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Master’s Thesis

Application of the ”Maintenance Loop” for land-based manufacturing

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Abstract

The maintenance function is an important part of any organization that possesses tangible assets. Whether it is machinery, buildings, equipment, or others, maintenance of these assets are vital to enable them to deliver as intended. In this thesis the focus is on maintenance of industrial production machinery and equipment. The literature on the topic of industrial maintenance is extensive, and there are lots of different frameworks and strategies proposed to enhance the performance of the maintenance function.

In this thesis the model of the Maintenance Loop, developed by the Norwegian Oil Directorate in the late 90s, are used to assess the performance of the maintenance function at Benteler Automotive Farsund. The model divide the maintenance function into 11 elements. For these 11 elements, the current status, problems and challenges, and finally, improvement potentials and future goals were identified.

The results show that a thorough review of the maintenance function like the one performed in this thesis will reveal much information and several minor improvement potentials not visible by the naked eye.

From the results of this thesis it can also be seen clearly how important it is to have a properly functioning Computerized Maintenance Management System (CMMS) at hand, and how important good communication is to be able to work efficiently.

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Chapter 1

Introduction

1.1 Benteleer Automotive Farsund

The history of what today is named Benteler Automotive Farsund started in 1996. The factory was established as a joint venture between Alcoa and CMI, with the main purpose of supplying Volvo with hollow core subframes. In January 1998 the production started. Over the years the plant have supplied customers like Ferrari, Porsche, BMW, Daimler, and more, with complex aluminum alloy castings. Plant name and ownership has changed multiple times, and the company even suffered a bankruptcy in 2009, followed by a re-start later the same year. In 2012 the German based Benteler Automotive bought 100% of shares in the plant, and the name were changed to Benteler Automotive Farsund (in the following termed BAF).

Currently the plant employs about 300 workers, and in 2014 the total turnover were 419 mill. NOK. Figure 1.1 shows the $23000m^2$ production facility.

The process of production and product quality control includes 7 steps:

- Sandcore Production
- Casting
- Core Knock-out
- Cleaning/Processing
- X-ray (ADR)
- Heat Treatment
- Crack and Dimension Control

These steps all have high quality requirements and include complex machinery. In addition to this machinery, the facility houses an advanced overhead conveyer system carrying the parts from station to station, and a complex system of tempered flow lines and vessels for distribution and storage of liquefied aluminum alloy.

Fig. 1.1. Picture of the factory premises.
Photo source: BAF.

1.2 Background

The industrial markets of today are characterized by the continuous introduction of new competitors, new production processes, fluctuations in product demand, and profit margin reduction. This situation urges the need for companies to differentiate themselves in new ways, gaining more profit and better competitive position.

In a perfect world a manufacturing system works, and produces high quality products, at all times. Unfortunately this will remain in our dreams in foreseeable future. At present time all systems need proper maintenance to be more productive (Renna, 2011). Several researchers have made efforts in discussing the role of the maintenance function in keeping, and improving; availability, production efficiency, and product quality (e.g. (Al-Naijar, 1997); (Al-Naijar and Alsyouf, 2003); (Riis et al., 1997)). In addition to this, Alsyouf (2007) ties the maintenance impact on production cost, working environment, work in progress, and tied up capital to the overall internal effectiveness of the company.

More and more companies, and their decision-makers, are now realizing the critical need for proper maintenance of manufacturing systems (Stephen (2000); Cholasuke et al. (2004); Meulen et al. (2008); Pinjala et al. (2006); Alsyouf (2007)Alsyouf (2009); Dowlatshahi (2008)).

Kamoun (2005) emphasized that as companies, and its customers, count on availability, reliability, and quality of service of corporate assets, any compromise in these areas will lead to both decreased revenues and increased costs. This high equipment availability and performance is best achieved through efficient equipment management programs (Raouf and Ben-Daya, 1995).

1.3 Problem Analysis and Thesis Objectives

The production at the BAF facility has now been ongoing for 18 years. Throughout these years maintenance has to some extent been seen as a necessary evil, and there has been a lack of any clear maintenance strategy that embraces the thought of maintenance adding value to the company. Breakdown maintenance has been used to a large degree, and with different owners, and also a bankruptcy, there have been times with economic motives of making the maintenance process a process of patch up as quickly as possible to make production limp on. At the time of Benteler takeover there was a major lag in the maintenance, and extensive resources had to be used to overcome the lag. As of today the situation is better, and the curves are pointing upwards as a result of implementation of several new measures, and improvement of old measures. The current top-management recognizes the greater potential of multiple benefits achievable with the implementation of more sophisticated and proven maintenance strategies. The organization suffers the lack of knowledge and resources to undertake the comprehensive task of evaluating and improving the entire maintenance function. The objectives of this thesis are firstly to get an overview of the current status of the maintenance function at BAF. This overview will further be used to identify areas for potential improvements throughout the function. When these areas of potential improvements are identified, the main objective is to identify measures that are proven to improve performance of these areas.

1.4 Definitions

This section provides a brief desctiprion of some definitions and obbreviations used in this text.

OEE (Overall Equipment Effectiveness) is a metric that identifies the percentage of planned production time that is truly productive. This metric can be used as a benchmark metric, to compare the performance of a given production asset to industry standards, to similar in-house assets, or to results for different shifts working on the same asset. It can also be used as a baseline to track progress over time in eliminating waste from a given production asset. The preferred calculation method is based on the three OEE-factors; Availability, Performance, and Quality.

$$OEE = Availability \times Performance \times Quality \tag{1.1}$$

$$Availability = \frac{RunTime}{PlannedProductionTime} \tag{1.2}$$

$$Performance = \frac{IdealCycleTime \times TotalCount}{RunTime} \tag{1.3}$$

$$Quality = \frac{GoodCount}{TotalCount} \tag{1.4}$$

Boundry-Less A boundry-less organization is an organization where the usual boundaries between levels and departements, namely, horizontal and vertical boudries, has been removed to allow easy flow of information and knowledge throughout the entire organization.

1.5 Delimitations

The intention of the Maintenance Loop (Oljedirektoratet, 1998) concept is to use it on a regular basis to monitor the continious improvement process. The scope of this thesis limits the work to completing the first, and most comprehensive report.

The time limits of this thesis also prevents the implementation of measures, and the possibility of seeing any results of these measures.

The original model has a heavy focus on safety related maintenance in the offshore oil and gas industry. In this thesis the main principles of the model is used, but the focus is somewhat shifted to better fit the land-based industry, and its higher focus on profit and availability.

Due to a major ongoing restructuring process of the organization at the time of this thesis some aspects regarding the organization may not be representative after the restructuring is completed.

Chapter 2

Methodology

In this chapter the methods used throughout the work with this master thesis is discussed. First an overview of the model used in this thesis is presented, secondly the methods used to gather the information needed are presented, and then the reliability and validity of the findings are discussed.

2.1 Basic Study Maintenance Management

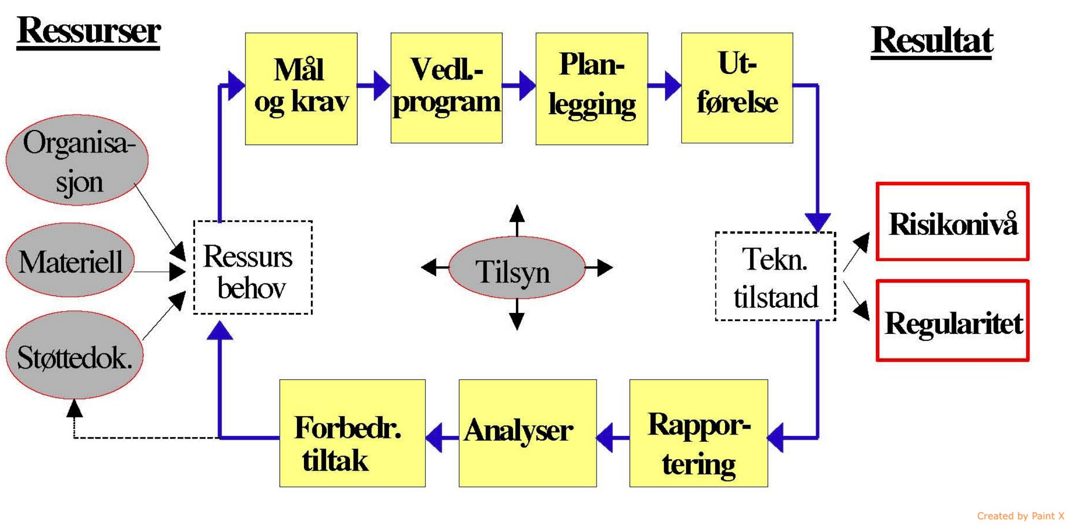

Fig. 2.1. Maintenance Loop
Oljedirektoratet (1998)

This thesis uses the “Maintenance Loop” model developed by the Norwegian Petroleum Directorate through its project “Basic Study Maintenance Management”(Oljedirektoratet, 1998). The project was initiated late 1996 with a goal to develop a method for systematic and complete evaluation of a company maintenance management system. The model is to be used to continuously improve the maintenance function, with repeated reports at a set time interval to monitor the improvements.

