance
9. Maintenance Reporting
10. Predictive Maintenance
11. Reliability Engineering
12. Maintenance – Key Performance Indicators
13. Financial Planning

The MDA is developed by the authors themselves, also the justifications to the questions, this was made before the CNA was consigned to them and hence, the CNA has not been used as an aid. Each question and also the majority of the justifications is based on published literature.

The literature which have been used are: (Wireman, 2010; Smith, 2004; Stig-Arne Mattson, 2004; (UTEK, 2006; European Federation of National Maintenance Societies, 2012; Moubray, 1997; Wireman, 2009; Reliasoft, 2012;
(http://media.wiley.com/product_data/excerpt/60/04705173/0470517360.pdf, 2012-04-16;
NASA, 2008).

4.3.1.1 The areas included in MDA

Below is each area included in the MDA justified and the corresponding issues which are addressed in each area.

Maintenance Organization

According to (Wireman, 2010) is the maintenance organization either an enabler or disabler to success. In order find out the answer for the companies does this area address the following issues:

- The maintenance department's organizational chart.
- The coverage, documentation and communication of work descriptions and responsibilities.
- The usability and clarity of the maintenance organization's document management system.
- Continuous improvements culture

Education Programs within Maintenance

(Wireman, 2010) points out that in order for the maintenance craft to maintain and repair new high-tech equipment it is crucial to provide them education, and for achieving the level of proficiency necessary for a successful planning and scheduling program also planners need to be provided education (Wireman, 2010). In order to find out how strong or weak the companies are within this area, are the following issues addressed:

- Education for employees with planning responsibility
- The frequency of which education concerning new technology and changes in equipment are provided to maintenance craftsmen.
- The considered competence and work quality of performed maintenance tasks.

Maintenance Work Orders

One of the keys for successful maintenance management is work orders. Work orders are documents which are used to collect necessary maintenance information (Wireman, 2010). This area addresses issues such as:

- The percent of the total amount of work orders processed in the system that are tied to an asset/equipment number.
- The percent of the total number of maintenance man-hours that are reported to a work order.
- The percent of the total amount of work carried out that is covered by work orders.
- The percent of the total amount of work orders that are available for historical data analysis- follow up.
- The categories covered in a work order.

Maintenance Planning and Scheduling

Not dedicate maintenance planners to plan and schedule maintenance activities is a great mistake. A planner has a full-time job, where approximately 80 % of their time is expected to be spent on paper and computer work while only about 20 % spent on the floor (looking over equipment parts or spare parts). The planner responsibilities are both important and time-consuming. The planners need to have good craft skills in order to be effective in planning the job (Wireman, 2010). Controlled work reduces waste and planned work therefore costs less to perform than unplanned work (Wireman, 2010). Another advantage with planned work is that the practices within inventory and procurement can be optimized if the work is planned several weeks in advance (Wireman, 2010). In order to find out how well or poor the planning and scheduling area is at the companies are the following issues addressed:

- The total amount of work orders that have been delayed due to poor or incomplete plans.
- The position the one who is responsible for the planning of preventive work orders has or if no one in particular is responsible.
- The one who reports the performed jobs with regard to the actual working time, used material, downtime duration, and other data.

Preventive Maintenance (PM)

By actively work with preventive maintenance, the downtime can be minimized, and therefore, the productivity can be maximized. The PM program is the key when improving the maintenance process. The amount of reactive maintenance is reduced by this program (Wireman, 2010). If the frequency of the preventive maintenance program is not based on accurate estimates the result may be over- or under scheduling which in turn lead to missed PM or altered frequencies and, ultimately, breakdown or a failure. This PM program is unsuccessful and due to that, will lose management support. The equipments' energy consumption is reduced by performing preventive maintenance. Thus, less energy is required to operate equipment which is well-serviced because all mechanical drives, shaft alignment and bearings receive timely attention (Wireman, 2010). Issues addressed in order to find out how strong or weak the PM program is, are the following:

- The extent of critical equipment that is covered by the PM program.
- The percent of the PM program that is reviewed annually in order to ensure good coverage of the program.
- By what, the frequency of maintenance tasks in the PM program is based on.
- The percent of the total amount of work orders that have been generated from PM inspections.

Maintenance Inventory and Purchasing

The right parts must be provided at the right time. Downtime due to absence of spare parts may cost the company more than having the part at stock (Wireman, 2010). A goal to strive for is to have enough spare parts, not too many and not too few. If spare parts are not available when needed by the customers (maintenance personnel), the customers will be unsatisfied and may cause them to keep their own stock and circumventing the standard channel for procurement in order for them obtain their materials (Wireman, 2010).

To have an upper and lower level of quantity for a spare part, can be seen equally to a reorder point system. By having these levels, the availability is secured, meanwhile is the warehousing cost and order costs minimized (Stig-Arne Mattson, 2004). This area address issues such as:

- The extent of spare parts to critical equipment available in stock.
- If the maintenance department themselves control the inventory of spare parts.
- The extent of specified minimum and maximum levels for stored materials.

Maintenance Automation – Computerized maintenance management system (CMMS)

The utilization of CMMS facilitates the collection, processing, and analysis of the data. In order to control the maintenance organization properly information about occurring events are needed (Wireman, 2009). Data is the foundation for conclusions and decisions, without effective data gathering cannot incidents be truly investigated and defined (Vanden Heuvel, 2008). To gather and analyze data manually requires a tremendous amount of both time and effort. Due to this, are computerized maintenance management systems (CMMS) to prefer, they are designed to gather all data related to maintenance and to file it in the history of corresponding asset (Wireman, 2009). To control and manage maintenance tasks is one of the main functions of a maintenance management system (Ylipää and Harlin, 2007). In order to find out how useful the maintenance system is are the following issues addressed:

- The utilization of CMMS for maintenance operations.
- The structure and updating of data in the CMMS.

Operator Maintenance

The operations personnel are on place and have big knowledge about the equipment which they operate. It is therefore an advantage if they themselves can generate work orders and perform minor maintenance tasks by themselves. This is to save time and to decrease the impact of failures. Furthermore, if operations personnel get authority to generate work order they will probably be more observant. In order for the maintenance department to focus on extensive problems and to develop their knowledge for maintaining and repairing equipment strategic, operator maintenance is a vital part. The higher the operators knowledge is, and the greater competence he/she have, less the maintenance have to deal with these minor tasks which only are time consuming. Thus, the complexity of equipment and the operators' skills are factors which may decide the extent of operator maintenance (Wireman, 2010). This area address issues such as:

- The percent of the total amount of operations personnel that generate work order requests.
- The tasks which the operators are trained to perform.

Maintenance Reporting

The reports provide management with information needed to manage and control the maintenance function (Wireman, 2010). This area focuses on which reports that are produced in order to manage and control the maintenance function, therefore are the following issue addressed:

- The reports that are produced for the equipments.

Predictive Maintenance (PdM)

When performing predictive maintenance, the actual operating condition of equipment and systems are monitored. Equipment is used to monitor the condition of other equipment, for example changes in vibration characteristics or changes in temperature, and these techniques are known as *condition monitoring* (Moubray, 1997). Condition-based monitoring solves or mitigates chronic equipment problems (Wireman, 2010). If the problems are detected early and even before occurring, the data can be used to improve the asset performance and the life cycle of the equipment can be extended. This will save both time and money due to both fewer failures and less frequent investment. This area addresses the following issues:

- If a PdM program exist. (If not, then the rest of questions are answered with not applicable and the interview moves on to the next area).
- If the PdM program include condition-based monitoring.
- If preventive maintenance and corrective maintenance work orders are generated from the PdM program.
- If the data that are gained from the PdM program are used to improve asset performance and asset life expectancy.

Reliability Engineering

Every physical asset is put into service because there is a need for a specific function or functions, and this asset is expected to fulfill this need (Moubray, 1997). Reliability focuses on the assets ability to perform this function under certain specified condition during a stated period of time (Gulati and Smith, 2009). Risk analyses should be made in order to reveal possible failures (evaluate the inherent reliability) and predict the effects which the failure will have on the system as a whole. This is useful in order to pinpoint potential areas for reliability improvement or if not possible, identify possible failures and take action to mitigate the effects before the failure occurs (Reliasoft, 2012; http://media.wiley.com/product_data/excerpt/60/04705173/0470517360.pdf, 2012).

To find the root causes or causes of a problem within an organization is the single most important determinant of failure or success of any problem-solving method (Monroe, 2010). There are several techniques and tools that can be used to improve the reliability of equipment (McCormick, 2002; Bergman and Klefsjö, 2010). This area address several issues included in reliability engineering in order to find out how reliable the organizations are, i.e. how reliable the equipment's are.

- The extent to which risk analyses are used.
- If RCM methodology are used on critical equipment to adjust or refine the PM/PdM program.
- To what extent failures are clearly identified to its root cause.
- The extent to which the cause of failures accurately can be tracked by work order history.
- If failure analyses are conducted by the use of an analysis tool such as fishbone, tree, five why's and Pareto diagram to assure accuracy and standardization for each analysis.
- If failure frequencies are calculated according to "The Six Failure Patterns" included in the RCM methodology.

- If any certain software (ex: Reliasoft, Relex etc.) are used for calculating failure frequencies and other calculations.

Maintenance – Key Performance Indicators

Key performance indicators are to combine metrics and indicators for critical or key processes in order to yield as an assessment, and thus to indicate the maintenance performance (Smith, 2004). This is important because the measurement of process performance becomes critical to know how they perform relative to the overall objectives of the maintenance organization. As also previously mentioned, it is important that the targets are measured in order to be performed (Bergman and Klefsjö, 2010). Thus, these questions were targeted.

- The extent to which the OEE is calculated to monitor the condition of critical equipment.
- If the extent of downtime, due to CM, in relation to total production time for the facility/equipment is known by the company.
- If the percentage of PM costs in relation to the total maintenance costs are known by the company.
- If the proportion of total amount of maintenance man-hours that are devoted to corrective maintenance are known by the company.

Financial Planning

It has been shown in the report that maintenance costs can account for as much as 10-40% of the cost of your company. It is considered 30% consist of unnecessary spending, such as poor planning and overtime (Salonen and Delaryd, 2011). Further demonstrating Ahlmann (2002) to improve the OEE of 60-80% can lead to economic improvement up to 20%. Much of this is in the life cycle cost of equipment. Equipment maintenance can account for such large numbers as 2-20 times the initial cost (Barringer, 2003). This shows the importance that the initial investment to life cycle cost is taken into consideration.

- If ’Life cycle cost’ or similar are regarded when initial investments are planned.
- If assets ‘Life cycle cost’ are utilized and taken into account when its condition is determined.
- Classification of the organization’s financial knowledge regarding condition determination and classification of assets.

4.3.2 Client Needs Analysis – CNA

The Client Needs Analysis (CNA) provides a picture within and with maintenance at present, and also in relationship to benchmark. SKF use the CNA to improve their own organization but it is also used as a tool in consultancy services towards SKFs external customers. More than 2100 CNAs have been performed by SKF globally, 18 different industry segments are measured and the results are stored in a database. Therefore, when an analysis has been made the result for the analyzed company can be compared and benchmarked with other analysis made in the same industry segment. SKF have developed four different CNAs and the CNA used in this master thesis is focused on asset management and asset efficiency optimization.

The CNA within maintenance consists of 40 questions divided equally into the areas of:

1. Maintenance strategy
2. Work identification
3. Work control
4. Work execution

1. Maintenance strategy, 2. Work identification	Strategic
3. Work control, 4. Work execution	Tactic

Maintenance strategy

This area focuses on executing maintenance on the right things. The aim is to know which parts that should be in focus and why one should execute necessary maintenance. The one who perform the analysis look on; how the maintenance program is connected and prioritized to the company business goals and how maintenance is measured, the maintenance system (CMMS) update, accuracy and depth. The area of maintenance strategy concern questions about:

- Maintenance cost versus estimated replacement value
- Overall availability
- Maintenance cost versus total sales turnover
- Stores value versus estimated replacement value
- Planned versus unplanned maintenance
- Asset register current/accurate
- Asset register depth
- Criticality
- Maintenance strategy – planned work derived from a standardized technical process beforehand
- Root cause failure analysis

Work identification

This area focuses on finding/identifying work that needs to be executed. The aim is to implement selected maintenance program, measure, analyze and take decisions about which work that are to be executed. The one who perform the analysis look on; the existing for preventive and predictive maintenance connected to operator maintenance and system support for decision, the work order process and how the maintenance system is configured with work types and system for changes. The area of work identification concern questions about:

- Work order coverage
- Predictive maintenance program effectiveness
- Work order types
- Decision support
- Operator care

- Operator conducting preventive maintenance
- Work order priority
- Change Management – structured procedures
- Work order process
- Who will do work well

Work control

This area focuses on having full control of the work for best possible effectiveness. The aim is to prepare and plan work to be executed, in order to execute them effectively. The one who perform the analysis look on; how the process for preparation and planning are established, how the backlog (work order queue) and prerequisites are for preparers/planners and the management, if there is any standard preparations and also how the spare parts management functions. The area of work control concern questions about:

- Planning accuracy
- Number of planners
- Scheduling horizon
- Preventive maintenance schedule compliance
- Predictive maintenance schedule compliance
- Budget compliance
- Spare parts
- Standards job plans and procedures
- Work backlog
- Overtime levels

Work execution

The aim is to do the right things and do the things right. The one who perform the analysis look on; how the repair process for critical equipment is established and also how education/training is integrated in the daily work, if there are quality assurance procedures with post control and also follow-up of rework, if there is technical and financial follow-up/history of the equipments. The area of work execution concern questions about:

- Work orders history
- History practices – financial data recorded in work orders
- Maintenance labor productivity
- Training hours per maintenance craftsperson
- Supervisor to craftsperson ratio
- Total craft designation
- Post maintenance testing
- Maintenance rework
- Living program – corrective maintenance
- Living – preventive/predictive maintenance

The result from the CNA is presented in two different ways. One way is as a spider diagram divided into four levels (from bottom to top):

1. Firefighting
2. Maintaining
3. Promoting
4. Innovating

The second way is in a Pareto chart which visualize a ranking of the deviation (in percentage) from the corresponding segment.

When SKF performs a CNA analysis it's done by an experienced maintenance specialist who based on the 40 questions performs the interview with personnel from maintenance and production. In these interviews the people from the customer site is interviewed together and the interviews take 3-4 hours. The result from the CNA analysis is during a second meeting presented to the customer together with a report with recommended actions. In addition to the 40 questions, the analysis begins with asking questions focused to create an understanding of the present state regarding driving forces, threats, the future and goals. In addition to the four areas is there one area concerning continuous improvements – living program. The aim of this area is to improve, update and follow-up the effects of the maintenance program, in order to learn. The one who perform the analysis look on how well continuous improvements are integrated into the daily work and also how well one have a possibility to follow-up the development and effect.

The resulting polar diagram from performing CNA on Volvo Trucks is presented in Appendix V, and the resulting Pareto chart is presented in Appendix VI.

4.4 The results of the benchmarking conducted

The result from the benchmarking of Volvo Trucks and the three other companies are presented in this chapter. The benchmarked companies will be discussed individually in aspects of working procedures and concepts used. The last section of the chapter will compare each of the companies in a polar diagram.