The model divides the maintenance function into 11 elements, which is evaluated separately. Figure 2.1 is an illustration of the maintenance loop, and its elements. For each element in the model the information gathered by the methods described later in this chapter will be used to determine;

- Current status
- Problems and challenges
- Improvement potentials and future goals

This part of the thesis will be presented in chapter 4. In chapter 5 the results from chapter 4 will be discussed, and a prioritized list of actions to be taken will be presented. A general conslusion will be given in chapter 6

2.2 Information

2.2.1 Primary Information

Primary information is information collected for usage in a specific study. Gathering primary data is important to create an understanding of a specific research object (Bjørklund and Paulsen, 2003). The primary information for this thesis has been collected through questionnaires, observations, interviews, and from operation and maintenance management systems. These different methods are briefly described below.

Questionnaires

The questionnaires were prepared with a total of 168 questions with the purpose of mapping the current status of the 11 elements in the basic study method described previously. The general questionnaire where then used to create 7 individual questionnaires for 7 different employees on different levels, and with different responsibilities in the maintenance function. The questions included in the individual questionnaires where questions found relevant for his/her position.

Observations

The most important part of the information gathered for this thesis stem from observations. Observations gave valuable information on how the maintenance function operated at a daily basis, and not how it was said to operate. Observations also give an overview on daily issues and challenges. Issues and challenges not great enough to be thought of and mentioned in an interview situation. Observations also provide information on the behavior of the employees involved, what pride they put in their effort, how they respect different procedures, communication, and so on.Bjørklund and Paulsen (2003) also states that observations provide more objective information than other methods. It is also stated that observations can be a very time consuming task. The observations of this thesis were conducted over a period of approximately 3 months at site with regular working hours (07:00 – 15:00). This amount of time spent on site is believed to be sufficient to get a proper inside view of the case at hand in this thesis.

There are many different ways to conduct an observation. The observers can be participating in the activity, observe from distance, informed observation, undercover observation, and so on. For the observations conducted for this thesis all maintenance crewmembers were informed of my presence at site, hence the observations were informed. The observations included both observation of the hands-on activity at the factory floor, and information gathered just by being part of the open office landscape in the administration. The passive observations are a great source of information about the current state. When it comes to the improvement potentials and improvement measures, the dialogue with the workers is a great source of information. They work in this setting, with these machines on a daily basis, and they probably have knowledge about the processes not captured by passive observations, or covered by general academic literature.

Interviews

Throughout the period at BAF the author conducted a series of interviews, both with maintenance staff and with employees from other parts of the organization, to get an outside perspective on some elements in the study. These interviews were conducted in a non-structured, or semi-structured manner. This is believed to be the best way to extract information in a setting like this. The interviewee is then more relaxed, and speaks more freely around the topic. Interviews like this is a good way to gather information that could be hard to acquire through the other methods used (Esaiasson et al., 2009).

Operation and Maintenance Management Systems

The operation and maintenance management systems at BAF consist of 3 partly integrated systems.

- APIS automatically logs the production processes and the downtime. After a downtime the operator only needs to enter a code of reason for downtime. The codes have different groupings to separate maintenance reasons from operational reasons or others. This system also logs different parameters of the production cycles. Information from this system can easily be trended or compared.

- Maisy is the main tool for both planned and corrective maintenance. This system is used to schedule and plan the planned maintenance, and it is used by the maintenance personnel to log both planned and corrective maintenance jobs. The log includes information about; what machine, time consumed, who did the job, a description of what was the problem, and how it was solved. Information from this system is also used to get an overview of the past maintenance jobs. Extracting information is more complicated than from APIS, but the extracted information include more details.

- Visma is the system used for inventory management. Information from this system was not used extensively. The warehouse manager provided information regarding the procedures and processes of inventory management.

2.2.2 Secondary Information

Secondary information is information that has been produced for another purpose than the forthcoming study (Bjørklund and Paulsen, 2003). The secondary information of this thesis consists of information gathered from an extensive literature study. Academic literature regarding maintenance and maintenance management topics were studied. This information were then used as a basis for the identification of inefficiencies in the maintenance function not identified by the primary information of this thesis, and as a basis for suggesting proven effective measures to improve the maintenance function.

The main part of this literature study was performed in the initial phase of the thesis work, but expanded to cover more topics throughout the work process. The needed literature where found in the university library, or through university online literature databases. The literature study covered papers on maintenance management systems, corrective maintenance, preventive maintenance, maintenance planning, maintenance frameworks, key performance indicators, cost of maintenance, maintenance strategies, among several others.

2.3 Reliability and Validity

When conducting a study it is important to evaluate the trustworthiness of the results. Different terms are used for this evaluation (Eliasson, 2010). Reliability and validity are two of these terms used to assess to what extent the results of the study are reliable and valid (Bryman and Bell, 2005).

2.3.1 Reliability

Reliability of the study means to what extent the results are repeatable. Meaning if it were done again would the results be the same (Bryman and Bell, 2005). According to Olsson and Sørensen (2007) the reliability of a study is dependent on the quality of the input. The most weighted inputs for this study were qualitative data gathered from interviews, questionnaire, and observations.

The interviews were conducted as semi-structured, or non-structured interviews. The loose structure of the conversations opens up for the conversation not necessarily to reveal the exact same information if performed repeatedly. The number of interviews and the number of different interviewees make the author believe that the information gathered from interviews are sufficiently reliable.

The information gathered from the questionnaires is also believed to be reliable. The questions were selected to fit the role of the person that answered. They are believed to have sufficient competence in their field, and the result would most probably be the same if repeated.

Observations can be conducted in a number of ways, and the results can vary some. Another source of variation is the relationship between the observer and the observed. The amount of observations performed for this thesis is believed to even out these variations, and the results from these observations are believed to be reliable.

Data from the operation and maintenance management systems were also used to some extent. The functionality of the systems, and their integration with each other were assessed as a part of the study. The information entered into the system was not sufficiently standardized at the time, and the information showed flaws in respect to both qualitative and quantitative information. This information was not believed to be sufficiently reliable to be much weighted, and were used only as an indicator.

2.3.2 Validity

The validity of a study where divided by Bryman and Bell (2005) into internal and external validity. External validity is concerned with whether the results of the study are valid for other purposes than the study at hand. The internal validity is concerned with the methods used in the study really measured what was intended (Bryman and Bell, 2005). This study was performed as a case study. This results in the study not having a general high external validity, although some of the results are believed to be able to serve a purpose in other studies as well. On the other hand, the case study setting ensures a high level of internal validity.

Chapter 3

Frame of Reference

In this chapter a literature review in the area of maintenance is presented. The purpose is to create a theoretical basis for the problems identified and the suggestions for improvements discussed in chapter 4. The scope of this thesis covers a broad range of aspects in the maintenance literature. This chapter gives an introduction to some of the main elements studied.

3.1 Maintenance

The maintenance function is a business function that is necessary to support the organizations primary process. In manufacturing environments, maintenance of a machine is defined as 'all activities necessary to restore the machine to, or keep it in, a specified operating condition (Batun and Azizoglu, 2009). This includes all the technical and associated administrative actions necessary to achieve this goal. The maintenance process can be seen to add value in terms of profit, quality, time, and service (Zhu et al., 2002). This leads to the quality of the maintenance function being essential for a manufacturing organization to be able to maintain its competitiveness (Al-Najjar and Alsyouf, 2004).

Cost/Benefit of Maintenance The cost of maintenance is most often divided into direct and indirect costs. Direct costs being the direct labor, spare parts used, etc. and indirect costs being production losses due to downtime, lost customers, etc. The direct costs can quite easily be quantified. Quantifying the indirect costs most often is a challenge, and the accuracy of the calculations is not good (Al-Naijar and Alsyouf, 2003).

Traditionally the cost of maintenance has been viewed without considering the savings and profits that maintenance accounts for. In recent years, as mentioned previously, more and more companies and decision makers acknowledge the fact that maintenance is not a pure cost factor, but also include economic benefits. The economic benefits of a proper maintenance strategy can be found as savings in many areas of the company, like machine and spare parts inventory, less wreck production, etc. Profits are also gained by increasing production efficiency, higher quality products, more customers, etc.

Most literature focuses on the direct costs and profitability of maintenance (e.g. Salonen and Deleryd (2011) ; Dhillon and Liu (2006)). Ben-Daya and Duffuaa (1995) on the other hand focus on the importance of maintenance to secure quality, and clearly states an important relation. Quality is a term with several interpretations. When discussing quality in relation to maintenance it is interpreted as products free from deficiencies (Juran, 1998).

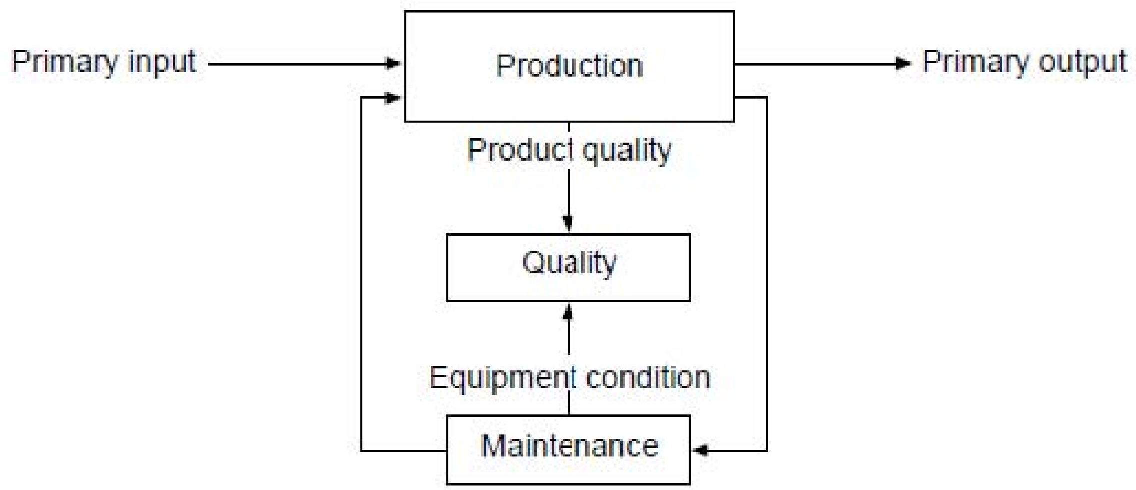

Fig. 3.1. Relationship between maintenance and quality
Ben-Daya and Duffuaa (1995)

3.2 Definitions of Maintenance

Maintenance work is commonly separated and categorized as; preventive, predictive, and corrective maintenance. The different types are categorized from the time and basis of the work as described below.

- Preventive maintenance is referred to as planned maintenance that is carried out at given intervals based on calendar or hours/cycles of use, in order to keep the equipment in good condition (Dhillon and Liu, 2006).
- Predictive maintenance describes maintenance that is performed on basis of a monitoring of the equipment condition with the use of monitoring equipment and techniques.

A good monitoring of the equipment ensure that the maintenance is carried out on the best time. The time available to plan the maintenance depends on the time interval from detectable fault, to the failure of the equipment.This interval is called the P-F interval and is illustrated in Figure 3.2

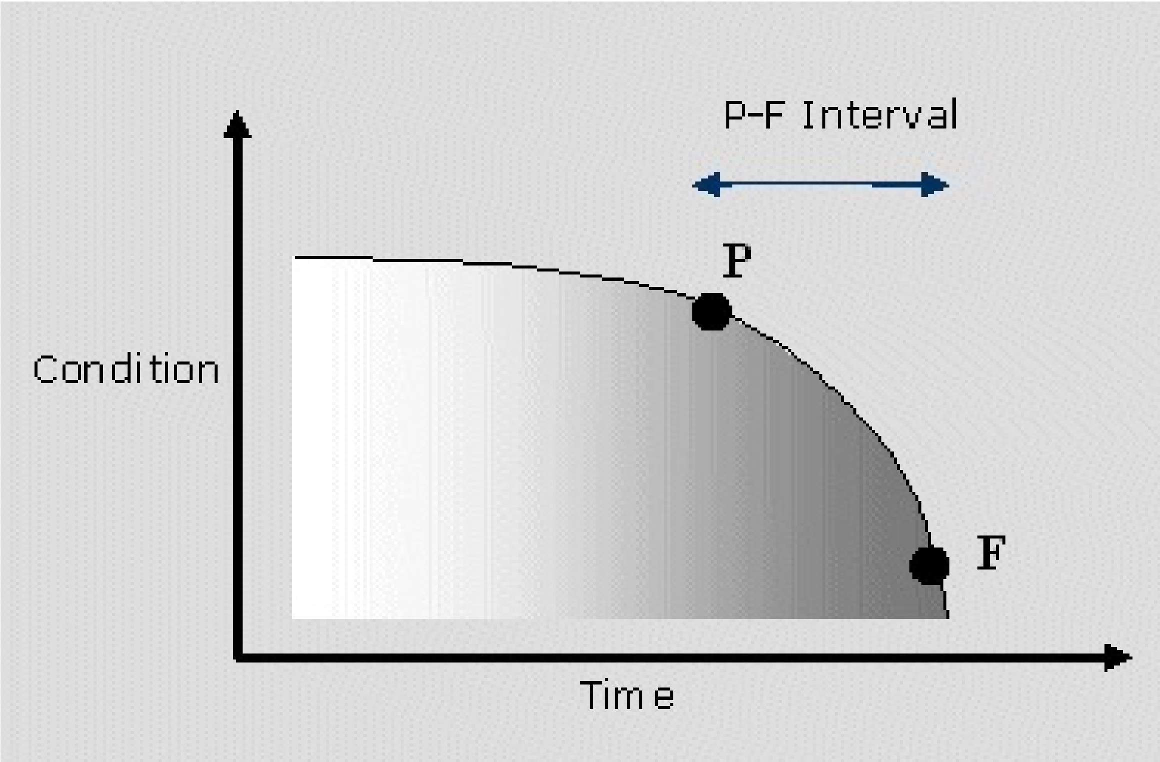

Fig. 3.2. Illustration of the P-F interval

- Corrective maintenance is performed in order to return the equipment to working condition after a breakdown or period of unacceptable performance (Dhillon and Liu, 2006).

Preventive and predictive maintenance is closely related, and in most literature they are treated similarly. If nothing else is specified it can be seen as a rule of thumb that predictive maintenance is incorporated in the discussion of preventive maintenance.

According to Salonen and Deleryd (2011), preventive maintenance can be seen as value adding, while corrective maintenance is seen as waste. This statement relates to the fact that preventive maintenance ensures the optimal performance of the equipment, while breakdowns are a signal of the lack of proper preventive maintenance, human error or other undesired events that should have been avoided.

Campbell and Jardine (2001) states that a rule of thumb is that corrective maintenance in general have a 50 % higher cost than planned stops before breakdown. This cost aspect is the main driving force for companies to shift to more preventive maintenance.

There are several reasons why corrective maintenance is more costly than preventive maintenance. The most obvious reason is that preventive maintenance can be planned and scheduled to a preferred time of low or no production (Campbell and Jardine, 2001). Other cost effective aspects of the planned maintenance is that the correct resources can be allocated, spare parts prepared, procedures undergone, tools prepared, and so on. All of this while the equipment is still in production, in contrast to breakdowns.

Considering only these facts it is seen that the ideal situation is to only have preventive maintenance. Salonen and Deleryd (2011) state that it is not always justified to do so. Preventive maintenance should be used where feasible, while corrective maintenance should handle random distributed errors and other failures that are not financially justified to prevent.See Figure 3.3 for an illustration of this. For these reasons both preventive and corrective maintenance are important parts of a maintenance organization (Dhillon and Liu, 2006).

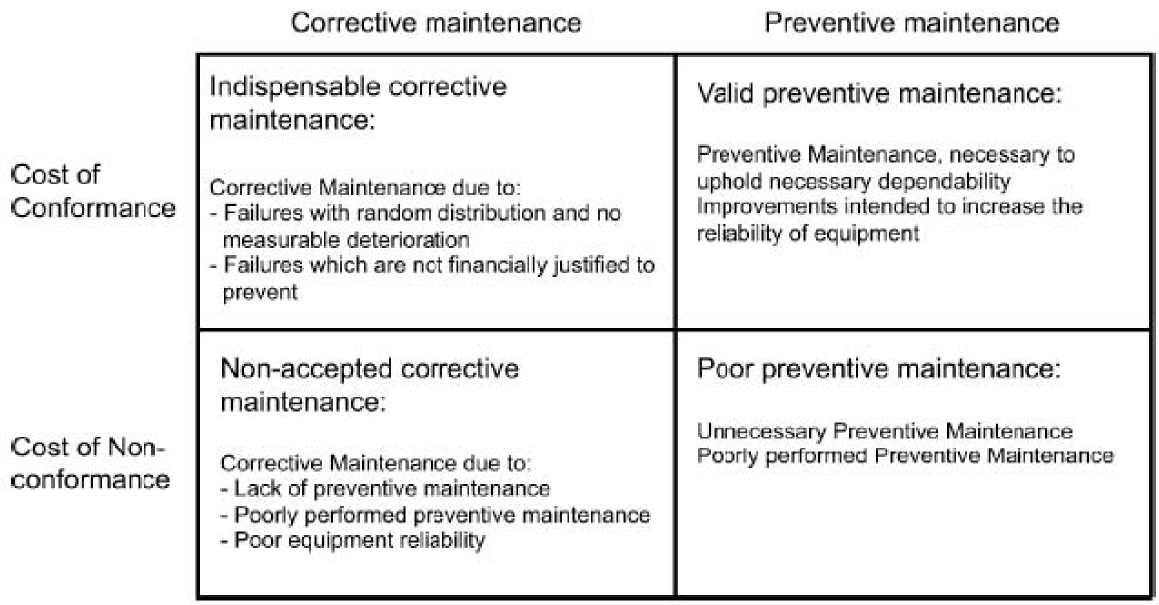

Fig. 3.3. Cost of maintenance types.
(Ben-Daya and Duffuaa, 1995)

The distribution of the share of corrective and preventive maintenance is a theme with different views. Jonsson (1997) states that corrective maintenance should not exceed 40 %. Ben-Daya et al. (2009) claims that an effective maintenance organization has 20 % or less corrective maintenance. Also Kelly (2006) uses 20 % as a goal. It is also stated that a distribution with higher corrective maintenance share signals a lack of control of the equipment. Nyman and Levitt (2010) state that only a proactive maintenance organization can reach this distribution.