4.4.1 Parker Hannifin

Parker Hannifin is world leading company within technologies for motion and control and operates within the field of construction, industry, aviation and space markets. Parker Hannifin operates in 47 countries with 58 000 employees. Of these, about 300 are employed at Parker Hannifin in Trollhättan. Business areas are hydraulics, pneumatic, electromechanical, filtering, process control, liquid- and gas control, sealing and shielding, climate control and aircraft technologies.
Parker Hannifin's division at Trollhättan provides manufacturing for hydraulics, pump- and engine division.

4.4.1.1 Work performed to obtain a production less vulnerable to disturbances

Parker opted in 1998 to embrace the philosophies and culture of Lean production. A commencement with obtaining pull production instead of push began and has proven to reduce the buffers and storage. 5S has also proven to be successful, tools and equipment are in the right place and the production has been thoroughly cleaned. In addition to the Lean work, Parker also adopted to TPM, TBM and its containing philosophies. No work done today is a single working procedure with a single employee performing the task; everything is performed as a group work. The maintenance tasks are performed cross-functional and problems are considered in terms of the PDCA cycle, Five why's and fishbone diagrams.

The preventive maintenance program is a big part of the daily maintenance program, if not the most pronounced. All preventive maintenance work is planned 14 days in advance to ensure required parts and tools are in stock and to minimize the downtime. A preventive maintenance downtime for an asset is handled by working up a buffer after the station being handled. Thus, a well-planned program is essential. Besides the 14 day advance planning there is a yearly planning meeting where all preventive maintenance to be perform during the year are discussed.

During uptime of an asset/equipment, each operator has a preventive program to follow. These are documented in a very detailed manner. Pictures showing what requires observation and how to observe it are clearly highlighted. The documentation also contains separate sections in which the operator can note that the preventive maintenance program has been followed but also possible problems identified, such as noise and vibration.

During each day, maintenance operators specifically employed to work with the preventive program stop by to hear whether there have been any problems, but also to check that the preventive program has been followed. This is also done in conjunction with the Gemba walks performed by production managers, maintenance managers as well, in terms of the production, other interested persons.

The maintenance department, besides all other work, has a meeting each week to discuss improvements. Each employee have the ability to suggest improvements, and the group in which the operator is part of, have a budget of 10 000 Swedish kronor, from which they may try the improvement. Should the improvement be successful the group is rewarded with allowances in form of a certain amount of money per group member, in order for the group to make a journey, undertake any activity or what they would like to spend their share on. This has proven successful and Parker now has a participation rate of more than 97 %. As also shown in the MDA analysis of Parker, the company, and more precise the maintenance department, has a high level of understanding for the economic involvement in the maintenance department but also the impact the maintenance department can have on the entire company. The maintenance department is engaged in the start of investment projects. Clear guidelines are present, and which must be ticked off in order for the project to move on. One of these is, as said, that the maintenance has been consulted and are part of the project. Below in Table 2 are some improvement factors Parker Hannifin has achieved.

Table 2. Improvement factors for Parker Hannifin

Factor	Old performance	New performance
Overall Equipment efficiency	40%	90%
Delivery service	40%	90-95%
Sick leave	NA	3%
Staff turnover	NA	Non

4.4.2 SKF

SKF was founded in 1907 and are today a global company represented in 130 countries and production in 100 countries with over 40 000 employees, of these 3500 people are employed in Sweden.
SKF are today the world leading supplier of products, solutions and services within the areas of roller bearings, sealing, mechatronics, services and lubrication systems. The service areas cover technical support, maintenance services, condition monitoring and education (SKF, 2011).
The production in Gothenburg manufactures three bearings, the spherical bearing, spherical roller thrust bearing, and CARB toroidal roller bearing.

4.4.2.1 SKF maintenance work structure

A prevention team has been assembled, and together with a group of maintenance engineers they are responsible to develop the preventive maintenance work and planning of the remedial working. In Gothenburg SKF have eight preventive teams. Besides this, the maintenance engineers are responsible for increasing the reliability of the process, and thus their work is conducted in close collaboration with the production. Work related to reactive maintenance is driven by a central maintenance organization, and consequently their focus areas are emergency work orders. However, the central maintenance employees contribute with improvements suggestions generated from the work they perform.

SKF works with what they call, manufacturing excellence in which SKF act as a bridge between their suppliers and customers. From the manufacturing excellence continuous improvements has been presented, which involves reduced variation, experimental learning, key performance indicators to identify improvement areas, questioning our working procedures and eliminate waste. And the ability to up keep the improvements lies in standardized work. Manufacturing excellence also contains a simple model for how SKF wants their work and improvements to proceed; principles, methods and result, shall all be performed with feedback from each other. Here, principles equal the way of thinking, method the way of doing things and finally, the result which continuously will be improved when working correctly, that is, with feedback from each other. This loop is a continuously process, where one always is intended to firmly scrutinize the way they work (see Figure 39).

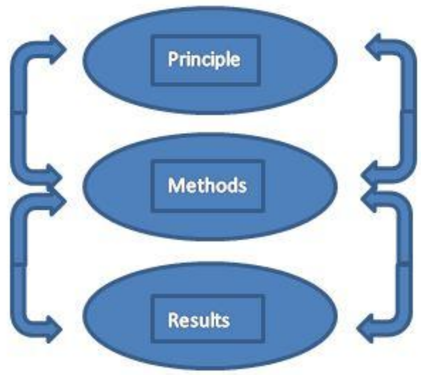

Figure 39. SKF loop of continuously evolve

Furthermore, SKF has developed a methodology of working for the annual planning of preventive maintenance work. They call this, Goal oriented maintenance, see Figure 40. The idea is that maintenance department and production department develops jointly goals for respective area in the production facility. From these goals, the maintenance department develops activities which will lead to these goals. These activities are reviewed by the production department, which either approves the activities, or asks for a revised version. The final version then has a monthly reconciliation. This is a major undertaking from SKF, but has been shown to increase collaboration between maintenance and production. A greater insight into, and understanding of, each department's workload and thinking, thus, facilitates the cooperation. It is also proven to improve the preventive maintenance work. SKF has also shown a clear commitment to root cause failure analysis, a modified version of root cause analysis, in which the requestor of an work order are to clarify the work order by describe multi-level nature of the problem at hand. The perception is that this is not done equally much on the various levels of the production, but at the areas where it's used, problems occurring twice have decreased. The cause of absenteeism in some areas has been perceived to be a skills gap in the way of it should be noted but also complexity in various areas of the department.

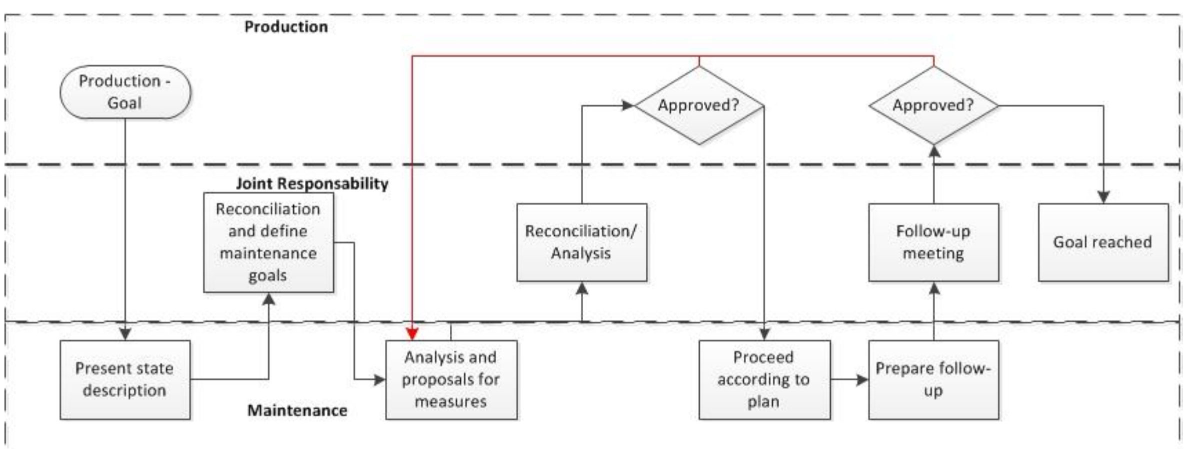

Figure 40. Goal oriented maintenance - SKF

4.4.3 Polar diagram comparing the companies, including Volvo Trucks

In the polar diagram below are the scores for each benchmarked company presented. The scores are ranked on a scale from zero to four points where four is the highest. The score minus one are assigned on questions not applicable for that certain company and those will not be regarded when analyzing the result. The categories relevant for the “not applicable” questions are planning and scheduling, predictive maintenance, reliability engineering respectively key performance indicators:

- *Planning and scheduling* – SKF do not follow up work order delays and therefore, question 13 cannot be answered.
- *Predictive maintenance* – Volvo Trucks does not have a predictive maintenance program and therefore are all supplementary questions concerning predictive maintenance assigned the value minus one.
- *Reliability Engineering* – Parker Hannifin, SKF and Volvo Trucks do not use RCM methodology within the organization and therefore, question 37 are assigned the value minus one for these companies.
- *Key performance indicators* – Volvo Trucks and SKF do not have data available concerning the extent of downtime (hours/year) due to corrective maintenance and therefore, question 40 is assigned the value minus one for both Volvo Trucks and SKF.

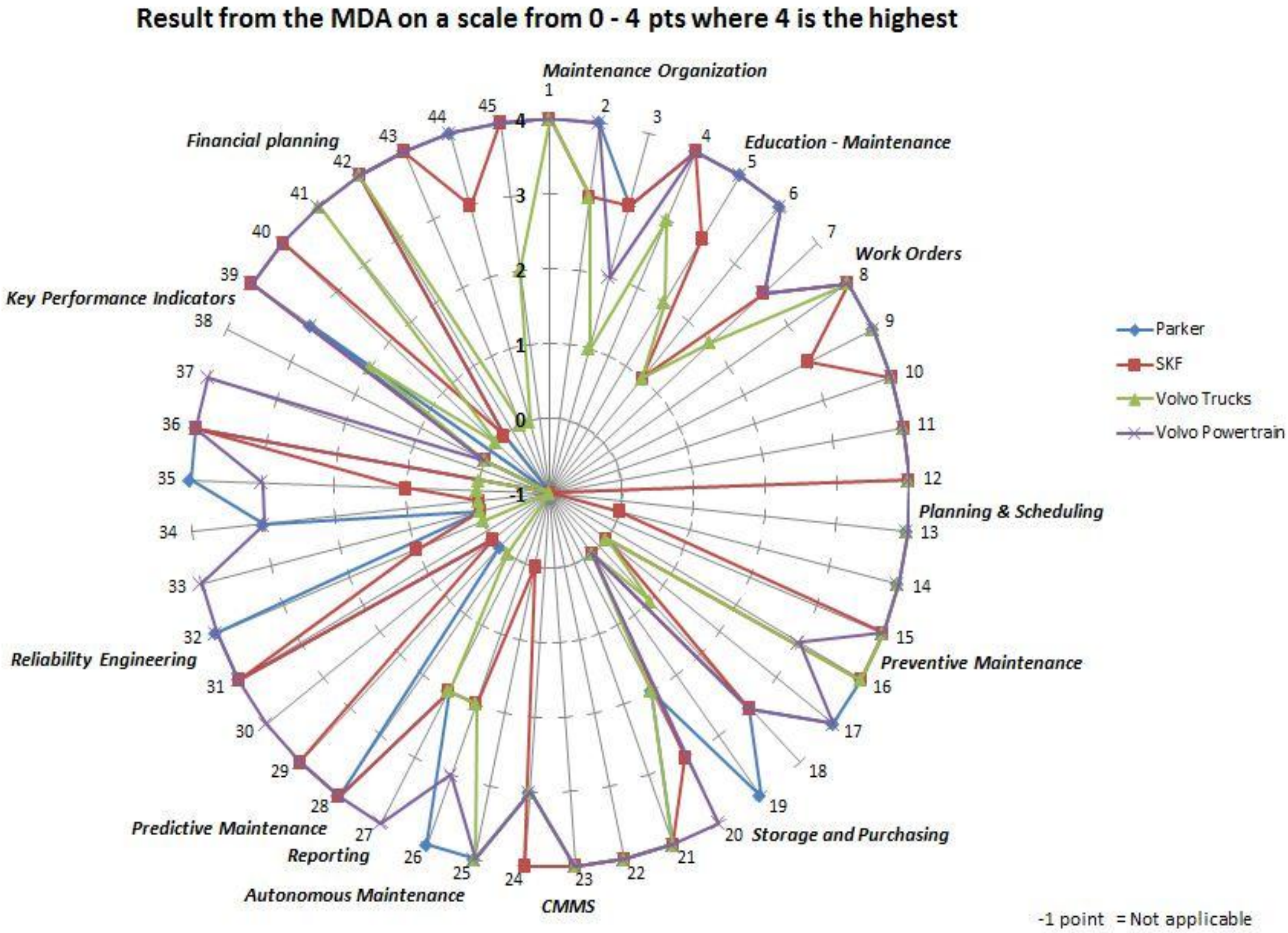

Figure 41. MDA comparison between the benchmarked companies.

4.4.4 Bar diagram comparing the companies, including Volvo Trucks

In Figure 42 below is the average score for each company presented and arranged from the highest to the lowest - from left to right. The average score from the MDA is calculated for each company according to equation 4.1. Only the applicable questions are included in the average score, therefore are all points summarized at first and then are the score adjusted to include only applicable questions.

Equation 4.1: Average score from the MDA

$$MDA_{Average} = \frac{\sum_{x=1}^{45} S(x)+n}{x-n} \qquad (8)$$

S(x) = Score at question x for 1 ≤ x ≤ 45
n = Number of questions not applicable (questions not applicable has been scored with -1)

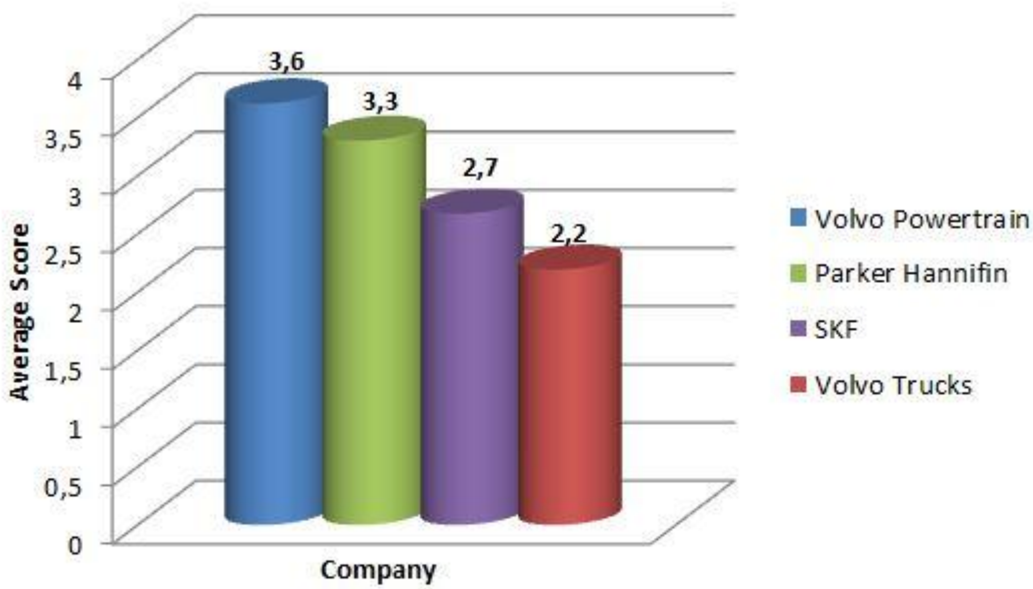

Figure 42. A bar diagram presenting the average score for each company

As can be obtained in Figure 42 above are the average scores the following:

- Volvo Powertrain – 3,6 points
- Parker Hannifin – 3,3 points
- SKF – 2,7 points
- Volvo Trucks – 2,2 points

The average score, 2,2 points, from the MDA of Volvo Trucks is in accordance with the average score, 2,2 points, from the CNA of Volvo Trucks, which is calculated from the polar diagram presented in Appendix V.