3.3 Planning Strategies

In order to perform effective and efficient maintenance, proper maintenance planning is important.

3.3.1 Forecasting

Ben-Daya et al. (2009) argues that a key aspect of maintenance efficiency is the number and skills of maintenance personnel. Skills can be mapped, and training provided if needed. To properly size the staff is a more complex case, especially when dealing with a high share of corrective maintenance. This is due to the uncertainty of the corrective maintenance workload (Ben-Daya et al., 2009). To counteract the uncertainty, Ben-Daya et al. (2009) argue that forecasting is important. Having a to large staff will reduce the overall utilization of the personnel, while having a to small staff can create a backlog of unfinished work. An important tool to use in this forecasting is the Computerized Maintenance Management System (CMMS) discussed later in this chapter. Forecasting can be based on either qualitative or quantitative data, depending on the data available. Qualitative forecasting is often used when there is lack of historical data, or the quality of the data is unsatisfactory. In these cases the forecasting is based on experts opinions and judgments. Quantitative forecasting is used when historical data is accessible, and of good quality.

3.3.2 Scheduling

The size of the staff is a concern when dealing with the long-term strategic planning. Scheduling on the other hand is short-term maintenance planning. Scheduling is most often concerned with the resource planning for one day up to one week (Ben-Daya et al., 2009). Corrective maintenance is often difficult to schedule in advance. To best handle corrective maintenance work orders, Ben-Daya et al. (2009) highlights three guidelines to be used:

- Arrange orders by priority/criticality
- Consider job duration, location, travel distance, and possibility of combining jobs in the same area

- Schedule multi-craft jobs to start at the beginning of every shift

These three points are not applicable in every situation, but can be used as general guidance.

3.4 Computerized Maintenance Management System (CMMS)

The subject of computerized maintenance management system is widely discussed in the literature. As basis for this section it is used an aptly article by Valesko (2010) that covers the highlights of CMMS. It is stated that a CMMS is an invaluable tool. CMMS is a productivity tool that provides a centralized database for maintenance operations. There are many different CMMS models on the market, and most of them run perfectly on the already existing computer network. Valesko (2010) further argues that proper utilization of CMMS will increase productivity by reducing downtime, decreasing parts usage, streamlining the purchase order approval process and connecting inventory with purchasing. Additionally, CMMS will allow management to make more informed decisions and help industrial maintenance technicians do their job more effectively and efficiently.

Some of he benefits of utilizing a CMMS is described in some more detail below.

- SCHEDULING – CMMS simplifies the scheduling, as work orders can be scheduled across departments or even companies.
- WORK ORDERS – With a CMMS, maintenance staff can create, print and track all maintenance in every category. The work orders can be linked to a variety of options, such as assets, tasks, procedures, parts, tools, labor used, and diagrams or drawings. The planned work orders can be sorted and viewed by day, week or month, Reports can be sorted by failure and lost time codes.
- INVENTORY – The CMMS is a great tool for tracking inventory, even across multiple storage locations. One key benefit is the ability to set minimum inventory level for each part in stock, enabling the system to alert key personnel when reorder points are reached. This should eliminate unplanned downtime due to missing parts.
- PERSONNEL – The CMMS is used as a database of maintenance personnel information, such as; name, identification number, department, work team, labor grade and craft. In addition to this, managers can track actual hours spent on a work order compared to the estimated time, and by this resolve disagreements.
- TIME CARD ENTRY – The CMMS enables automatic calculation and adding of the associated labor costs to the total cost of each work order. Hours spent by each employee, and the responsible employee for each work order can also be tracked.

- PURCHASING – Automatically generate and print purchase orders, and easily track them for future reference. Receipts are processed quickly, and it is easier to stay on budget by monitoring current, quoted and average prices.
- REPORTING – CMMS simplifies reporting, an often mundane and tedious task. Maintenance staff starts with all relevant information in one place and reports it by choosing from templates or customizing their own.
- SECURITY – Security is a constant concern in every department. With CMMS, maintenance managers can easily decide who has access, to what they have access, and what they are authorized to perform. For example, create work order, close work order, order spare parts, request stare parts, and so on. Different access codes can be given to individuals, or groups of employees.
- LINKING FILES – With CMMS it is possible to streamline the operations even further by linking; CAD drawings, electrical diagrams, maps, pictures, sound recordings, and other files to the work orders.

As seen from the above statements, CMMS is a very flexible tool that can be configured to each locations unique need. It allows for increased productivity in all areas of maintenance management.

3.5 Maintenance Strategies

In the literature today there are several different strategies and frameworks to be adopted to secure an effective and efficient maintenance function. The most attention is given to Lean Maintenance. This is considered the ultimate atrategy to optimize the performance of the maintenance function. Some foundation elements, in particular TPM, must be in place before an organization can effectively build on the maintenance management pyramid and move towards Lean Maintenance. For this reason we consider TPM a good starting point for improvements, and focus is limited to this strategy. Below there is a brief discussion on some of the key elements of TPM.

Total Productive Maintenance (TPM) TPM is a lean manufacturing strategy, which has a premise to optimize overall equipment effectiveness (OEE), making equipment as efficient and profitable as possible. With a universal definition it can be said that TPM is productive maintenance performed by all employees in small group activities that have a zero defects target. (Ferrari et al., 2002)

TPM emphasizes proactive and preventive maintenance to maximize the operational efficiency of equipment. It blurs the distinction between the roles of production and maintenance by placing a strong emphasis on empowering operators to help maintain their equipment. The implementation of a TPM program creates a shared responsibility for equipment that encourages greater involvement by operators. In the right environment this can be very effective to overcome the "Six Big Lossess":

1. Unplanned Stops - Tooling Failure, Corrective Maintenance, Overheated Bearing, Motor Failure, etc.

2. Setup and Adjustments - Setup/Changeover, Material Shortage, Operator Shortage, Major Adjustment, Warm-Up Time, etc.

3. Small Stops - Component Jam, Minor Adjustment, Sensor Blocked, Delivery Blocked, Cleaning/Checking, etc. Typically only includes stops that are less than five minutes and that do not require maintenance personnel.

4. Slow Running - Incorrect Setting, Equipment Wear, Alignment Problem, etc. Anything that keeps the equipment from running at its theoretical maximum speed.

5. Production Defects - Rejects during steady-state production.

6. Reduced Yield - Rejects during warm-up, startup or other early production

These lossess all influence the OEE of the factory, which is the key performance indicator of the TPM state. To improve the equipment reliability, and to achieve its goals TPM rely on the "Eight Pillars of TPM":

- Autonomous Maintenance - Places responsibility for routine maintenance, such as cleaning, lubricating, and inspection, in the hands of operators.

- Planned Maintenance - Schedules maintenance tasks based on predicted and/or measured failure rates.

- Quality Maintenance - Design error detection and prevention into production processes. Apply Root Cause Analysis to eliminate recurring sources of quality defects.

- Focused Improvement - Have small groups of employees work together proactively to achieve regular, incremental improvements in equipment operation.

- Early Equipment Management - Directs practical knowledge and understanding of manufacturing equipment gained through TPM towards improving the design of new equipment

- Training and Education - Fill in knowledge gaps necessary to achieve TPM goals. Applies to operators, maintenance personnel and managers
- Safety, Health, Environment - Maintain a safe and healthy working environment.
- TPM in Administration - Apply TPM techniques to administrative functions.

(Unknown, 2014)

Chapter 4

Results

This chapter focuses on the study findings in the different elements of the Maintenance Loop. The basis for this chapter is described in Chapters 2 and 3.

4.1 Goals and Requirements

In order for the maintenance function to perform at an acceptable level, and to be able to improve, it is important to have goals and requirements on key performance indicators. These goals and requirements are valuable guiding beacons in the daily operations.

Current status When considering the current status of goals and requirements in the maintenance function the only properly quantified goal is a goal of 92 % availability of equipment. The performance of this indicator is evaluated regularly from the data in the APIS system. This data derives from the operator assessment of the cause of downtime, and the following choice of error code.

Another goal is to reduce the amount of corrective maintenance. This goal has not been quantified, but "as low as possible" is the general interpretation of this goal. To improve the performance in this area it has been implemented a measure. This measure is that the corrective maintenance staff post notes on their thought of what could reduce the corrective maintenance share. The performance of this measure is monitored using information from Maisy and APIS.

Problems and Challenges The main problem of today when considering the striving to achieve goals is the quality of information. The performance indicators for the two goals stated previously are, logged availability, and reported share of corrective maintenance. The systems APIS and Maisy include simple functions to extract this information. The problem here is that the quality of the information will never be greater than the quality of the input.

For the availability logging the system automatically logs the downtime. The source of error is the error codes that the operator has to choose from to get back to service. Some codes are too general, some are unnecessary, and some maintenance codes reflect operational issues, and possibly vice versa.

For the corrective maintenance reporting there is many corrective maintenance jobs that are never reported. The main reason for this is that the maintenance personnel themselves need to create the job, and by many, this is not rewarding enough to battle the low user-friendliness of Maisy. For planned maintenance the situation is different. In these cases the planner have already created the job, and the job need to be closed when performed, so there is no way around it.

During my observations and interviews at the site I identified that communication is an issue that is not contributing in the positive direction when it comes to improving the maintenance performance.

Improvement Potentials and Future Goals To have a quantified goal on the availability of the equipment is a key performance indicator of the overall performance of the maintenance function. The improvement potential for this lay in the quality of the information that the performance is assessed from. A solution to this problem could be to split the responsibility of the choice of error code. The operator enters an error code, and if this is a maintenance related code, a question for confirmation is sent to someone in the maintenance staff, and similar for operation related, etc. The better solution would be closer integration of APIS with Maisy. In this case the use of a maintenance code in APIS would require linking to a maintenance work order in the Maisy system. Similar measures need to be implemented for non-maintenance codes as well. In the opposite case the maintenance codes would have been avoided, with the result of no increase in information quality.

The solution described above would have the advantage of also improving the quality of the information needed to properly assess the performance of the share of corrective maintenance goal. This goal is an important performance indicator that measures the effectiveness and quality of the preventive maintenance strategy. As discussed in chapter 3(referere) it is widely proven in the literature that corrective maintenance is more costly than the preventive maintenance, due to reasons like resource and competence planning, production planning, spare-parts inventory, and so on. For this reason the share of corrective maintenance should be kept at a minimum. To be able to monitor the status of today, and set an appropriate goal for this performance indicator it is needed to collect valid data.. To obtain this it is needed to standardize the routines of reporting in the Maisy system. An alternative solution for this is as previously mentioned to link the maintenance downtimes in APIS to a work order in Maisy. This would ensure the logging of all corrective jobs, and the downtime associated with each job. For the planned jobs the work order is already created in the system. A problem here is that the planner enters an estimate for the time consumption of the repair, and when the work order is to be closed, this estimate comes up as a default. I know from observations that this number is rarely changed to the actual time. For the share of corrective maintenance it is important that the information regarding planned maintenance have as high quality as the information regarding corrective maintenance. The simplest solution to this is to remove the default time, and force the entering of actual time. This would probably better the quality, but to what extent is uncertain. The better alternative is to completely digitalize the plans and work orders. The system of today includes blackboards and paper copies of the work orders. By digitalizing this part the procedure could be that the maintenance employee went to the computer, generated the next scheduled job, accepted the job and printed the work order. When the job was completed he returned to the computer to close the work order with at least a minimum of information entered. This would ensure the correct time and information being entered into the system. Another benefit from this procedure would be that the blackboards now could be substituted with digital screens. This would make it easier for the maintenance supervisors to keep track of personnel, and to rearrange the priority of work orders. It could also be used in communication to other functions that the system always knew where work is being performed.

In order for the maintenance function to improve at a satisfactory pace these goals are good, but not enough.

When considering goals for the performance of a function it is necessary to identify key performance indicators for this function. When the key performance indicators are identified, quantified goals for the performance of the different indicators can be set. In order to support continuous improvement these goals need to be ambitious but attainable. This is important in order to create willingness to strive for these goals, and the satisfaction of achieving these goals regularly. As the performance stabilizes at a level the goals must be set even higher. Some key performance indicators that the author thinks would be appropriate to monitor and target by quantitative goals are discussed below.

As mentioned in chapter 3(referere), corrective maintenance will exist in the maintenance function. Based on this the effectiveness of the corrective maintenance affect the overall performance of the maintenance function. A key performance indicator for this would be the response time of the maintenance personnel. This performance indicator could easily me monitored by a function in the system that the operator initiates when the emergency work order is placed, and the maintenance personnel stops when the repair job is started. The system function that logs these response times should be set to include the weekday, and time of the day. This is due to the main parameter affecting this performance is the staffing allocated to corrective maintenance throughout the week, and the measure to overcome issues would be to revise the staffing.

Maintenance originating from communication faults should be avoided. To keep track of these problems it is needed to monitor them. To be able to collect the needed information it is needed to implement a standardized routine of reporting events occurring due to communication failures. The easiest way to do this would be to put a checkbox in the work order-closing screen, where the employee checked if the job originated from a communication failure. It is of interest to everybody to ensure good communication, and therefore the quality of this information is believed to be satisfactory.

To improve the performance of this indicator it can be effective to shorten the communication lines, and make them less rigid (more boundary-less). Another measure that would improve the performance of this indicator is to make relevant information more accessible in the system.

Another key performance indicator is the amount of planned work that is performed as scheduled. This is an indicator that can easily be monitored if the system is configured to monitor this. The performance of this indicator tells something about the quality of the planning. Planning is an important part of the maintenance function, so high performance here is valuable.

To be able to easily identify equipment that is performing well, and not so well, monitoring the MTBF (Mean Time Between Failure) is a good measure. This measure would identify the equipment that have the shortest interval between breakdown, and this could initiate an analysis of reasons for this. For similar equipment it is also helpful to consider the reason why there are differences in the MTBF. Is anything done differently??

We have now discussed some key performance indicators and their goals. On the other end of the scale from the goals we have the requirements. The requirements indicate what minimum performance is required before extra effort should be put in to overcome the situation. Requirements should be defined for all the previously discussed indicators, and in addition requirements should be set for issues like backlog in planned maintenance, minimum competence of responsible maintenance personnel, and possibly others.

4.2 Program

The maintenance program is an essential part of the maintenance function. The program should include strategies and methods on as much as possible equipment and facilities of the company. Developing a satisfactory program like this requires as much information as possible from the manufacturer, similar industry, etc. and still the result will have potential for improvement. This is the reason why it is so important to have a clear strategy on the continuous improvement of the program.

Current Status For the case in this study no clear basis for the initial program where identified, but the most commonly mentioned basis were "trial and error". At the Farsund site there are some thoughts and ideas about continuous improvement of the program, but no clear strategy. Large parts of the program in use today seem rather unchanged for quite some time.

One major change that has been implemented from the BOSLE principles (see below) is the Pit-Stop. The Pit-Stop is a weekly two hour shutdown of the equipment for simple maintenance tasks, inspection, and cleaning of the equipment.

Problems and Challenges The initial program is not that relevant for this study, but the strategies for improving the program is important. From my experience at site there exist no clear strategy. Benteler have a general system of operational principles for there plants, called BOSLE (Benteler Operating System Lean Enterprise), this system also include the maintenance function. The casting process at the Farsund plant is a one of a kind facility in the Benteler portfolio, and hence these principles do not match this facility to the same degree as other plants.

Other problems in adopting a good strategy for continuous improvement are the resources and competence needed, and a major problem is that in a few places of the maintenance function the will to change seem non-existing.

Improvement Potentials and Future Goals The improvement potential from the Pit-Stop measure can be quite good if it is utilized properly. The first point here is the human resources allocated for the different equipment. This should be based on a thorough criticality analysis of the different equipment, together with the complexity of the equipment with regards to the need for inspections. The inspections should be clearly standardized through work orders for each equipment every week. The inspected components do not need to be the same every week, but the interval should be reflect the criticality of the part for the equipment to function. A properly planned and executed Pit-Stop should cover all the inspection needs for the equipment. This in turn will contribute to better prediction of failures and planning of maintenance actions.

A prerequisite for prediction of failure is that the failure occurs from wear of the component, and not sudden failure. With the complex equipment in this case there are lots of components that do not show sign of wear before failure. This points in the direction of preventive maintenance. Cost effective preventive maintenance is balancing on a thin line. Too long intervals lead to breakdowns, and too short intervals lead to unnecessary maintenance. Most preventive maintenance at BAF is performed as calendar based maintenance campaigns on each equipment, called revisions. It is the author opinion that there is room for improvement of this practice.