4.4.4 MDA - Volvo Trucks

The scores which can be obtained in figure 29 above and with support from the MDA form in Appendix III is Volvo Trucks present state concerning the maintenance organization the following:

Maintenance Organization

A chart over the maintenance organization is updated and complete. The maintenance departments responsibilities are clear, well communicated and have a good coverage, but are not fully documented. The usability and clarity of the maintenance organization's document management is poor. The organizational support to continuous improvement efforts is moderate.

Education Programs within Maintenance

Training is provided to new planners by supervisors for at least the first month. Education concerning new technology and changes in equipment is provided to some of the maintenance craft employees at the frequency of less than 18 months. Maintenance competence and work quality of performed maintenance tasks are considered to be adequate.

Maintenance Work Orders

85 percent of the total amount of work orders that is processed in the system is tied to an asset/ equipment number. 100 percent of the total number of maintenance man-hours is reported to a work order. 100 percent of the amount of work carried out is covered by work orders. 100 percent of the total amount of work orders is available for historical data analysis – follow up. Required downtime, craft hours, materials and requestor's name are categories all covered in the work orders.

Maintenance Planning and Scheduling

Less than 10 percent of the total amount of work orders has been delayed due to poor or incomplete plans (from today and a year back). The responsibility for planning the preventive work orders rests on a dedicated maintenance planner. When the maintenance job is completed, do the craftsmen that performed the job report the actual working time, used material, downtime, and other data.

Preventive Maintenance

The production department has classified the critical equipment and out of these are 100 percent covered by the preventive maintenance program. Less than 40 percent of the PM program is annually checked against corresponding item's history to ensure good coverage of the program. The frequency of the preventive maintenance program is based on calendar intervals. Less than 20 percent of the total amount of work orders has been generated from preventive maintenance inspections (from today and a year back).

Maintenance Inventory and Purchasing

80 percent of spare parts to critical equipment is available in storage. Maintenance controls the inventory of spare parts. The maximum and minimum levels are specified for 100 percent of the stored materials.

Maintenance System – Computerized maintenance management system (CMMS)

100 percent of all maintenance operations utilize CMMS at present. CMMS data is structured and updated for approximately 75 percent.

Operator Maintenance

100 percent of the total amount of operations personnel generates work order requests. Operators perform inspections and lubrication of equipment used in assembly.

Maintenance Reporting

Reports concerning duration of downtime, MTBF, MTTR and maintenance cost are produced when needed (for analyses). Information about maintenance cost for equipment arranged in highest to lowest cost can be created for all equipment.

Predictive Maintenance

A predictive maintenance program does not exist.

Reliability Engineering

Risk analyses are performed on different parts of equipment, less than 40 percent of the facility's equipment has been analyzed with a method intended to evaluate and minimize risks. RCM methodology is not used on critical equipment to adjust or refine the PM program. Less than 40 percent of all failures are clearly identified to its root cause and thus, the cause of failures cannot be accurately tracked by work order history. Failure analyses are not conducted by the use of an analysis tool such as fishbone, tree, and Pareto, to assure accuracy and standardization for each analysis. Failure frequencies are not calculated according to "The Six Failure Patterns" included in the RCM methodology and no certain software are used for calculating failure frequencies or other calculations.

Maintenance – Key Performance Indicators

OEE is calculated for approximately 35 percent of the critical equipment to monitor the condition. The extent of downtime in relation to total production time for the facility/equipment due to corrective maintenance is difficult to follow up at present and is therefore unknown. The part of the maintenance cost which consists of preventive maintenance is approximately 10-20 percent of the total maintenance cost. Approximately 29 percent of the total number of maintenance man-hours has been devoted to emergency corrective maintenance (during the last year).

Financial Planning

The concept 'Life cycle cost' or similar is not regarded when initial investments is planned nor utilized and taken into account when assets' condition is determined. The organization's financial knowledge regarding condition determination and classification of assets are limited.

4.4.5 MDA - Volvo Powertrain

The scores which can be obtained in figure 29 above and with support from the MDA form in Appendix III is Volvo Powertrain's present state concerning the maintenance organization the following:

Maintenance Organization

A chart over the maintenance organization is updated and complete. The maintenance department's responsibilities are clear, have a good coverage and are fully documented. The usability and clarity of the maintenance organization's document management is medium well. The organizational support to continuous improvement efforts is strong.

Education Programs within Maintenance

Training is provided to personnel with planning responsibility through seminars aimed at planning and scheduling. This is often performed together with universities and other companies. Education concerning new technology and changes in equipment is provided to the maintenance employees at the frequency of less than 12 months. Maintenance competence and work quality of performed maintenance tasks are considered to be good.

Maintenance Work Orders

100 percent of the total amount of work orders that is processed in the system is tied to an asset/ equipment number. 100 percent of the total number of maintenance man-hours is reported to a work order. 100 percent of the amount of work carried out is covered by work orders. 100 percent of the total amount of work orders is available for historical data analysis – follow up. Required downtime, craft hours, materials and requestor's name are categories all covered in the work orders.

Maintenance Planning and Scheduling

The amount of work orders which have been delayed due to poor, or incomplete, planning is considered to be approximately 10 %. The responsibility for planning the preventive work orders rests on an appointed maintenance planner. When the maintenance job is completed, the craftsmen that performed the job report the actual working time, used material, downtime, and other data.

Preventive Maintenance

80 percent of the critical equipment is covered by the preventive maintenance program. 100 percent of the PM program is annually checked against corresponding item's history to ensure good coverage of the program. The frequency of the preventive maintenance program is based on

run time, calendar interval and the condition of equipment. Less than 20 percent of the total amount of work orders has been generated from preventive maintenance inspections (from today and a year back).

Maintenance Inventory and Purchasing

99,6 percent of spare parts to critical equipment is available in storage. Maintenance controls the inventory of spare parts, the lead time and amount in storage. The maximum and minimum levels are specified for 100 percent of the stored materials.

Maintenance System – Computerized maintenance management system (CMMS)

100 percent of all maintenance operations utilize CMMS at present. CMMS data is structured and updated for approximately 80 percent.

Autonomous Maintenance

100 % percent of the total amount of operations personnel can generate work order requests. Operators perform inspections, lubrication, and assists in maintenance tasks when needed. They do however not perform any maintenance tasks by them self.

Maintenance Reporting

Reports concerning duration of downtime arranged from highest to lowest number of hours, duration of downtime arranged from highest to lowest lost in production income, maintenance cost arranged from highest to lowest cost, MTBF and MTTR are produced for all equipment.

Predictive Maintenance

A predictive maintenance program exists, it is however not automatically included in any continuously condition based program. But the craftsman knows how to read changes and it can thus be performed manually. The predictive maintenance program does generate work orders and the data obtained from the predictive maintenance program is used to improve the performance and life cycle for assets.

Reliability Engineering

Risk analyses have been made on 100 percent of the facility's equipment in order to evaluate and minimize risks. RCM methodology is used on critical equipment to adjust or refine the PM program. 80-85 percent of all failures are clearly identified to its root cause and the cause of failures which are identified (80-85 percent) can accurately be tracked by work order history. Failure analyses are conducted by the use of an analysis tool to assure accuracy and standardization for each analysis. Failure frequencies are calculated according to "The Six Failure Patterns" included in the RCM methodology but no certain software is used for calculating failure frequencies or other calculations.

Maintenance – Key Performance Indicators

OEE is calculated for approximately 100 percent of the critical equipment to monitor the condition. The extent of downtime in relation to total production time for the facility/equipment due to corrective maintenance is calculated to be about 8-10 %. The part of the maintenance cost which consists of preventive maintenance calculated to be 10 %. Approximately 50 percent of the total number of maintenance man-hours has been devoted to emergency corrective maintenance (during the last year).

Financial Planning

The concept 'Life cycle cost' or similar is regarded when initial investments is planned. It is also utilized and taken into account in existing assets' condition, and when changes in the process are to be done. The organization's financial knowledge regarding condition determination and classification of assets are considered to be great.

4.4.6 MDA – Parker Hannifin

The scores which can be obtained in figure 29 above and with support from the MDA form in Appendix III is Parker Hannifin's present state concerning the maintenance organization the following:

Maintenance Organization

A chart over the maintenance organization is updated and complete. The maintenance department's responsibilities are clear, have a good coverage and are fully documented. The usability and clarity of the maintenance organization's document management is good. The organizational support to continuous improvement efforts is strong.

Education Programs within Maintenance

Training is provided to personnel with planning responsibility through seminars aimed at planning and scheduling Education concerning new technology and changes in equipment is provided to the maintenance employees at the frequency of less than 12 months. Maintenance competence and work quality of performed maintenance tasks are considered to be excellent.

Maintenance Work Orders

100 percent of the total amount of work orders that is processed in the system is tied to an asset/ equipment number. 100 percent of the total number of maintenance man-hours is reported to a work order. 100 percent of the amount of work carried out is covered by work orders. 100 percent of the total amount of work orders is available for historical data analysis – follow up. Required downtime, craft hours, materials and requestor's name are categories all covered in the work orders.

Maintenance Planning and Scheduling

The amount of work orders which have been delayed due to poor, or incomplete, planning, is today not present. Work orders are only delayed or if external help is needed. The preventive maintenance program does not have any delays, thus 0 %. The responsibility for planning the preventive work orders rests on an appointed maintenance planner. When the maintenance job is completed, the craftsmen that performed the job report the actual working time, used material, downtime, and other data.

Preventive Maintenance

100 percent of the critical equipment is covered by the preventive maintenance program. 100 percent of the PM program is annually checked against corresponding item's history to ensure good coverage of the program. The frequency of the preventive maintenance program is based on operation time and the condition of equipment. More than 80 percent of the total amount of work orders has been generated from preventive maintenance inspections (from today and a year back).

Maintenance Inventory and Purchasing

Approximately 85 - 90 percent of spare parts to critical equipment is available in storage. The ones not in storage is known to have a very short lead time from suppliers in the local area. Maintenance controls the inventory of spare parts, the lead time and amount in storage. The maximum and minimum levels are specified for 100 percent of the stored materials.

Maintenance System – Computerized maintenance management system (CMMS)

100 percent of all maintenance operations utilize CMMS at present. CMMS data is structured and updated for approximately 75 percent.

Autonomous Maintenance

100 % percent of the total amount of operations personnel generates work order requests. Operators perform inspections, lubrication, minor maintenance tasks and assists in maintenance tasks when needed.

Maintenance Reporting

Reports concerning duration of downtime arranged from highest to lowest number of hours, maintenance cost arranged from highest to lowest cost, MTBF and MTTR are produced for all equipment.

Predictive Maintenance

A predictive maintenance program exists but do not include continuous condition based monitoring. Neither does it generate work orders to the preventive maintenance program or the remedial program. The data obtained from the predictive maintenance program is used to improve the performance and life cycle for assets.

Reliability Engineering

Risk analyses have been made on 100 percent of the facility's equipment in order to evaluate and minimize risks. RCM methodology is not used on critical equipment to adjust or refine the PM program. 85 percent of all failures are clearly identified to its root cause and 100 percent of the failure causes can accurately be tracked by work order history. Failure analyses are conducted by the use of an analysis tool to assure accuracy and standardization for each analysis. Failure frequencies are not calculated according to "The Six Failure Patterns" included in the RCM methodology and no certain software is used for calculating failure frequencies or other calculations.

Maintenance – Key Performance Indicators

OEE is calculated for approximately 75 percent of the critical equipment to monitor the condition. The extent of downtime in relation to total production time for the facility/equipment due to corrective maintenance is at present not applicable. The part of the maintenance cost which consists of preventive maintenance is not calculated or anything which is monitored. Almost 0 percent of the total number of maintenance man-hours has been devoted to emergency corrective maintenance (during the last year).

Financial Planning

The concept 'Life cycle cost' or similar is regarded when initial investments is planned. It is also utilized and taken into account in existing assets' condition, and when changes in the process are to be done. The organization's financial knowledge regarding condition determination and classification of assets are considered to be great.

4.4.7 MDA – SKF

The scores which can be obtained in figure 29 above and with support from the MDA form in Appendix III is SKF's present state concerning the maintenance organization the following:

Maintenance Organization

A chart over the maintenance organization is updated and complete. The maintenance department's responsibilities are clear, have a good coverage and are well communicated but are not fully documented. The usability and clarity of the maintenance organization's document management is good. The organizational support to continuous improvement efforts is strong.

Education Programs within Maintenance

Training is provided to new planners through seminars aimed at planning and scheduling and also through documents to support the work. Education concerning new technology and changes in equipment is provided to some of the maintenance craft employees at the frequency of less than 18 months. Maintenance competence and work quality of performed maintenance tasks are considered to be good.

Maintenance Work Orders

99 percent of the total amount of work orders that is processed in the system is tied to an asset/ equipment number. 95 percent of the total number of maintenance man-hours is reported to a work order. 99 percent of the amount of work carried out is covered by work orders. 100 percent of the total amount of work orders is available for historical data analysis – follow up. Required downtime, craft hours, materials and requestor's name are categories all covered in the work orders.

Maintenance Planning and Scheduling

The amount of work orders which have been delayed due to poor, or incomplete, planning isn't something which is calculated. It is to be included in the PM program in the near future. The responsibility for planning the preventive work orders rests on maintenance technicians, which all are educated to perform it. When the maintenance job is completed, the craftsmen that performed the job report the actual working time, used material, downtime, and other data.

Preventive Maintenance

100 percent of the critical equipment is covered by the preventive maintenance program. Less than 40 percent of the PM program is annually checked against corresponding item's history to ensure good coverage of the program. The frequency of the preventive maintenance program is based on calendar interval and the condition of equipment. Less than 20 percent of the total amount of work orders has been generated from preventive maintenance inspections (from today and a year back).

Maintenance Inventory and Purchasing

Above 90 percent of spare parts to critical equipment is available in storage. Maintenance controls the inventory of spare parts, the lead time and amount in storage. The maximum and minimum levels are specified for 100 percent of the stored materials.

Maintenance System – Computerized maintenance management system (CMMS)

100 percent of all maintenance operations utilize CMMS at present. CMMS data is structured and updated for more than 90 percent.