For most components the length of life depends on the stress from usage, and in this case meaning the cycles it has been operated. The previously mentioned revisions are performed on a strictly calendar based interval. This means that even if the equipment have been out of production for a substantial amount of time, the components will still be replaced when the calendar says. This is not cost effective. APIS logs the number of cycles, and Maisy automatically schedule the revisions. Only practical thing missing to change this practice is integration between these two programs. When the integration is in place the number of cycles between each revision needs to be set. This involves analysis of previous data, component manufacturers, and a period of close monitoring of the equipment condition. In cases where equipment has been out of production for prolonged periods of time without revisions it should be re-qualified for production before startup

Another important part of the preventive maintenance is the maintenance of molds. This is similarly to the revisions done at calendar-based intervals. The maintenance of the molds consists of replacing the mold in the casting machine with a newly maintained one, and bringing the removed mold to the mold-workshop for maintenance. From the observations it is observed that the period of production for a mold before needing maintenance vary greatly. In many cases it needs maintenance before planned, and in one case the mold were 50 percent over time for change, and produced high quality products with low amount of wreck. This implies that a more sophisticated strategy regarding the maintenance and qualification for production should be implemented. This said, there is an ongoing project that will completely change the way the maintenance of the molds is performed, and this will hopefully solve this problem. The process of changing molds puts the casting machine out of production for several hours, and an increase in average interval will contribute substantially to a better equipment availability.

The maintenance not captured by the predictive or preventive part of the maintenance program is left to corrective maintenance. At the Farsund plant a relatively high proportion of the maintenance fall into this category. The best solution for a decrease in the corrective maintenance is to get what is possible integrated in the predictive or preventive maintenance programs. For this to be possible it is needed to either make a comprehensive analysis of the equipment and its components, or to identify recurring problems through logging data and experience. These two methods will both make it possible to include more work in the programs if given sufficient attention. Recently there were initiated a measure of the maintenance personnel to post notes with their ideas of improvement areas to reduce the corrective maintenance. One of the results from this could be identification of problems possible to include in the programs.

4.3 Planning

The planning part of the maintenance function is an important part, and is concerned with the scheduling and prioritizing of actions, resource allocation, and the communication of the plans to the affected parties.

Current Status The main tool for planning of maintenance work in this case is Maisy. The program is used for all the parts of the planning effort. The first part of the planning is the semi-long-term planning. This includes the maintenance work planned for the following week. In this part the calendar based maintenance tasks are automatically scheduled by the system, and they only need minor adjustments to fit into the rest of the schedule. The next effort is to generate work orders, prioritize, and schedule the maintenance requests received earlier, but can wait for some time. The most important considerations when performing this task is to ensure the allocation of the correct resources, and prioritize the correct jobs. The prioritizing and time estimating is done solely on experience and knowledge, and there exist no clear system for this. When the plan for the following week is completed it is communicated to the affected parties through Maisy. This means that the affected parties manually need to check the plan. The next part of the planning is during the week that has already been planned. During this week the plans will change. New work orders will be generated that cannot wait till next week, already planned work becomes more urgent and need higher priority, and so on.

Problems and Challenges The implementation of new work orders in the existing plan is the most critical part of the planning, and this is where most mistakes happen. These mistakes arise from the amount of information, and the time limitations. Re-scheduling and prioritizing down a work order to make room for another is tricky. You might think the new work order is more urgent, but do you have all the information the original prioritizing was based on?? Another problem in this phase is that information needs to be extracted manually. This is not always being paid attention to. One observed example is when the maintenance crew showed up for a re-scheduled Pit-Stop, another crew where in the middle of a mold change. From this we can state that the single largest problem in the planning is the information sharing and the communication.

Improvement Potentials and Future Goals To solve this problem the information need to be easily accessible, and the communication lines need to be shortened. When a problem is identified, but needs to be communicated up and down the hierarchy, information is lost, and the person who identified the problem loses ownership and interest in the problem. Another important issue here is to think about all the affected parties, not only the immediate group involved. This is illustrated with the Pit-Stop example above. Shorter and more freely communication lines are proven to be more effective in organizations, and the concept of boundry-less communication is maybe worth considering. An important thing to remember is that no matter how free the communication is, this is no substitute for proper reporting and information sharing up the hierarchy.

A good tool to overcome the lack of information sharing and communication faults is a proper information system. A proper information system will automatically spread the necessary information to the involved parties, and there will be no need of manually checking for updates. The manual check for updates is an area where the observations revealed several slips. This is mainly caused by the workload being high, and this is not a prioritized effort.

4.4 Execution

The proper execution of a work order is dependent on a lot of different information, knowledge, and skills. The most important information needed is a properly defined work order. This is important to understand the scope and intention of the work to be performed. The quality of the work order is dependent of the person who makes the work order, his understanding of the problem, and the ability to formulate it understandable and in proper details.

Current Status The procedure today is that before the work is initiated it is important to consider all the aspects of the work, and to look into relevant information that could be useful. This includes; hazardous area plan, safety routines, work procedures, equipment drawings, simultaneous work in the area, and so on. This information exists and is available to ensure correct work is performed in a safe manner for all personnel in the vicinity.

In many companies it is needed to fill out a SJA (Safe Job Analysis) before any work is initiated. For the case of this study this has not been implemented yet. The injury statistics tells that this has not been a problem, and the potential for improvement judged to be very low. Meaning that the few injuries that have occurred over the years most certainly would not have been prevented by an SJA.

When arriving at the site of the job it is important to ensure that the equipment is properly shut down, and that temperatures and pressures are at acceptable levels for the work at hand. The equipment should be locked down with a key-box on the shutdown knob. This box contains the key to the padlock locking the shutdown button. This key-box is then locked with individual padlocks for all personnel involved in the job. This means that the key to the main padlock can only be retrieved when all personnel have removed their individual padlock, and no longer are present at site. This is an effective measure to prevent starting of equipment when personnel are present.

Some jobs are more time consuming than others, and quite often the job stretches over more than one shift. The information exchanged during the handover is very important. This should ensure that the one who takes over get a clear picture of the problem, what is done, and what is to be done. For the maintenance personnel this handover period is set to 10 minutes. The general opinion is that this is sufficient, and the observations did not reveal any problems with this.

When a maintenance job is completed it is important that the result of the job is in accordance with the intended job. A control of the performed job is necessary to verify the quality of the job. Someone who knew and understood the problem to be solved by this job best does this. For the case of this study there are no clearly defined routines for this, and it is performed on basis of a judgement of the size and complexity of the work. When controls like these are performed, someone from the operations department most often performs it.

Problems and Challenges A consideration has to be given to the key-box previously mentioned. The fact that there are no personnel present does not tell that the job is completed. Procedures say that only maintenance personnel can remove the key-box, even if no personnel padlock is attached, but the observations revealed weaknesses of this practice. Equipment where started up without the job being completed. This was only a single event, but it reveals the potential of other situations with more severe outcome. This event could stem from a personnel slip, communication fault, or intentional deviation from procedures. No matter what caused it, this event point to a revision of the practice to prevent recurrence.

The final step of the maintenance job is to register the data and to close the work order. A proper registration of information creates a useful database to use for analysis and troubleshooting. In order for this database to be useful it is necessary to have the information stored in a manageable system with a simple user-interface. For the case in this study there are some issues in this topic. The information entered into the system varies greatly in quality and detail. This problem most certainly originates from the Maisy system. The reporting, and later extraction of information is too laborious and the system is too hard to navigate. This is a factor that demotivates the user to enter the information properly. The low usability, and the hard navigation and data extraction also limit the usability of the information. More or less the only usage of this information today is a print of the last 24 hours of closed job orders being a topic at the management morning meeting.

Improvement Potentials and Future Goals Although not observed to be a problem, a recommendation for improvement would be to make the verification of the performed jobs over a certain time-limit obligatory. This would better secure the quality of the job, and result in less re-work. To not frog-leap this step it is recommended to include the name of the controlling person as obligatory information in the closing of the work order. This control should also include the approval that the working area is cleared, and that tools and equipment are removed.

To overcome the problems of shared information there should be a minimum requirement of information before the work order could be closed. This could be implemented in the system, or an alternative is to give only a handful of people the authority to validate the information entered, and finally close the work order. This alternative would of-course be more laborious than to implement the requirement in the system, but the diversity of the work performed makes it hard to catch in a simple template.

For this important information to be more usable, and easier to enter, it is needed a new software system, or a re-programming of Maisy. A properly functioning system would make troubleshooting, knowledge transfer, data analysis, and so on, much easier.

4.5 Reporting

Reports in a correct format with a manageable scope and an appropriate timeframe can reveal important hidden information about a subject.

Current Status As of today there is not a lot of resources put into making reports at BAF. As mentioned before a 24-hour report of the maintenance work is presented at the management morning meeting. Another report used today is the trending of the overall availability of the equipment, both short, medium, and long-term trending.. The most important source for these reports are the information stored in the Maisy and APIS systems.

We have now discussed reports concerning mainly the economic/availability aspect of the maintenance function. It could also be worthwhile to mention the HSE aspect. When an accident, minor or major, occurs there are clearly defined procedures to follow, and a report is created in collaboration with an HSE-representative. This ensures the quality of the information in the report.

Problems and Challenges What is observed to be the problem of the reporting is the limitations they carry in terms of revealing important information. The 24-hour report reveals big issues the last day, but is useless in identifying long-term issues and small problems that require a lot of resources over time. Equal limitations apply for the trending of the equipment availability. It is a good way of identifying the improvements in the overall maintenance function, but is not usable to identify the effects of each measure isolated.

Improvement Potentials and Future Goals As discussed previously the quality of the information used in reporting is variable. It is therefore in this context also important to raise the quality of the information. Another recommendation in order to enhance the continuous improvement of the equipment maintenance would be to create monthly, or even longer-termed maintenance reports for single equipment. This would help in better identification of minor recurring problems and other resource waste. In order to improve the overall performance of the maintenance function, measures will be implemented. Before a measure is implemented it is important to identify a performance indicator that clearly indicate the effect of this single measure. It is also important after the implementation to give some time to allow the effects of the measure to be identifiable. Most measures do not have over-night effects. The performance indicator for each measure is important to be able to identify the effects of the measure in comparison with the resources needed for the measure. A measure that over time does not improve the performance of the maintenance function is not worth spending any resources on.

Although not seen as a problem it is observed an area of potential improvement in the HSE context. This would be the reporting of near misses. A proper reporting of these incidents could contribute to the identification of potentially dangerous situations, and to prevent them from occurring later. To overcome this it is needed to implement routines and requirements on the reporting of these incidents. The most important factor here is to gain acceptance and understanding from the employees that the reporting effort is to secure the safety of themselves and their colleagues.

4.6 Analyzes

The collecting and storage of information is of no need unless the information is analyzed and benefited from in some way. A useful application of the information is as previously mentioned to create reports and to monitor performance indicators. These reports and the results of the monitoring is still of no value if no effort is put into analyzing the information it contains. An important aspect of the analyzing is that it is equally important to analyze a good result as a bad result. “Why are the results so good??” is an equally important question as “Why are the results not good??” More efforts are usually put into analyzes of a negative result than of a positive result. This is a good practice, but it is important to remember that valuable lessons can be learned from the analysis of a good performance as well.

Current Status At BAF there seem to be no clear statements on when, and on what basis, a more thorough analysis of data is to be initiated. The reports and performance indicators mentioned previously are worked through, but a causal analysis is not initiated at a regular basis.

Problems and Challenges The result of the lack of proper analysis is the loss of important lessons, and loss of ability to identify improvement potentials. The author believes that the main reasons for not performing the proper analysis of data stem from three factors; quality of information, accessibility/ease of use of the gathered information, and a lack of resources to perform this potentially time consuming task.

Improvement Potentials and Future Goals For the quality and ease of use of the information it is previously mentioned some measures to be taken to improve this. For the resources needed it is a matter of managers to understand the benefits of the effort, and to allocate the extra resources needed. The recommendations for improving this area of the maintenance function is to first raise the quality and accessibility of the information as previously described. When the information is of sufficient quality, and stored in a more manageable system it is important to assess what should initiate a thorough causal analysis. Examples of this could be; emergency repairs of more than, say 5 hours, duration, to high corrective maintenance share on individual equipment, to low long-term availability on individual equipment. These few examples all focus on the "negative" end of the scale, but most of them can easily be flipped over to the "positive" end; very low corrective maintenance share compared to other similar equipment, very high long-term availability compared to other similar equipment, and so on. More resources used in a proper way in the field of information analysis is a good way of embracing the continuous improvement philosophy, and the company could benefit greatly from this effort.

An even more important analysis effort than discussed above is the proper analysis of the HSE related reports discussed previously. In this area there should be no threshold before analysis is initiated. All incidents and accidents reported should be followed by a root cause analysis, and measures should be taken to eliminate all causes of the event.

4.7 Improvement Measures

To be able to implement improvement measures it is important to have a clear idea about what areas improvements are needed. These areas could be technical, human, or organizational. The technical area is the easiest to quantify by measurements, but improvements in other areas can be important as well.

Current Status At BAF today there is a focus on reducing the corrective maintenance share, and to increase the overall availability of the equipment. The measures implemented for this purpose are the notes on improvement potentials from the employees mentioned earlier, and some other more or less unstructured attempts to increase the overall performance of the maintenance function.

Problems and Challenges The performance indicators monitored are to general to identify what measure is effective, and what is not.

Improvement Potentials and Future Goals To obtain continuous improvement and achieve the desired goals it is recommended to implement several measures, some possible measures are discussed earlier in this chapter. It is also important to consider measures to improve performance in the human and organizational areas of the maintenance function. The most important parameter identified in my observations is the communication. Here it is believed to be great potential of improvement. The allocation of resources to allow for a proper follow-up and analysis of the implemented improvement measures are equally important as to implement them. Another example of a measure in the human and organizational area is to arrange for more knowledge and experience transfer between employees from different shifts and different functions. From operations to maintenance, project to maintenance, and so on. This is today more or less only done at a managerial level, and would be more effective if moved down to the factory floor.

4.8 Supervision

Maintenance supervision, the heart of any maintenance program. Many companies invest time and money in improvement efforts, and do not receive the return on investment they expected. In most cases this is due to either the measure was not sustainable, or was not accepted by the maintenance staff. To be able to execute measures effectively you are dependent on leadership, management, and technical skills of your maintenance supervisor or supervisors (Smith, 2014).

Current Status The maintenance function at BAF is centralized and of a manageable dimension. Mid-level managers are responsible for the supervision in their area of responsibility. For multidisciplinary tasks this responsibility are shared between the managers of the different disciplines. The maintenance manager have the overarching responsibility of supervising the performance of the mid-level managers.

Problems and Challenges From the observations it is identified that large parts of the time is spent on creating urgent work orders, handle emergency repair, and re-schedule the maintenance plan for the day or week. This leaves to little time for the tasks that is needed in order to contribute in the continuous improvement process. An example is the supervision of the information entered into the system during work-order closing. This is as previously mentioned of unacceptable quality.

Improvement Potentials and Future Goals The origin of these problems mainly stem from the fact that there are to much corrective and urgent maintenance. This need to be handled immediately, and interrupts all other tasks.. The distribution of work between supervisors and planners is not organized properly. The planners should take responsibility of more of the urgent planning, leaving more time for supervisors to concentrate on the supervision of the execution of the work, and on supporting their teams. In the future there will be more performance indicators to supervise, but hopefully less urgent and emergency repairs. The total workload of supervisors and planners will be of the same magnitude, less urgent planning, but more supervision. No matter the distribution of tasks, it is obvious that there is a need for more resources in planning/supervision to be able to support the continuous improvement effort in a satisfactory manner.

4.9 Organization

The structure of any organization is determined on the basis of capacity needs to execute the workload efficiently, and to be able to meet the objectives of the organization. The main organization can be split into smaller organizations, like the maintenance organization, which will be the focus of this section.

The main objectives of a maintenance organization in general consists of:

1. Keeping assets and equipment in good condition, well configured and safe to perform their intended functions
2. Perform all maintenance activities including preventive, predictive, corrective, and emergency maintenance in an efficient and effective manner
3. Conserve and control the use of spare parts and material

(Haroun and Duffuaa, 2009)

Current Status The maintenance organization has clearly defined individual roles and responsibilities, reporting lines, and communication lines. The span of control of the organization is effective and supported with well-trained personnel. The organization have a wide network of external specialists that is called in when outsourcing of tasks are needed due to lack of competence.

Problems and Challenges The organization has clearly defined individual responsibilities. The issue here is that the different responsibilities do not seem to be distributed between individuals in the most effective manner.

As previously mentioned there seem to be some issues regarding the defined communication lines. The communication lines are clearly defined and accepted throughout the maintenance organization, the problem is the efficiency of these lines. Information is late, and some is lost.

Another problem in the maintenance organization is the resources allocated, in terms of personnel and knowledge. This lack of proper resources prevents the work from being effectively controlled, and it limits the time to spend on continuous improvement efforts. A result of this is that the cost of maintenance is at a higher level than needed.

As mentioned earlier, in some parts of the organization there seem to be a lack of motivation for implementation of new measures, and to change the way tasks are solved.

During the observations there were also identified cases where maintenance tasks were outsourced due to lack of in-house competences. Later this turned out incorrect, and the needed competence existed in-house.

RACI CHART FOR WORK EXECUTION

Tasks Decisions/Functions	Maintenance Supervisor	Maintenance Planner / Scheduler	Maintenance Manager	Production Supervisor	Tradesman	Reliability Engineer
Work Planning and Scheduling Process	C	R	A	C	C	
Managing with Leading and Lagging KPIs	R	R	R	R	I	I
Execute PM to Specifications	R	C	A		R	C
Execute CM Work to Specifications	R	C	A		R	C
Adjustments to PM Procedures based on KPIs	C	C	A		C	R
Adjustments to CM Procedures based on KPIs	C	C	A		C	R
Rework	R	C	A		R	C
Work Order Close Out	A	C			R	C

Responsibility	"the Doer"
Accountable	"the Buck stops here
Consulted	"in the Loop"
Informed	"kept in the picture"

Fig. 4.1. Effective distribution of responsibilities
(Smith, 2014)

Improvement Potentials and Future Goals To better utilize the competences and distribute the responsibilities in the most effective way it is recommended to use the distribution seen in table 4.1

To solve the issue of late and lost information it is recommended to make the communication lines less rigid. This does not need to cancel the defined communication lines, but to allow shortcuts in addition to them.