Operator Maintenance

30-40 % percent of the total amount of operations personnel generates work order requests. All operations personnel does not know how to, but at least one person in each area are trained to do it. Operators perform inspections and lubrication. Maintenance tasks are only performed if there exists simplified instructions. The personnel can also participate in other maintenance tasks together with the maintenance craftsmen, however only on emergency's since they have not been educated to perform it. For this reason, minor maintenance tasks and assisting in maintenance tasks is not seen to be present.

Maintenance Reporting

Reports concerning duration of downtime arranged from highest to lowest number of hours, MTBF and MTTR are produced for all equipment.

Predictive Maintenance

A predictive maintenance program exists and includes continuous condition based monitoring. It does not generate work orders per automatic but manual preventive team can create work orders. The data obtained from the predictive maintenance program is used to improve the performance and life cycle for assets.

Reliability Engineering

Risk analyses have been made on less than 60 percent of the facility's equipment in order to evaluate and minimize risks. RCM methodology is not used on critical equipment to adjust or refine the PM program. Less than 40 percent of all failures are clearly identified to its root cause and approximately 50 percent of the failure causes can accurately be tracked by work order history. Failure analyses are conducted by the use of an analysis tool to assure accuracy and standardization for each analysis. Failure frequencies are not calculated according to "The Six Failure Patterns" included in the RCM methodology and no certain software is used for calculating failure frequencies or other calculations.

Maintenance – Key Performance Indicators

OEE is calculated for approximately 100 percent of the critical equipment to monitor the condition. The extent of downtime in relation to total production time for the facility/equipment due to corrective maintenance is calculated to be about 73%. The part of the maintenance cost which consists of preventive maintenance is not calculated or anything which is monitored. Approximately 60 percent of the total number of maintenance man-hours has been devoted to emergency corrective maintenance (during the last year).

Financial Planning

The concept 'Life cycle cost' or similar is regarded when initial investments is planned. It is also utilized and taken into account in existing assets' condition, however only for critical equipment. The organization's financial knowledge regarding condition determination and classification of assets are considered to be great, with a great amount of help from the production department.

4.5 Improvement meeting – Maintenance

During the improvement meeting, a range of important factors was highlighted. The resulting fishbone diagram is presented in Figure 43.

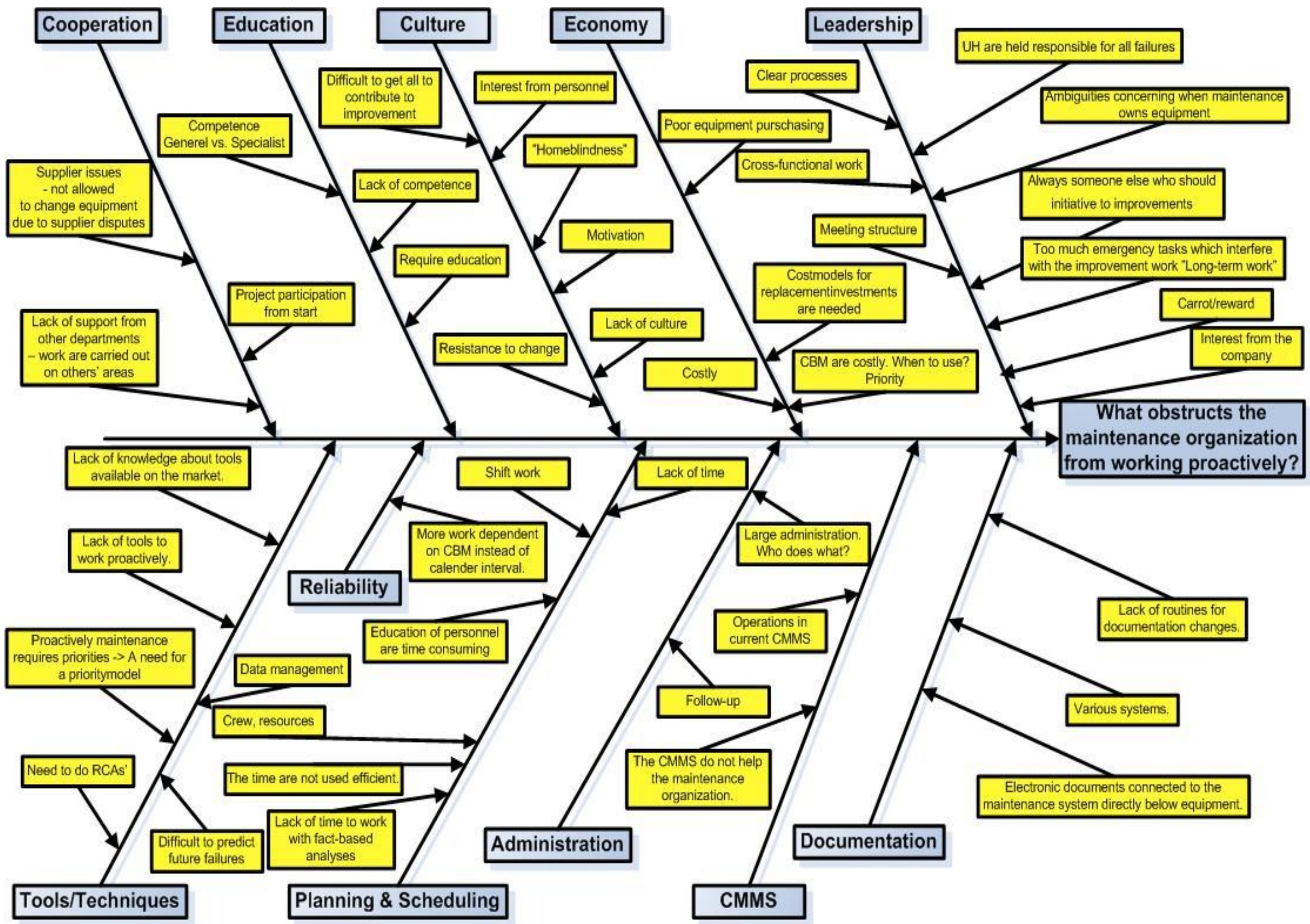

Figure 43. The fishbone diagram developed during the improvement meeting

As can be obtained in the figure main causes are the following:

- Cooperation
- Education
- Culture
- Economy
- Leadership
- Techniques and Tools
- Reliability
- Planning and scheduling
- Administration
- CMMS

- Documentation

Each main cause is further explained below.

Cooperation
It is perceived by the employees that consensus and cooperation between different departments in the plant is inadequate. This is also seen towards suppliers, where maintenance has problems getting their voice heard and understood. As to a whole, the view is that maintenance be left out of decisions and are not considered until late stages in processes.

Education
New equipment can in many cases be purchased without the maintenance department's awareness and thus creating a lack of knowledge towards the new equipment. This is, in combination with the evolving of technology that is the basis for the view that there is a lack in competence. The feeling is that one is often held accountable for things oneself not feeling to have competence to perform, and not receiving in order to perform.

Culture
There is an obvious opinion that the culture might hold back evolvement in the maintenance organization. It is perceived to be hard to get hearing for efforts in improvement, that interest is lacking among the employees, motivation is low and that the culture of working preventive is missing and hindering the improvements at hand from taking effect.

Financial aspects
When it comes to the financial aspects, it is viewed to be the lack of cost models and investment models that is crucial. A greater understanding for these are seen to be important and considered accepted by all.

Organization and leadership
The interest and appreciation in the work performed by maintenance are important to the employees and desired to be increased. It is desired to be part of, and projects and processes intended to change the work environment in any cases. One wishes that there were incentives for the workers, and that time is given in order to work with problems in more depth.

Techniques and tools
The employees have the opinion that it is hard to predict upcoming problems and that there is a lack of analytical tools used by the organization today to start the proactive work. Data are not tracked and root cause analyses are not performed enough. There is a need to use a priority model in order to prioritize problems. Tools and techniques offered on the market need to be investigated.

Reliability
The frequency of preventive maintenance tasks need to be decided more by the actual condition of equipment and less by calendar interval.

Planning and scheduling
There is not a sufficient amount of time available for the maintenance department to work with fact based analyses and the time are not used efficient. There is a need for more resources, thus there is a lack of time. The maintenance craftsmen works in shifts. There is a need for education but it the opinion concerning education is that it is time consuming, which also indicates the lack of planning.

Administration
Confusing concerning who is responsible for which administration tasks. There is a need for a follow-up of previous problems.

CMMS
CMMS can be a major aid, today it is not. The usability and operations in present maintenance computer system is not effective and is hard to utilize efficient.

Documentation
There are a different systems used for documentation and documentation changes is not performed in a standardized way. Electronic documents are not connected to the maintenance computer system directly under equipment.

4.6 Presentation at Volvo Trucks

The three questions asked to managers at the maintenance department at Volvo Trucks:

4. Which are the prerequisites to succeed change the organization?
5. Why were not the TPM implementation completed and what knowledge was gained?
6. Which are the critical success factors for the future implementation work?

The responses were:

1. Facts are needed in order to convince upwards and downwards within the hierarchy. Prioritizations' with regard to costs. Perseverance and commitment. Knowing the present state and have a common vision. Goals for the individual. Communicate and spread the message of the change.
2. The TPM coordinates left and by that also the interest disappeared. There was no follow up. Improvement teams remained but the improvement workers had a lack of competence for the equipment that they were responsible for. Still, TPM have not been phased out. Some parts from the implementation remain but it is now not communicated as TPM instead the specific remaining parts are communicated within the organization.

3. Pilot areas need to be exploited in the beginning to introduce the changes and also to create a curiosity. In addition to that are the following factors considered to be critical:
    - Support
    - Educate the management
    - Add resources
    - Training concepts
    - Have enough knowledge in order to demand and challenge
    - Consultants
    - Learning, understanding and arouse interest

4.7 Presentation at SKF - Validation

The feedback pinpointed some improvements areas in the CFM. It was pointed out that there should be a more obvious connection to integration between the production and maintenance department, that maintenance need to prioritize where to locate resources and also that authorities and responsibilities need to be decided. The model was improved with regard to these opinions. Further, the overall comments were that the thesis covered and captured significant areas within maintenance which validates the work performed and also the literature study.

5 DISCUSSION

5.1 Formulation of a maintenance strategy

Based on the findings in this master thesis, a Customer Focused Model (CFM) for the formulation of a maintenance strategy is presented. The model are named customer focused because it are focused on the customers, both the internal customers; the maintenance craftsmen and technicians, and the external customers; production. The customers' needs and expectations are identified and then translated into maintenance objectives which then are used as a foundation when to formulate the strategy.

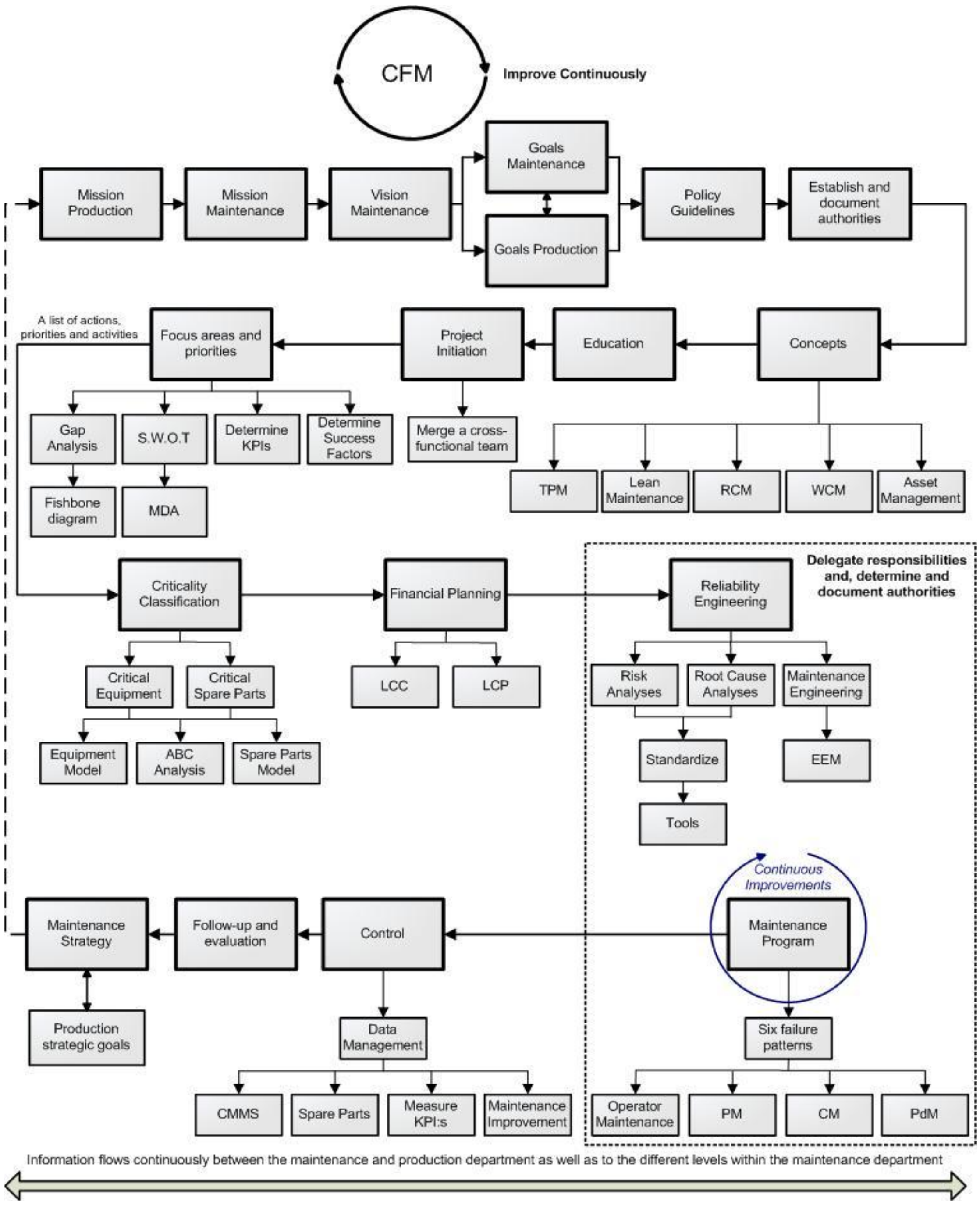

Figure 44. A Customer Focused Model for the formulation of a maintenance strategy.

5.1.1 Comprehensive discussion of the model

As have been demonstrated in Figure 10, by Bergman and Klefsjö (2010) the linkage between what the organization wants to achieve – the mission, and where they want to be – the vision, are how they are to do it – the policies, goals and the strategies. Thus, first the organization must know what the mission is, what are expected from our external customers, why are we here and what makes our customer choose us? Onwards, the vision should present the future state in which it is clear where the organization is to be heading. In order to reach this future state it is described that long and short term goals are to act as basis for activities. Together this will create a strategy according to the standard, which states that a maintenance strategy is a; "Management method used in order to achieve the maintenance objectives" (prEN 13306, 1998).

Several times it has been highlighted of the importance of never satisfied and constantly strive to improve. Salonen (2009) points on the importance of continuously develop efficiency in businesses and maintenance is an important factor in this. Further on, Hagberg and Henriksson (1996) shows that companies that have proved successful in TPM also continually have been seeking to improve. Onwards, in the authors' opinion, the technical development is in itself an argument that continuous organizational development is required. A change is not something that is done in the short term but, as Rubenowitz (2004) puts it, an ongoing process. Finally, Slack and Lewis (2009) believes that change is a project and hence should be treated accordingly. It is on these arguments, the authors believe that the model, and strategy of primarily shaping should be developed. Constant feedback from stakeholders and the various departments within the company is crucial. One method to accomplish this is to apply the PDCA cycle as previously been described in chapter 3.4.9.1. PDCA cycle is an approach that is intended to solve problems through continuous improvements (Larsson, 1993; Bergman and Klefsjö, 2010). The cycle begins with the identification of targets and methods to solve the problem in question. After the cause has been established, activities are carried out, with full awareness of the problem, too solve the issue. Results are measured continuously, allowing for analysis. If the result is successful, the cycle starts over. If it is not successful acting should be performed accordingly. This thus reflects operating in, the Plan-Do-Check-Act. Finally, the authors share the view that a change of this magnitude is a progressive process, which should also be a sufficient argument for the model's constant demands for feedback and closed loop.

5.1.2 Discussion and description of the component parts of the model

The following describes each part further. It discusses the content of what the authors believe are of interest in various stages and levels of the model.

Mission - Production

Where in the whole the production accounts for the measurable results of the organization's existent, it would appear, in the authors' opinion, appropriate in a first stage to study the reason why these exist. The production department's existence constitutes the essential processes in which the needs of the external customers and refinement of products are to be fulfilled. By this view, the production acts as customer for the maintenance department, and as Mobley (2004) states it, maintenance delivers uptime to its customer. As have been explained, the mission states the reasons for being at hand, what to produce and for whom. As maintenance customer is the production department, it would thus be ignorant not to take into account the customers mission and then state how help would be appropriate.

Mission – Maintenance

When the production mission has been taken into consideration, maintenance mission is considered to be the natural step. It is here believed to be important to state, why the customer should prefer oneself before any other alternative and what the customer will benefit from it. By stating this, one also states what not to pursue which according to the authors is equally important. In many cases it is common that one does not have a clear line between what to perform and what not to perform. The case is then to be taking on too much and not be able to focus on the right things.

Vision - Maintenance

A vision is the end result of where the organization wants to be, or to achieve, and what they want to be identified by (Bergman and Klefsjö, 2010). Also, well-developed visions gives purpose to the work performed and motivates and encourages people at work (Bergman and Klefsjö, 2010), (Kotter, 1996). Also, according to Kotter, (1996) the single greatest obstacle in changing organizations is a vision which is not communicated or understood by all employees. For this reasons it is the authors opinion that the vision is of great importance for the organizations development to initially become preventive in their work, and finally also proactive. Thus, a well formulated vision, communicated to the whole organization, understood by the whole organization is of great importance in the continuing work with the strategy.

Goals production and Goals maintenance

The goal should explain what the organization strives to achieve within a certain amount of time. These should be clear and measurable. As explained by Bergman and Klefsjö, (2010), only the things which are measurable will be done.

As shown in Figure 44 it is recommended by the authors that the goals for the production and maintenance department are to be developed alongside one another. This is based on a variety of sources, as stated earlier. Among other, Kelly (2006) notes the importance to understand how the plant operates, the relationship between the plant and its market and how maintenance function within this context. Kelly (2006) also states that the objectives should be in accordance with the production since the production and maintenance are inseparable from each other. Furthermore, McAllister (1999) addresses that maintenance are to be considered as partner within the business with shared overall goal and all functions within the business contributes to profitability. Hence, maintenance should be part of the overall goals. Further, it is argued by Salonen (2011) that the overall goals of the company should be taken into account when developing a maintenance strategy, and more specifically, the objectives and goals of the production department in person of the customer. Thus, it is in the authors' opinion a vital part to consider. It is believed to be clearly motivated both in the context by literature, but also in the context that the benchmarking and more precise, the maintenance department analysis, have proven that successful companies have a strong communication and collaboration between the production department and the maintenance department. This should be a focal point to appreciate each other's knowledge, which is an important part in terms of investment.

Policy

The policy are to work as a guiding principle for how the company are to achieve its vision and goals, taking into consideration the values and methodologies of the company. A policy may be a bigger picture for the employees, feeling the attendance of doing something with the right cause. The policy is a way in which the higher objectives are translated to more concrete objectives. It is a means to explain the objectives for all employees. In order to get an understanding and support in these goals and objectives it is important that everyone understands the meaning of it. And as described in section… this is best done by policy deployment, meaning that all involved in a certain processes are present when formulating the goals and objectives. Also, as stated in section XX, change management, dedicated staff is a result of them understanding the purpose of the change and feeling control over what are to happen.

Establish and document authorities

The leadership, on average, may contribute to as large part as up to a quarter of the profitability for the company (Rubenowitz, 2004). To be a leader has also been described to as getting all employees in moving in the same direction, thus, the leader must be able to articulate the vision and set goals that are realistic and acceptable. It has also been argued that there exists a consensus among executives that a substantial degree of delegation is a prerequisite for enable the leader to work with these kinds of matters and not being tied by routine matters. Furthermore, delegation will increase the challenge in the daily work for any subordinate who assumes the responsibility, thus increasing the inner desire to perform. For this reasons, it is, in the authors believe, important that the leader is focusing on the overall goals and objectives, while delegating responsibility for daily routine matters. Thus enabling the leader the opportunity to manage strategies, economic issues and thinking in terms of customer and market perspective. If this is to be performed, focusing on continuous improvement will be facilitated and become natural. However, delegating should only be executed if the subordinate are willing to accept the responsibility, hence fore, the delegation should also be well documented, leaving no misinterpretations or ambiguities.

Concepts

The work has gone through a number of concepts and methods. Among the concepts it has been about TPM, Lean Maintenance, RCM, WCM and Asset Management. The authors' opinion is that these concepts constitute a sufficient foundation of knowledge to support their change. These concepts have been around for a long time and have been well-tested, both theoretically but also practically in the industry where they are found to perform in a satisfactory manner. Working along a concept is also beneficial when employees can constantly keep pace with change and understand what is happening and what will happen, and the outcome expected.

What has been highlighted in the different concept is; TPM largely seeks to maximize OEE. In order to succeed in their changes and to obtain a longer perspective and cultural spirit, TPM emphasizes on the need for commitment from management, which is considered a critical aspect (Ljungberg, 2000). In lean maintenance one combine TPM and RCM with lean production and the methods that proved to be effective (Smith, 2004). Onwards, RCM aims to exploit reliability and availability, and maximize these in order to eventually be able to minimize LCC. The WCM concept also originates from TPM and seeks to improve quality, productivity and customer satisfaction and is to be achieved with high management commitment.

Concerning Asset Management has (Schneider et al., 2006) argued that aging of an asset has major impact on the reliability of performance, and thus production. Age is usually divided into three phases for the assets, reliable, degenerated and unreliable. Asset management must be seen in a time perspective and over the whole life cycle, thus including original investment, maintaining, disposal, modification etc., supported by (Woodhouse, 2007). The authors' points out that it is important to care for the assets and gain better awareness of their value at different phases of its life cycle.

From this the authors consider that the concepts of both highlighting the important aspects, traps, and the critical points and hence, working with a concept one should carefully study its purpose, goals and vision in order to fully benefit from the knowledge they bring with them. Also, it is in the author's opinion important to view the concepts as philosophies and not tools. It has been pointed out, both in the authors' education and in literature, to embrace a concepts solutions and tools for the short term to achieve a particular result is an operation which should be avoided in the vast opportunity. In the long run, there is a risk of a lack of commitment and belief in what you do is for the better.

Education

It has been proven, both with the interactive assignment and interviews with various craftsmen that education is a welcomed aspect and something that is perceived to bring great opportunities. The feeling is that technology is proceeding and the issues are becoming more and more complex. As the production department has the ownership of all equipment, and together with the perception that the maintenance department be left out when it comes to investments, has also been shown to leave an impression that education becomes more prevalent.

As explained by Lindér (2006), do a person's reaction towards a task depends on three things, namely; Knowledge and skill, Individual efforts to develop and factors not correlated towards a certain task or work. Furthermore, according to the flow principle, a person feels a flow, and thus a will to perform, when the challenge and skill is proportional (Bergman and Klefsjö, 2010). The authors consider this to be sufficient argument in order to state that a well-formulated educational plan should be included in the strategy. It is believed that this is the difference between success and struggle when working with improvements.

As described by Rubenowitz (2004), the earlier the employees involved are educated and informed, the more the individual will experience the control of the situation and the ability to affect the employment relationship. The probability that the change then is seen as positive increases markedly thereof and commitment becomes the natural step.

Project Initiation

Merge a team to initiate the project whose main task is to manage the remaining steps in the CFM. It is important that the team consist of stakeholders from different levels of the company and also from both the production and maintenance department. The case study performed by Salonen (2009) showed that involvement from stakeholders may in turn contribute to higher cooperation between the production and maintenance departments, which the company's productivity will benefit from. Stakeholders, or customers, such as maintenance technicians and craftsmen are important to include in the team since they need to be satisfied in order for them to do a good work, which is supported by (Bergman and Klefsjö, 2010) In addition, their opinions and view of maintenance play a significant role for when to formulate a strategy since they are the ones who actually perform the work. According to Salonen (2009) is the achievement of the stated maintenance objectives affected by the stakeholders, which is further argument for stakeholder, or customer, involvement.

Focus areas and priorities

The project group shall together perform three activities in order to establish focus areas and priorities. As output from this step is a list of actions, priorities and activities.

- ***Perform a Gap analysis were the fishbone diagram is to be used as a foundation and guidance***

Address the gaps in maintenance performance, and identify the factors which may influence the gap between present state and desired state. The gaps should then be put in relation to factors which are considered to be strategic for the maintenance function development. The fishbone diagram includes several problem areas or gaps, and should therefore be used during this work. The result is a set of factors which preferably should be prioritized for when to improve the organization.

- ***Perform a SWOT analysis were the MDA result is to be used as a foundation and guidance***

As described by Salonen (2011) it is important during the formulation of a maintenance strategy to consider the company's strengths, weaknesses, opportunities and threats. The result from the

MDA addresses the company's strengths and weaknesses, and should therefore be used during this work. The SWOT analysis may result in a list of identified actions.

- ***Determine the KPI:s***

Based on theory presented by (Smith, 2004),(Wireman, 2010),(Salonen, 2011) KPIs are used as an assessment of critical or key processes, to measure the maintenance performance as well as the fulfillment of the strategic goals and to track where the organization is headed. It is therefore important that resources are dedicated to determine which KPIs to measure and follow.

- ***Determine success factors***

The team should determine the success factors for the transformation of the organization. The specific success factors and goals for the changes to be carried out are to be identified in this step, it is also important to establish methods to perform the transformation. Corroborated by (Larsson, 1993), (Karlöf and Lövingsson, 2005).

Kotter (1996) and Stanleigh (2007) points out several factors of why firms fail when transforming organizations, some of these factors are: not engaging all employees, allowing too much complacency, permitting obstacles to block the new vision, failing in the creation of a sufficiently powerful guiding coalition, telling people we have to change – we are in a crisis, underestimating the power of vision and failing to create short-term wins. These factors need to be evaluated and regarded by the team. The three critical success factors presented by (Waeyenbergh and Pintelon, 2002) should preferably also be taken into consideration:

1) The direct production personnel and the maintenance craftsmen and technicians need thorough knowledge of maintenance technology and competence to prevent disruptions early in the production process.
2) Management skills regarding maintenance planning and control tasks as well as human resources management are of major importance.
3) Flexibility to exploit trends and opportunities.

The organization transformation is far more than a technical project. Human change is involved, which is the hard part. It is crucial not to ignore change management on every level within the organization, supported by (Campbell and Reyes-Picknell, 2006).

Criticality Analysis

Perform a criticality analysis in order to establish which equipment and spare parts that are critical and thus, should be assigned the resources. When the financial planning, risk analyses and root cause analyses is performed the critical analysis result is used as an aid to know where to assign the resources. Also when the maintenance program is established is the criticality analysis result of great help.

- ***Critical Equipment***

When performing the criticality classification of equipment it is recommended to follow the equipment classification model proposed by (Börjesson and Svensson, 2011) and also the ABC classification described by (Ylipää, 2012). This is, in order to assess the need of maintenance and to optimize the maintenance activities (Ylipää, 2012).

- ***Critical Spare Parts***

When determining the criticality of spare parts it is recommended to use the spare parts model proposed by (Börjesson and Svensson, 2011) and also the ABC analysis which are described by for example (Gupta, 2009) and (Wireman, 2010).

Financial Planning

(Smith and Hawkins, 2004) argues that correct maintenance scheduling and planning procedures of maintenance resources contribute to a vast and rapid increase in understanding of what is required of maintenance resources. (Gupta, 2009) points out that the maintenance function must integrate five major factors in order to achieve optimum costs for upkeep and repair:

1. People
2. Policies
3. Equipment
4. Practices
5. Performance evaluation

In order to do so, financial planning is crucial.

- ***Life Cycle Cost - LCC***

In order to distinguish the best investment alternative, with regard to its total cost during its intended life span, LCC should preferably be used. LCC can also be used for when to find out when the asset no longer is profitable and it is time to recycle/scrap the asset. (Nord et al., 1996) points out that a calculated LCC for equipment's creates a better insight and profitability.

- ***Life Cycle Profit - LCP***

As mentioned earlier, maintenance have for a long period of time been viewed to be a cost driver and a necessary evil in order for production to be able to generate revenue. To illustrate the importance of a dedicated maintenance at an early stage LCC was presented and showed that maintenance could cost as much as 2-20 times the initial cost of a machine (Barringer, 2003). It is now desirable to illustrate how maintenance can generate profits in order to further enhance the reputation of maintenance activities. Here the LCP concept comes at hand. LCP denotes the capability of an asset to generate revenue. It is sensitive to disruptions in production and thus emphasizes the importance of maintenance (Ahlmann, 2002). It has also been demonstrated that LCC is to be considered in stable markets, while LCP provides a better picture in a market that is difficult to predict and it is dynamic in its nature, which also profit becomes ever more interesting (Ahlmann, 2002). The further the elaboration of maintenance reputation becomes, the authors believe that the importance of demonstrating revenue is becoming increasingly clear.

*When performing the following to steps; **Reliability engineering** and **Maintenance program**, it is important to consider the maintenance responsibilities, or tasks, and authorities. These need to be delegated and communicated to the employees; otherwise it won't be clear who is responsible for what or who has the authority to make decisions.*

Reliability Engineering

As described by NASA (2008), is a reliability centered maintenance approach to find the most applicable cost-effective maintenance technique to minimize the risk of impact and failure and to create a healthy working environment while preserving and protecting capital investments and their capability. According to Birolini (2010) is the purpose of reliability engineering to develop tools and methods to demonstrate and evaluate reliability, maintainability, availability, and safety component, for systems and equipment, as well as to support production and development engineers in order for them to build in these characteristics.

This can only be accomplished through maintenance engineering and identification risk analyses. Failures that already have occurred need to be investigated in order to find and eliminate the root cause to prevent that the failure occur again.

- ***Maintenance Engineering***

The maintenance engineering department needs to focus on reliability, maintainability and safety. In cooperation with production engineering should maintenance engineering design in reliability and maintainability into equipment, in balance with financial constraints. Analyses of current assets historical records concerning trends of types of failures, frequency of component failures, or root causes of failures should then be made. The information gained from the analyses can be examined further in order to determine how to eliminate the problem and reduce maintenance by changing a process or changing the design (Wireman, 2000).

  - ***EEM – Early Equipment Management***

The maintenance department should be involved from the beginning of a procurement of equipment process. Issues such as: accessibility, serviceability, safety, component standardization, interchangeability and modularization need to be addressed. Reliability is a design attribute and should therefore be "designed in" when the asset is designed and built. This is achieved by the use of reliable components, simplify replacements and ease inspections (Gulati and Smith, 2009). Assets must be designed to fail safely, designed for fault tolerance, designed with early warning to the user of the failure, have a built in diagnostic system to identify the location of the failure and if possible also designed to eliminate all or critical failure modes cost effectively (Gulati and Smith, 2009). The analyses proposed by (Gulati and Smith, 2009) should preferably be used during the design phase of new assets.

- ***Risk Analyses***

Proactive maintenance is, according to (Sasaya, 2009), based on theoretical risk analyses. Proper countermeasures based on the risk analyses are taken to avoid failures. As described by (Hinchcliffe and Smith, 2004) and (Bergman and Klefsjö, 2010) are risk analyses made in order to evaluate system and equipment weaknesses, its function, failure modes, failure causes and failure consequences, and also their interrelationships that can lead to product or process unreliability. This is to decrease the risk of failure and the effects of the failure which in turn lead to higher equipment reliability. It is suggested that resources are dedicated to perform risk analyses on critical equipment, and later also on the rest of the equipment.

- ***Root Cause Analyses***

As pointed out by (Monroe, 2010) is root cause identification within an organization the single most important determinant of failure or success of any problem-solving method. The goal of a root cause analysis is to understand not only “what” and “how” of a failure but also “why it happened”, it attempts to address all of the underlying causes of the failure and also to learn as much as possible from the occurred failure. By finding the root cause of problems, the understanding needed to solve the problems will be gained more easily. In turn, higher equipment reliability will be achieved.

  - ***Standardize***

Methods for the root cause analyses of failures are used to facilitate and standardize the work procedure during the problem resolution and also the documentation. If this is done in the correct way failures are eliminated or reduced, which in time can save significant costs. If these procedures are standardized the problem-solving and problem-finding procedures can continuously be improved and the work will be more efficient and less time consuming. It also ensures that a sufficient amount of data and information are documented from each analysis for future work, follow-up and as a ground for investment arguments.

  - ***Tools***

There are several tools that can be used to perform risk analyses and root cause analyses, some proposed for Volvo Trucks are: Plan-Do-Check-Act cycle, Failure Mode and Effect Analysis, Fault Tree Analysis, Root Cause Analysis, Five why analysis respectively Fishbone diagram. Only a few, preferably one for each type of analysis, should be selected. This is, to standardize.

Maintenance program

The maintenance program needs to be established in order to secure equipment availability and by that satisfy the external customer. The program which is established should be improved continuously, due to for example, occurring events and capacity changes. Root cause analyses and also risk analyses should continuously be performed, which also may initiate to maintenance program improvements.

When developing the maintenance program is it suggested to begin with analyzing equipment according to the six failure patterns:

- ***Six failure patterns***

According to (NASA, 2008), is the frequency of failure useful when determining maintenance intervals and for making cost decisions. The traditional view of failure is based on the assumption that most items operate reliably during a period of time and then wear out. The same traditional view suggests that extensive records about failure will enable the possibility to determine that period of time and perform preventive tasks shortly before the item fail. However, equipment is today in general far more complex than that and this has led to changes of that view and resulted in the patterns of failure which are referred to as “The six failure patterns” (Moubray, 1997), (NASA, 2008). Therefore, the authors suggests the team to consider the six failure patterns for when to assign developing the maintenance program to assets, i.e. to categorize the assets into any of the six patterns.

The maintenance program should thereafter be evaluated according to any of the following concepts in order to categorize the tasks and decide the approach:

- ***Operator Maintenance***

Operator maintenance means that maintenance tasks are carried out by the operator, tasks such as lubrication, cleaning and minor repairs may be carried out by the operator. At Parker Hannifin there was a well-functioning operator maintenance program, which provides the maintenance craftsmen with time to perform extensive and more complicated maintenance tasks and also to find and eliminate root causes. It is suggested that Volvo Trucks review their own machine park and develop an operator maintenance program. The documents which the operator use when performing maintenance tasks should preferably be visual and instructive, it should also include signature by the one performing the maintenance task. This is, to provide the maintenance craftsmen and technicians with the ability to communicate and discuss with the responsible operator about the maintenance performed, if necessary.

- ***Preventive Maintenance – PM***

As described by (Moubray, 1997), the preventive tasks mean replacing components or overhauling items at fixed intervals that is, to premature equipment damage and prevent unscheduled downtime that would result in repair or corrective activities. This approach to maintenance management is predominantly recurring or time-driven tasks performed to maintain acceptable levels of availability and reliability. By actively work with preventive maintenance, the downtime can be minimized, and therefore the productivity is maximized. The PM program is the key when improving the maintenance process. The amount of reactive maintenance is reduced by this program. It is therefore of major importance to insure good coverage of the equipment in the program.

It is suggested that Volvo review the current preventive maintenance program and ensure a good coverage.

- ***Corrective Maintenance – CM***

According to Ylipää (2012) and Moubray (1997) is preventive maintenance not always the best approach to choose. According to Moubray (1997) and NASA (2008) preventive tasks can create more damage than good for certain equipment by introducing infant mortality in an otherwise stable system. This is valid for equipment whose failure pattern does not depend on age and thus, do not have an identifiable wear-out age. The failure pattern curves C, D and E (Moubray, 1997) do not have an identifiable wear-out age. For equipment whose failure pattern follow pattern C, D or E and also is non- critical (established from criticality classification) a corrective maintenance, i.e. run-to-failure, program may be to prefer.

- ***Predictive Maintenance – PdM***

According to Moubray (1997) is predictive maintenance basically to check if something is failing or about to fail. The tasks are performed before a failure occurred and thereby the failure is prevented. Conditions that can cause deterioration and lead to failure are searched for in predictive maintenance. A predictive maintenance program includes condition monitoring. The project group should investigate the need and profitability of this type of program for critical and high cost equipment. This type of program is costly and therefore, in order for the program to be cost effective it should be determined for which assets condition monitoring equipment may be of great help and also profitable.

Control

Increased control of the maintenance organization may provide a reduction of costs.

- ***Data Management***

In order to control the maintenance organization are properly information about events that occur needed, supported by (Wireman, 2009). Data is the foundation to gain control and without effective data gathering cannot incidents be truly investigated, root causes cannot be solved, improvements is hard to perform and the optimal amount of spare parts is difficult to establish. Techniques and tools such as The Plan-Do-Check-Act cycle, Failure Mode and Effect Analysis, Fault Tree Analysis, Root Cause Analysis, Five why analysis and Fishbone diagram are suggested, it is recommended that one of two of these are picked out to be used by the maintenance organization to solve problems and improve the organization.

- ***CMMS***
  In order to control and manage maintenance tasks effectively a computerized maintenance management system is needed (Ylipää and Harlin, 2007) and (Wireman, 2009). Therefore, it is recommended to use a computerized maintenance management system which also presents data visual and is easy to use. That is, to facilitate the control of the maintenance organization and to ease the maintenance craftsmen's reporting efforts.

- ***Spare Parts***
  Keep the critical spare parts (established after criticality classification) available in storage to avoid unnecessary waiting time and costs due to for example transportation and ordering when it is needed. It is recommended that the maintenance department themselves control the inventory of spare parts with regard to criticality.

- ***Measure KPI:s***
  Measure the established KPIs continuously and present their values visually to the stakeholders. Discuss reasons why they are leading or lagging and assign resources to investigate the reason for the variation further in order to take proper action to improve maintenance performance.

- ***Maintenance Improvement***
  Maintenance should improve continuously, in order to create motivation among employees assign appropriate persons to lead improvements. It is crucial that management support and inspire to improvement efforts and also creates conditions to cooperation when working with improvements.

Follow-up of goals achievement

Bellgran and Säfsten (2010) argue that it is difficult to control and improve what is not measured and followed-up. The achievements of goals need to be followed up, the work performed need to be evaluated and if suitable should established methods and activities be corrected. After correction should results be followed-up again, first when results are satisfactorily the team moves on to the next step. To get guidance for this step, see "The effective stoppage" developed by Idhammar AB.

Maintenance Strategy

At this point are a strong foundation of data, results, methods and activities available in order for the organization to formulate the maintenance strategy. Together with internal and external customers; establish standards for how to work, which problem solving tools to use and how to document data. To gain guidance for this step, see "the Coor model" proposed by Coor Service Management. When the strategy is formulated it should be evaluated, modified and improved at sufficient intervals.

- ***Production strategic goals***

The maintenance strategy should be developed in alignment with the production strategic goals and representatives from the management of the production department should participate when the strategy is formulated. This is supported by a case study presented by Salonen (2009). The case study showed that stakeholder involvement may lead to a unanimous view on the maintenance department expected deliveries to the production department which may contribute to higher cooperation between these departments. The company's productivity will in turn benefit from this. Also, the ability of an organization to achieve its objectives is affected by the stakeholders.

5.2 Success factors for implementation of the maintenance strategy

The work highlights many different concepts and sections, all of which touch on the success factors that are considered important in the development of organizations. Among other things, it is shown in TPM that the first step in implementation is done through the management information. The attitude for change is the single most important aspect (Nord and Pettersson, 1997). It also highlighted in TPM of the importance that in the start use pilot projects and training, something that proved to be a recurring theme in literature.

As mentioned earlier, it is noted in many sources that a universal solution to implementation does not exists. Every organization is different and will be built with different conditions and issues, and will thus face different challenges during the implementation phase (Rubenowitz, 2004). It is the authors' opinion, clear that an implementation plan should be done by thorough knowledge of the organization, the culture within the workplace and cross-functional by the organization's various departments. Slack and Lewis, also states that taking into consideration the risks of change and how to prevent, isolate or work with a problem that might arise from the change. For this reason, according to the authors' opinion, this is a factor which should be taken into account within the company and highlighted at top management. Campbell and Reynes-Pickell (2006) also shows that the implementation plan should first be considered when the strategy is in place.

Furthermore, the report shows which factors are decisive for change. What is highlighted throughout the report, and used in most parts, is change management, which also is highlighted as the single most important aspect (Campbell and Reynes-Pickell, 2006; Nord and Pettersson, 1997; Kotter, 1996). Organizational affects most employees, which also means that there are many opinions to consider and try to get along.

Onwards, the implementation phase is in some respects not a project, but rather a program. Slack and Lewis suggest that the difference is that a project has a beginning and an end, has defined targets and using defined resources. Major change programs can therefore be reconsidered as a program, without defined start and end points. It is an ongoing change. A critical factor is that one does not believe the change comes by itself rather sees the work change as constant to improve, and be competitive.

Another factor that the authors feel is crucial is feedback, both from internal customers as well as external customers. The implementation should document their stakeholders as these, which Slack and Lewis points out, can have a decisive influence on the change and thus never should be ignored. This area may also be politically sensitive within the company, stakeholders and support within the hierarchy may therefore prove to be decisive factors. Among other things, also noted, the ability to implementation in an initial stage, may display as negative economically, in this case, the authors view also is strengthened, the more significant supported within the hierarchy and by the stakeholders, the smoother the transition will be.

5.3 Maintenance Department Analysis – MDA and Client Needs Analysis - CNA

Both the MDA and CNA are tools to be used for benchmarking and determining potential improvement areas. The questions are not comparable but both results in an overview of current status, in terms of maintenance and asset management. The fact that both analyses resulted in equal average score shows that the credibility of the analyses are rather high.

The CNA is equally divided into four areas; Strategy, Work identification, Work control and Work execution. The first two areas concern a strategic level while the two later areas concern a tactical level. The MDA is not divided in the same way. The MDA is instead divided with regards to the different areas that the maintenance department manages, which reflects the aspects that, according to Wireman (2010), the maintenance management comprise. The questions within the MDA compared to the CNA are that the MDA reflects also on the company culture. The CNA is used not only to analyze a maintenance organization but also to provide consultancy services. The MDA is used only to analyze one’s own and other maintenance organizations in order to find where the major improvement areas are within one’s own organization and to do a comparison with other organizations. The execution phases of the MDA and CNA in this thesis work differ. The MDA was executed by personal interviews with the maintenance manager at each company which made it possible to discuss around the questions, while the CNA was sent to the maintenance department at Volvo Trucks where a competent employee answered the questions under the responsibility of the maintenance manager.

5.4 Reliability and validity of methods and results

The following discusses reliability and validity of the performed methods, and the results obtained in the work.

5.4.1 Reliability

The thesis has performed a present state analysis on the maintenance department at Volvo trucks. This was performed by a workshop, internship week, interviews and through the use of maintenance department analysis (MDA) and client need analysis (CNA). Regarding the stability of these methods, it must be noted that these are not stable. Stability is obtained if the method can be performed in the future and obtain the same result, but as the maintenance organization is constantly evolving (the same applies to the employees), it is likely that at a future survey responses also is developed and obtained new results thereof. This should not be considered as negative, and the hope is that through the use of the customer focused model the elaboration would prove more profitable opportunities.

In the case of internal reliability, this is always a factor to be taken into account. To be internal reliable, answers shall not affect the responses to each other. Hence, this is always a problem in interviews. In this case, however, the interviews carried out semi-structured, which meant that the opportunity has existed to ask supplementary questions. Of this reason, the responses are seen as internal reliable. Furthermore, in inter-observed consistency, it is possible that the authors' interpretations influenced the answers. As our interpretation may also be affected by each other the risk is then larger of the categorization responses are affected. It is our hope that this has not been the case, but the authors cannot guarantee this fully.

5.4.2 Validity

The literature described in the thesis is considered too be validated through the use of face validity, meaning that it has been examined by experts within the area; for example, during the presentation at SKF for the SMGC strategy group, but also through the support from the authors tutors.

For validation of the methods and results, it is considered that both parts have been validated through face validity. In addition, the present state analysis of Volvo is validated using both the maintenance department analysis (MDA) and the client needs analysis, (CAN) forms, resulting in convergent validity. This is also the case with interviews, workshops and internship week considered three different methods to validate the present state analysis. However, it should be noted that the benchmarking exercise carried out on the other companies could not be validated under the same conditions, as the authors here do not have access to the data in the same opportunity. The answers can therefore not be validated as far as desired, but our hope, and belief, is that the responses were honest.

Thus to conclude, the literature, methods and results, are considered by the authors to be both reliable and valid. In the case of the external benchmarking, it must unfortunately be said that these could not be validated in the desired amount, Due to the nature of the transparency of these companies. The stability of these answers is nor not high, however, this is natural, due to the fact that the organizations evolve, and thus not something that is considered to be a problem.

6 CONCLUSION

The purpose of this thesis is to develop a model for the formulation of a maintenance strategy and in order to do so have three research questions been formulated. These three questions are aimed at grasping the key objectives of the thesis and also to function as guidance along the way of developing the model.

The three research questions are the following:

1. *What is the present state of the maintenance department at Volvo Trucks, and what is the desired state?*
2. *Where do Volvo Trucks maintenance department stand in comparison with companies within similar industry segment, and what can Volvo Trucks learn from these companies?*
3. *What obstructs the maintenance department from achieving the desired state?*

The maintenance department at Volvo Trucks consists mainly of a fire-fighting or reactive approach, events and failures choose the direction. The Maintenance Department Analysis (MDA) developed in this thesis is a tool for analyzing the maintenance department and should preferably be performed with an interval of once or twice per year in order to follow-up changes and update the present state. The result from the MDA shows that the areas at Volvo Trucks in which there is greatest potential for improvement are education, financial planning, reliability engineering and preventive maintenance. In addition, the need and profitability for a predictive maintenance program may be determined in order to further develop the organization and the maintenance work.

More frequent and maintenance focused education opportunities for the maintenance craftsmen concerning new technology in assets will contribute to a higher level of efficiency and effectiveness for the maintenance work. The management should encourage the craftsmen’s ideas and utilize the competence they possess. This will also engage and motivate them to improve the organization which will facilitate reaching the desired state – a proactive environment. It is also essential that education concerning the ongoing changes within the organization is provided so that the customers gain knowledge about what is changing, why it is changing and what the objective of the change is. Otherwise, the resistance to change will most certainly be high. Therefore, education is an essential part in the Customer Focused Model (CFM). In order to improve the financial planning area the approaches ‘Life Cycle Cost’ and ‘Life Cycle Profit’ are highlighted in the CFM. There is a possibility to increase and highlight the cooperation between the maintenance and production department. The maintenance department needs to be involved at an early stage when new equipment is purchased in order to design reliability and maintainability into equipment. The step reliability engineering is included in the CFM to stress the importance of reliability and maintenance engineering. Reliability engineering with corresponding approaches is described thoroughly in the description of that step. The next step in the CFM is maintenance program. This area is included due to the MDA result which showed improvement potential within preventive and predictive maintenance. This step includes evaluation of failure patterns and a number of different types of maintenance programs, and the maintenance program need to be improved continuously.

The proposed CFM is a guidance for how to reach the desired state – a proactive environment, and the importance of cooperation with the customers during the journey towards world class manufacturing cannot be emphasized enough. Today is Volvo Trucks maintenance organization on average further away from a proactive environment compared to the companies included in the study. There exist a certain “home blindness” at all benchmarked companies, and to perform study visits may be good for every company. That is to gain inspiration and ideas for how to improve one’s own company, also the internal customers i.e. maintenance craftsmen and technicians should participate during the study visits.

The CFM has been developed primarily from the factors the authors found to obstruct the maintenance department from achieving the desired state and thus, it is a guidance and aid during the ongoing changes. Together with Volvo's expertise and experience within the own organization and the area of maintenance it is hoped that the model will function as a bridge when developing and improving the organization to reach the vision.

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Appendix I – Questions supporting interviews with maintenance craftsmen

1. How many maintenance technicians work at the department?
2. What is your own opinions concerning the maintenance work at your department? (Regarding workload, work pace, delays etc.)
3. Do you consider the tools/equipment supporting the work are high-quality and sufficient?
4. Is education provided for the maintenance department? (Concerning new technology, new machines etc.)
5. Do you consider your competence to be sufficient regarding the work you perform?
6. If you can't restore equipment, how do you proceed?
7. Do you consider the technicians to have sufficient competence?
8. Is there a maintenance schedule to follow over the work to be performed? If yes, in what interval is the schedule written?
9. When the work is completed, who reports the consumed time, the supply, downtime and other information?
10. Who do you report to?
11. The preventive maintenance program includes what among the following:
    A. Checklist lubrication
    B. Detailed checklists for inspections
    C. Employee responsible for the work
    D. Diagnostics such as vibration analysis and oil sample analysis
12. Are spare parts always in storage when needed?
13. Do operations personnel generate work order requests?
14. Are operations personnel involved in the maintenance work?
15. Are root causes clearly identified?
16. Do you work with continuous improvements? Do the organization support continuous improvements efforts?

Appendix II – Preserve system function

Compare two separate fluid transfer trains and each train has redundant legs, these trains are in a process plant. Train A pumps with a capacity of 100 percent in each leg and train B pumps with a capacity of 50 percent in each leg. The plant manager tells the maintenance director that the budget allow PM tasks on either train A pumps, or train B pumps, but not both. What should the maintenance director do? Clearly, if the director does not think function, there is a dilemma, since the background of a maintenance director says that his job is to keep all four pumps up and running. So, if the director think function, it is clear that the defined resources need to be devoted to the train B pumps due to that loss of a single pump reduces capacity by 50 percent. A loss of one pump in train A conversely, does not reduce capacity at all, and also most likely allows a sizeable grace period to bring the failed pump back to operation.

Appendix III – Maintenance department analysis

Maintenance Organisation

1. *A chart over the Maintenance organization*
   A. Updated and completed - 4 pts
   B. Not completed or over one year old – 3 pts
   C. Not updated and not completed - 2 pts
   D. Don't exist – 0 pts
2. *The maintenance departments responsibilities and work are:*
   A. Fully documented – 4pts
   B. Clear, well communicated and have good coverage but are not fully documented – 3 pts
   C. Informally supervised and coordinated, there are gaps in job coverage – 2 pts
   D. Not clear, there are unclear lines of authority, jurisdiction – 0 pts
3. *The usability and clarity of the maintenance organization's document management system is:*
   A. Excellent – 4 pts
   B. Good – 3 pts
   C. Average – 2 pts
   D. Poor – 1 pt
   E. Very poor – 0 pts
4. *How is the organizational support to continuous improvements efforts?*
   A. Strong – 4 pts
   B. Moderate – 3 pts
   C. Weak – 2pts
   D. None – 0 pts

Education Programs within Maintenance

5. *Education for employees with planning responsibility*
   A. Educations have been provided to all with planning responsibility, one or more seminars dedicated to planning and scheduling – 4 pts.
   B. Documents regarding planning and scheduling have been provided to support the planning work – 3 pts.
   C. Training is provided to new planners by supervisors for at least the first month – 2 pts.
   D. No training is provided – 0 pts.
6. *Education concerning new technology and changes in equipment is provided to the maintenance craft employees at the frequency of:*
   A. Less than one year – 4 pts
   B. From 12 to 18 months – 3 pts
   C. Not to all employees, but to some in any of the above frequencies – 1 pt
   D. No education is offered – 0 pts

7. *Maintenance competence and work quality of performed maintenance tasks are considered to be:*
   A. Excellent – 4 pts
   B. Good – 3 pts
   C. Fair – 2 pts
   D. Poor (major improvement required) – 1 pt
   E. Unsuitable – 0 pts

Maintenance Work Orders

8. *What percent of the total amount of work orders that is processed in the system are tied to an asset/ equipment number?*
   A. 100% - 4 pts
   B. 75% - 3 pts
   C. 50% - 2 pts
   D. 25% - 1 pt
   E. Less than 25% - 0 pts
9. *What percent of the total number of maintenance man-hours are reported to a work order?*
   A. 100% - 4 pts
   B. 75% - 3 pts
   C. 50% - 2 pts
   D. 25% - 1 pt
   E. Less than 25% - 0 pts
10. *What percent of the amount of work carried out is covered by work orders?*
   A. 100% - 4 pts
   B. 75% - 3 pts
   C. 50% - 2 pts
   D. 25% - 1 pt
   E. Less than 25% - 0 pts
11. *What percent of the total amount of work orders are available for historical data analysis – follow up?*
   A. 100% - 4 pts
   B. 75% - 3 pts
   C. 50% - 2 pts
   D. 25% - 1 pt
   E. Less than 25% - 0 pts
12. *Which of the following categories are covered in a work order? Add one point for each.*
   A. Required downtime
   B. Required craft hours
   C. Required materials
   D. Requestor's name

Maintenance Planning and Scheduling

13. *What percent of the total amount of work orders have been delayed due to poor or incomplete plans: (previous year)*
    A. Less than 10% - 4 pts
    B. From 10% to 20% - 3 pts
    C. From 21% to 40% - 2 pts
    D. From 41% to 50% - 1 pt
    E. More than 50% - 0 pts
14. *Responsibility for planning the preventive work orders rests on?*
    A. A dedicated maintenance planner – 4 pts
    B. A maintenance technician – 2 pts
    C. There is no responsible person, anyone can do it – 0 pts
15. *When the maintenance job is completed, who reports the actual working time, used material, downtime, and other data?*
    A. The craftsmen that performed the job – 4 pts
    B. The supervisor of the group – 3 pts
    C. Anyone else – 2 pts
    D. Data is not recorded – 0 pts

Preventive Maintenance

16. *To what extent does the preventive maintenance program cover critical equipment? [%]*
    A. At least 90% – 4 pts
    B. From 75% to 89% - 3 pts
    C. From 60% to 74% - 2 pts
    D. From 40% to 59% - 1 pt
    E. Less than 40% - 0 pts
17. *What percent of the PM program is annually checked against corresponding item's history to ensure good coverage of the program? [%]*
    A. At least 90% – 4 pts
    B. From 75% to 89% - 3 pts
    C. From 60% to 74% - 2 pts
    D. From 40% to 59% - 1 pt
    E. Less than 40% - 0 pts
18. *The frequency of the preventive maintenance program is based on:*
    A. The actual condition of equipment – 4 pts
    B. A combination of equipment run time or condition based, and fixed calendar interval – 3 pts
    C. Run time only – 2 pts
    D. Calendar intervals – 1 pt
    E. The program is dynamic and scheduled based on completion date of previous task – 0 pts

19. *What percent of the total amount of work orders have been generated from preventive maintenance inspections? (previous year) [%]*
    A. At least 80% - 4 pts
    B. From 60% to 79% - 3 pts
    C. From 40% to 59% - 2 pts
    D. From 20% to 39% - 1 pt
    E. Less than 20% - 0 pts

Maintenance Inventory and Purchasing

20. *The availability of critical spare parts is in storage to which extent? [%]*
    A. More than 95% - 4 pts
    B. From 90% to 95% - 3 pts
    C. From 80% to 89% - 2 pts
    D. From 70% to 79% - 1 pt
    E. Less than 70% - 0 pts
21. *Who controls the inventory of spare parts?*
    A. Maintenance – 4 pts
    B. Anyone else – 0 pts
22. *To what extent are the maximum and minimum levels for stored materials specified? [%]*
    A. More than 95% - 4 pts
    B. From 90% to 95% - 3 pts
    C. From 80% to 89% - 2 pts
    D. From 70% to 79% - 1 pt
    E. Less than 70% - 0 pts

Maintenance Automation – Computerized maintenance management system (CMMS)

A CMMS system can be utilized by the maintenance department to control and manage the maintenance function. The system is designed to collect all maintenance related data and file it into corresponding equipment's history.

23. *What percent of all maintenance operations utilizes CMMS at present? [%]*
    A. At least 90% – 4 pts
    B. From 75% to 89% - 3 pts
    C. From 60% to 74% - 2 pts
    D. From 40% to 59% - 1 pt
    E. Less than 40% - 0 pts
24. *To what extent is CMMS data structured and updated? [%]*
    A. At least 90% – 4 pts
    B. From 75% to 89% - 3 pts
    C. From 60% to 74% - 2 pts
    D. From 40% to 59% - 1 pt
    E. Less than 40% - 0 pts

Operator Maintenance

25. *What percent of the total amount of operations personnel generate work order requests? [%]*
    A. At least 90% – 4 pts
    B. From 75% to 89% - 3 pts
    C. From 60% to 74% - 2 pts
    D. From 40% to 59% - 1 pt
    E. Less than 40% - 0 pts
26. *Which of the following tasks are operators are trained to perform? Add one point for each.*
    A. Inspections
    B. Lubrication
    C. Minor maintenance task
    D. Assist in maintenance repair work

Maintenance Reporting

27. *Add one point for each of the following reports you produce for each equipment:*
    A. Equipment downtime arranged from highest to lowest number of hours (weekly or monthly)
    B. Equipment downtime arranged from highest to lowest in total lost production income (weekly or monthly)
    C. Maintenance cost for equipment arranged highest to lowest cost (weekly or monthly)
    D. MTBF and MTTR for the equipment

Predictive Maintenance

Terminology clarification: When performing predictive maintenance, the actual operating condition of equipment and systems are monitored. Equipment is used to monitor the condition of other equipment, for example changes in vibration characteristics or changes in temperature, and these techniques are known as *condition monitoring (Moubray, 1997)*.

28. *Does a predictive maintenance program exist? (If no, continue to question 32)*
    A. Yes – 4 pts
    B. No – 0 pts
29. *Does the predictive maintenance program include condition-based monitoring?*
    A. Yes – 4 pts
    B. No – 0 pts
30. *Is preventive maintenance, and corrective maintenance, work orders generated from the predictive maintenance program?*
    A. Yes – 4 pts
    B. No – 0 pts
31. *Is the data gained from the predictive maintenance program used to improve asset performance and asset life expectancy?*
    A. Yes – 4 pts
    B. No – 0 pts

Reliability Engineering

32. *To what extent is risk analyses used? [%]*
    (The percentage of the facility's equipment which is analyzed with a method intended to evaluate and minimize risks)
    A. At least 90% of the assets – 4 pts
    B. From 75% to 89% of the assets – 3 pts
    C. From 60% to 74% of the assets – 2 pts
    D. From 40% to 59% of the assets – 1 pts
    E. Less than 40% of the assets – 0 pts
33. *Is RCM methodology used on critical equipment to adjust or refine the PM/PdM program?*
    A. Yes – 4 pts
    B. No – 0 pts
34. *To what extent are failures clearly identified to its root cause? [%]*
    A. At least 90% of all failures – 4 pts
    B. From 75% to 89% of all failures – 3 pts
    C. From 60% to 74% of all failures – 2 pts
    D. From 40% to 59% of all failures – 1 pts
    E. Less than 40% of all failures – 0 pts

35. *The cause of failures can accurately be tracked by work order history to which extent?*
    A. At least 90% of all failures – 4 pts
    B. From 75% to 89% of all failures – 3 pts
    C. From 60% to 74% of all failures – 2 pts
    D. From 40% to 59% of all failures – 1 pts
    E. Less than 40% of all failures – 0 pts
36. *Is failure analysis conducted by the use of an analysis tool such as fishbone, tree, five why's or Pareto, to assure accuracy and standardization for each analysis?*
    A. Yes – 4 pts
    B. No – 0 pts
37. *Are failure frequencies calculated according to "The Six Failure Patterns" included in the RCM methodology?*
    A. Yes – 4 pts
    B. No – 0 pts
38. *Are any certain software (ex: Reliasoft, Relex etc.) used for calculating failure frequencies and other calculations?*
    A. Yes – 4 pts
    B. No – 0 pts

Maintenance – Key Performance Indicators

39. *To what extent is OEE calculated to monitor the condition of critical equipment? (Asset Management) [%]*

A. 90% or more – 4 pts
B. 60 to 89% - 3 pts
C. 30 to 59% - 2 pts
D. Less than 30% - 0 pt

40. *Is the extent of downtime in relation to total production time for the facility/equipment due to corrective maintenance known by the company?*
    (The proportion of production time that equipment has been down due to emergency corrective maintenance, including waiting time).
    A. Yes – 4 pts
    B. No – 0 pts
41. *Is the percentage of the maintenance cost that consists of preventive maintenance known by the company?*
    (Cost of preventive maintenance/Total maintenance cost) x 100
42. *Is the proportion of total number of maintenance man-hours devoted to emergency corrective maintenance known by the company?*
    (If operations personnel conducted emergency corrective maintenance shall that time be included)

Financial planning

43. *Is the concept 'Life cycle cost' or similar regarded when initial investments are planned?*
    A. Yes – 4 pts
    B. No – 0 pts
44. *Are assets 'Life cycle cost' utilized and taken into account when its condition is determined?*
    A. Yes – for all equipment – 4 pts
    B. Yes – only for critical equipment – 2 pts
    C. No – 0 pts
45. *How do you want to classify your organization's financial knowledge regarding condition determination and classification of assets?*
    A. The organization has extensive knowledge – 4 pts
    B. Limited knowledge – 2 pts
    C. Low or no knowledge – 0 pts

Appendix IV – Justification to questions – MDA

Maintenance Organization

1. The maintenance organization is either an enabler or disabler to success (Wireman, 2010). An updated and complete chart of the maintenance organization gives a comprehensive view of the organization. It can be used as an aid when to improve, reorganize and change the organization as well as when planning the weekly or monthly maintenance work.
2. In order to clearly develop an organization and an individual person, it is important that each and every employee are secure with his/hers obligation. Thus, it is important that one knows the basis for what is expected from the employees work.
3. There are numerous documents to handle during the life cycle of equipment (Wireman, 2010). The data is easier to handle if presented clearly and time is saved if it is easy to perform documentation. Keep it clear and simple.
4. Continuous improvements isn't one person's obligation, it is very much an effort needed from the entire organization. If the individual employee recognizes the importance by the actions of the management, it is more likely that improvement work will be successful and most important long termed secured.

Education Programs within Maintenance

5. Management's reluctance to realize that planners are a prerequisite for a successful maintenance program is one of the major obstacles to maintenance planning and scheduling. The planners provide logistic to support the maintenance craft workers. Responsibilities may be: Plan, schedule and coordinate maintenance activities, develop weekly schedule, ensure that maintenance related data are complete and updated, and also identify, analyze, and review equipment maintenance problems with maintenance engineering. Poor planning increases the craftsmen's work and frustrations. Education within the fields priorities, reporting, project management, inventory management, scheduling techniques and computer basics are essential for achieving the level of proficiency necessary for a successful planning and scheduling program (Wireman, 2010).
6. New technology is continuously being installed in factories. In order for the maintenance craft to maintain and repair this new high-tech equipment it is crucial to provide education concerning new technology and changes in equipment (Wireman, 2010). Smith (2004) recommends that each employee receives at least 100 hours per year in education.
7. Some workforces fall behind in technical skills due to the present rate of technology change. Many organizations have aging workforces and the skill level of those entering the workforce lie below the necessary skill standard (Wireman, 2010). It is therefore important to have knowledge about the skill level of one's own workforce.

Maintenance Work Orders

8. The use of work order systems to initiate, track, and record all maintenance activities are involved when to document and track performed maintenance work. True analyses can never be performed and data will be lost if this discipline is not in place. Effective planning

and scheduling can start if the work-order system tracks all activities corresponding to each asset. The equipment history is built from the work order history file, and budget projections, equipment repair forecasts, labor needs etc. are based on these files (Wireman, 2010).

9. See previous
10. One of the keys for successful maintenance management is work orders. Work orders are documents which are used to collect necessary maintenance information (Wireman, 2010). It is therefore important that all work is covered by work orders, otherwise the work won't be documented which will cause lost data for future analyses.
11. The work order is a key document to collect maintenance information. To be able to improve the maintenance procedures it is crucial with access to historical data. Trends, developments and changes are considerably more difficult to detect if equipment history data are not available.
12. The greater the extent covers by work orders, the longer the company has come with their preventive maintenance work.

Maintenance Planning and Scheduling

13. This question directly reflects how well the planning of the organization is performed and also the planners' insight of the work load. Controlled work reduces waste and planned work therefore costs less to perform than unplanned work (Wireman, 2010).
14. Not dedicate maintenance planners to plan and schedule maintenance activities is a great mistake. A planner has a full-time job, where approximately 80% of their time is expected to be spent on paper and computer work while only about 20% spent on the floor (looking over equipment parts or spare parts). The planner responsibilities are both important and time-consuming. The planners need to have good craft skills in order to be effective in planning the job (Wireman, 2010). See also question 5.
15. To get the most accurate and reliable data it is important that the one who have the most information about the completed job also reports it, and this person should preferably be the one who performed the job.

Preventive Maintenance

16. According to (Börjesson and Svensson), determination of the equipment criticality should be based on the cost of past events. This type of foundation for prioritization guarantees that maintenance resources are continuously focused on equipment which causing the most harm to the organization. A more robust production will be obtained by continuously improving the most critical equipment. By actively work with preventive maintenance, you can minimize downtime, and therefore also maximize productivity. The PM program is the key when improving the maintenance process. The amount of reactive maintenance is reduced by this program (Wireman, 2010). It is therefore of major importance to insure good coverage of the equipment in the program.
17. See previous.

18. If the frequency of the preventive maintenance program is not based on accurate estimates the result may be over- or under scheduling which in turn lead to missed PM or altered frequencies and, ultimately, breakdown or a failure.
19. This question shows how effective the PM program is as well as how preventive the maintenance environment is. If PM inspections does not generate any work orders than it is possible that the program need adjustments.

Maintenance Inventory and Purchasing

20. Downtime due to absence of spare parts may cost the company more than having the part at stock. It is therefore important to have a clear trade-off and to be able to justify its decision
21. The right parts must be provided at the right time. The maintenance personnel are the ones which know best which parts are needed and how often, it is therefore to prefer that a dedicated maintenance employee controls the inventory of maintenance items.
22. To have an upper and lower level of quantity for a spare part, can be seen equally to a reorder point system. The current level is compared to the reported number in stock. This is a way to secure availability but to a minimized warehousing cost and order costs (Stig-Arne Mattson, 2004).

Maintenance Automation – Computerized Maintenance Management System (CMMS)

23. The utilization of CMMS facilitates the collection, processing, and analysis of the data.
24. In order for the company to be effective in CMMS system usage it need to be complete utilized and the data need to be accurate and updated. Furthermore, a system which structures and visualizes the data clearly is a prerequisite in order for it to be useful (Wireman, 2010). An easy to access database will facilitate the usefulness of the historical data.

Autonomous Maintenance

25. The operations personnel are on place and have big knowledge about the equipment which they operate. It is therefore an advantage if they themselves can generate work orders. This is to save time and to decrease the impact of failures. Furthermore, if operations personnel get authority to generate work order they will probably be more observant.
26. In order for the maintenance department to focus on extensive problems and to develop their knowledge for maintaining and repairing equipment strategic, operator/autonomous maintenance is a vital part. The higher the operators knowledge is, and the greater competence he/she have, less the maintenance have to deal with these simple tasks which only will take time.

Maintenance Reporting

27. The reports provide management with information needed to manage and control the maintenance function (Wireman, 2010).

Predictive Maintenance

28. See definition in the form.
29. Condition-based monitoring solves or mitigates chronic equipment problems (Wireman, 2010).
30. The condition of an asset is monitored by small equipment and systems checking the asset for, for example, vibrations, oil, temperature etc. When implemented correctly one can receive work orders directly and continuously from the condition based equipment/system.
31. If the problems are detected early and even before occurring, the data can be used to improve the asset performance and the life cycle of the equipment can be extended. This will save both time and money due to both fewer failures and less frequent investment.

Reliability Engineering

32. A risk analysis is made in order to reveal possible failures (evaluate the inherent reliability) and predict the effects which the failure will have on the system as a whole. This is useful in order to pinpoint potential areas for reliability improvement or if not possible, identify possible failures and take action to mitigate the effects before the failure occurs (Reliasoft, 2012), (http://media.wiley.com/product_data/excerpt/60/04705173/0470517360.pdf, 2012).
33. When risk analyses are performed it is preferable that actions are taken in order to sustain the function of equipment, these actions should be included in the PM/PDM program.
34. If failures are not identified to its root cause then the real failure won't be solved, only the symptoms, therefore the same failure cannot be prevented from reoccurring. In order to really eliminate failures the root causes need to be found and eliminated. A variety of methods such as fishbone diagram, 5 why and tree diagram may be used for this.
35. Future work to prevent and work towards reducing causes of failures will be difficult if the root causes are not documented in the work order history.
36. Methods for the root cause analyses of failures are used to facilitate and standardize the work procedure during the problem resolution and also the documentation. If this is done in the correct way failures are eliminated or reduced, which in time can save significant costs.
37. Reliability can be described as the probability that an item don't fail during a given operating period. The six failure patterns included in the RCM methodology measures the probability that an item will fail during a given age interval and that probability is called the conditional probability of failure. The conditional probability of failure curves fall into six different failure curves, hence the name "Six Failure Patterns", and reflects the overall adverse effect of age on reliability. To categorize item into any of these patterns is useful when determining maintenance intervals and making cost decisions (NASA, 2008).
38. Software facilitates the reliability analyses and calculations (Reliasoft, 2012.

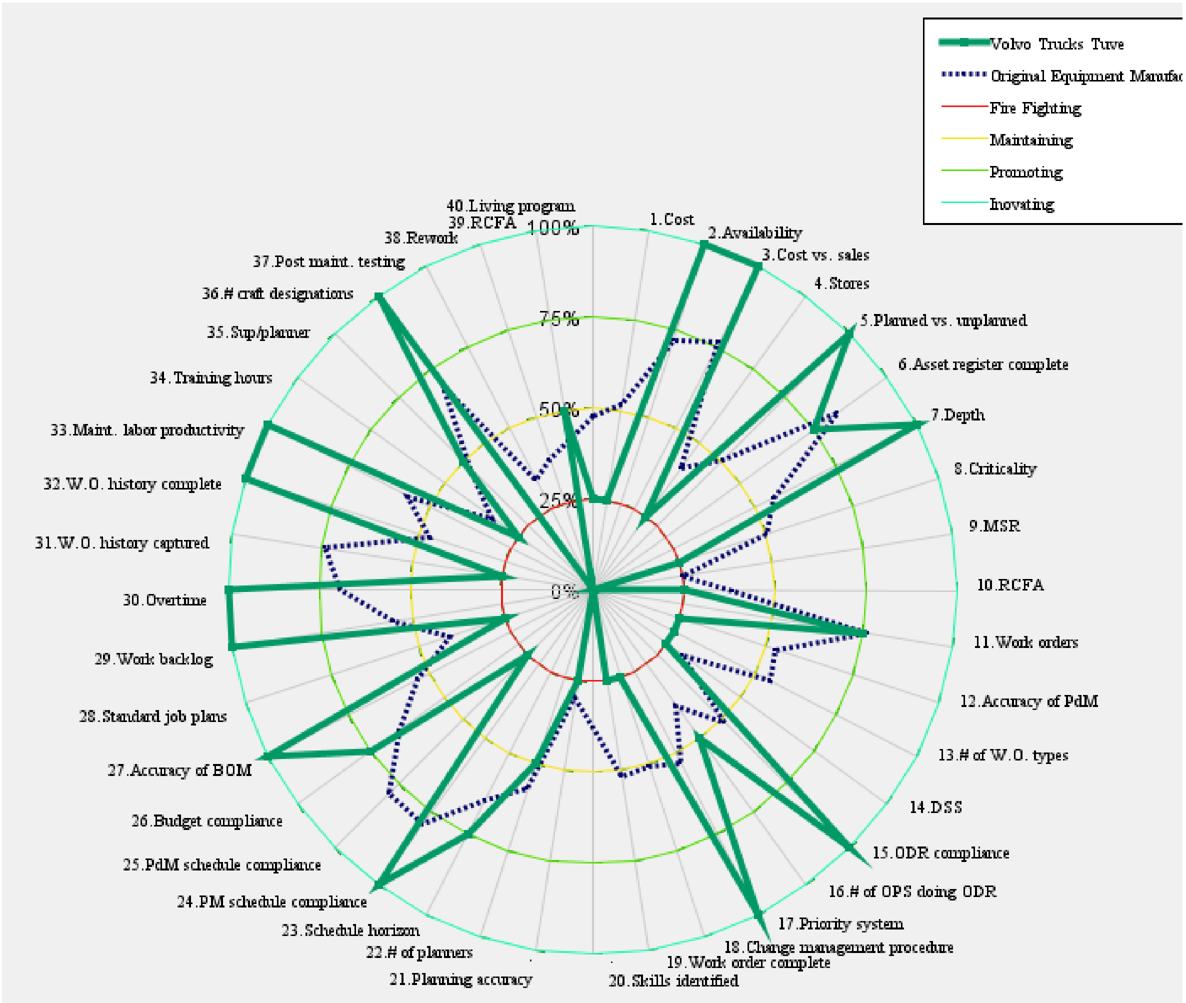
Maintenance - Key Performance Indicators

39. OEE is a method to understand the performance of the manufacturing area, but also to identify possible limitations (Hansen, 2002). A low OEE can indicate that the equipment are run in a wrong manner, or simply that something is wrong. It might thus be preferable to monitor the OEE.
40. Reactive maintenance has in many cases a much higher final cost than a preventive maintenance. Preventive maintenance has also in many cases the ability to minimize the downtime for an asset. Of this reason, knowing how much time is spent on a reactive behavior can determine the actual effectiveness of the maintenance work.
41. The question is of importance to firmly know how preventive the maintenance department is. A higher ration should be indicated in actual time spent on reactive jobs.
42. The question seeks to observe if the organization is aware of how much time, and to some extent money, that have been spent. As with all key performance indicators, these are to be monitored and a single answer doesn’t support any value, but a trending answer will.

Financial Planning

43. Life cycle cost is the cost of an item in its intended application during its entire life period (New South Wales Treasury, 2004). Thus, the objective is to distinguish the best investment alternative, with regards to its total cost during its intended life span. This knowledge will save money, time and increase reliability for the process.
44. LCC involves acquiring, utilization, maintenance, recycle/scraping of the asset. LCC summarizes the constituents’ total estimated costs during its life span and discounting to present day, or time of initial investment (Barringer, 2003). As described in asset management, with increasing age, reliability decreases for the asset, consequently the maintenance cost increase. By knowing the LCC of an asset and by knowing the state in which the asset performs discussions concerning continual maintenance in relation to new investment facilitates.
45. An organization with low economical knowledge might be limited when it comes to investments. To firmly understand the economic impact of one’s action, will improve the ability to affect them.

Appendix V – Polar Diagram from Client needs analysis



Appendix VI – Pareto Chart from Client needs analysis