The lack of resources is best solved by allocation of additional resources, and by providing additional training for the existing staff. Higher levels of leadership and management knowledge in mid-level management could also resolve the lack of motivation that exists in some parts of the maintenance organization.

To be able to fully utilize the knowledge and skills existing in the organization it is recommended to conduct a structured mapping of competencies of the individuals in the entire organization.

4.10 Materials

As organizations mature in their work planning, material planning becomes essential to successful maintenance operations, enabling the work to be executed with the right tools at the right time. For both tools and spare parts it is essential that they are available when needed to avoid costly extended downtime. To complicate the material handling, having a too high number of tools, or a too large inventory of spare parts are costly as well. This balancing act requires a well functioning material management system to keep sufficient track of available tools and inventory of spare parts.

Current Status At this time there is a central warehouse for storage of all spare parts. It is the warehouse function responsibility to keep the inventory of different spare parts at the level specified by the responsible in the project or maintenance department.

Tools and equipment is located in the maintenance department of the factory. It is the maintenance function responsibility to keep track of tools and equipment, and to notify if ordering of additional items are needed. It is also the maintenance function responsibility to secure the quality and functioning of tools and equipment. There are good routines for both internal and external calibration and verification of selected tools and equipment.

Problems and Challenges A general problem is a too high spare parts inventory. This is the result of the high levels of corrective maintenance, with the following lack of properly scheduled maintenance indicating the time of need. Another factor contributing to the high inventory is a lack of communication to the warehouse when equipment is modified or taken out of service and selected spare parts are no longer needed, or needed less.

Yet again the computerized management system emerges as an issue. The main problems concerning the material handling are a too low degree of integration between Maisy and Visma. Spare parts cannot be ordered directly from Maisy, and there is a lack of needed functions, like most used items, not used items, and so on.

Improvement Potentials and Future Goals To reduce the warehouse inventory there are several improvements that can be made.

As the maintenance program in the future turns more over to preventive maintenance, and reduces the corrective maintenance, there will be better control of the timing of the need for spare parts. Critical emergency spare parts still need to be in stock, but this should be based on a proper criticality analysis of each spare part.

Further improvement could also be achieved by implementing more strict routines of reporting when spare parts are no longer needed, or when stock levels can be reduced.

An upgrade of the computer management system to include queries like turnover of items stock level would also reduce the inventory. For a spare part with a two-week delivery, there is no need to have a stock level of four months turnover. This system upgrade would also help in identifying spare parts no longer needed. A query of parts not used for a set period of time would make this effort a breeze. As of today the information for both turnover and unused spare parts is hard to extract from the system, and to analyze the order history of items is a time consuming effort.

The procedures today says that after commissioning of new equipment, or after a modification project, a report is handed to the warehouse manager stating what spare parts inventory is needed due to these changes. Ironically, there appears to be no lack of communication for this matter. Over the years, this procedure has been done a few times, with a subsequent increase in the number of different spare parts in stock. Assuming all spare parts no longer in use have been removed as a result of some of the previously mentioned measures, there is still a potential of removing more parts from stock. This effort would consist of comparing the specifications of the different spare parts. If there are spare parts that are very similar it must be considered whether the same can be used for both purposes.

Another improvement potential that will not reduce the inventory, but reduce the need for maintenance, is an assessment of the most used parts. There is an ongoing process of moving the most used spare parts out of the warehouse and into cabinets close to the machinery. This measure would reduce the time needed for the job, and for that matter it is a good measure. The recommendation in this case is to rather ask the question, why is this spare part changed so often?? The spare part in use may not be the best-suited part on the market. Other spare parts in the market may last twice as long under the same conditions. This would not only slightly reduce the time needed for the job, but it would reduce the need for the entire job. A consideration has to be given to the fact that a higher-grade spare part most often comes with a price. This price needs to be weighted against savings from the reduction in maintenance need. This procedure can also be applied for other spare parts than the most used. An increase in the interval of the most laborious part-changes could be of great value. The procedure to follow to be allowed to alter the specifications of the spare parts used on equipment is today very laborious and time consuming, even when the alteration is an upgrade. To make this a more common way of reducing the maintenance needs, these procedures need to be revised.

4.11 Supporting Documentation

Supporting documentation in a maintenance context consists of all information relevant for the proper maintenance of the different equipment. This include; procedures, equipment data, drawings, wiring diagrams, lessons learned from previous jobs, and possibly more in some cases. This information is an important part of the maintenance function. It is available to secure the right basis for work to be efficient and safe. Outdated, lacking, or low-quality supporting documentation could lead to inefficient and unsafe job execution. Even though some jobs are routine jobs performed regularly it is still an important and good practice to review the supporting documentation on regular basis to check for updates.

Current Status Today, all necessary supporting documentation is available in different locations on the computer network, and binders located in the factory.

There exist clearly defined procedures to follow on when to update the information and secure its validity.

Problems and Challenges The observations and interviews conducted revealed that on a regular basis the maintenance work is delayed, or more time-consuming than would be necessary due to improper supporting documentation. This problem can originate from either the lack of updating, or the use of outdated information due to information not being updated in all stored locations.

The problem of using outdated information should not exist, unfortunately it does, and another problem follows it. It is seen in several cases that outdated information is being identified, and actions are taken to update the information. Unfortunately, in many cases, this good intention seems to vanish into thin air somewhere on the path to completion.

A similar problem is identified when it comes to procedures. A staff member finds a more efficient procedure to execute a specific job. This new procedure is communicated to the rest of the shift crewmembers, and they all agree on this new procedure. The problem now is to get the supporting documentation updated. In many cases this is not done unless it is a significant change, resulting in only the one shift using the improved procedure.

Improvement Potentials and Future Goals To solve the problem of outdated information being used it is recommended to allocate more resources to the supervision of this task, and to clearly communicate the benefits to the employees to gain their acceptance of the importance. Another recommendation is to completely digitalize the information, and remove all the paper information stored in binders. As the information is being digitalized it is also necessary to use only one well-structured central storage folder on the computer network. This is the only place the information should be stored, and it should be stored in a user-friendly system. This systematic, central storage will ease the updating because there is now only one location to update it. The easy-to-use system of storage would also reduce the time spent on locating the information.

To ease the locating of the relevant information even more it is possible to link the relevant information to the different equipment in the computer system. This would enable the relevant information being attached to the work order on basis of what equipment the work order applies.

Chapter 5

Discussion

In this chapter a discussion of the thesis work process and the results in chapter 4 will be provided.

5.1 Work Process

The model of the Maintenance Loop (Oljedirektoratet, 1998) were used to guide the work of this thesis, and it turned out to be a great tool to evaluate the current status, problems and challenges, and improvement potentials and future goals of all the key elements of the maintenance function.

The model was originally designed for the safety related maintenance in the offshore oil and gas sector. The use of the model in the work with this thesis show that this is not a limiting factor of the model, and it is applicable to other industries as well, like the onshore casting industry which is the case for the use in this thesis.

The model divide the maintenance function into 11 elements, and provide suitable questions to highlight the important areas of the different elements. This was seen as very helpful in order to cover all the elements, and their important areas, not missing out on important parts of the function. In order for the model to be more applicable to the onshore casting industry some of the questions needed to be replaced with questions regarding topics more weighted in the onshore industry. Great care was given in this process, to avoid any important areas to be forgotten. The final set of questions was distributed as mentioned in chapter 3. The replies on these questions however, were few. This is believed to be due to high workload and to little pressure from the author on the importance of these answers. The lack of answers was corrected to a great degree by collecting the information needed to answer these questions using other sources of primary information described in chapter 2.

The scarce information from the questionnaires in combination with primary information from observations, interviews, and data systems was used as basis to identify the current status and the problems and challenges in each of the 11 elements. The secondary information from the literature study was used as main basis for the identification of improvement potentials and future goals. The elements were worked through in the same order as they are presented in chapter 4. This is considered to be an advantageous order as the elements build on each other to a certain degree. This is also believed to be the reason why the model is structured this way, see figure 2.1.

5.2 Results

The results from the work with this thesis show no significant surprises when considering the current status. The current status of the maintenance function at BAF is shared with many other similar companies that have been in production for some years, and not put any great effort into continuous improvement of the maintenance function.

The results show a maintenance function that is still to a certain level operated from the principle that maintenance is an expense. From this principle we have that utilization of the personnel is important to keep expenses down. As can be seen in the case of the mid-level management is that the workload is high, actually too high. The workload is so high that tasks like supervision and efforts to improve the function is not prioritized and left behind. This is contributing to a lesser effective function, and it is the author opinion that this is not utilizing resources for the good of the organization. From this statement it is obvious that all resources available is needed to enable the maintenance function to operate under the current conditions. While the effort to improve the performance is initiated, the maintenance function still needs to perform their tasks under the current conditions. This implies that to be able to initiate and sustain an effort to improve the performance of the function, additional resources are needed. In order to be allocated these extra resources it is needed to present the improvement plan for the top management, and earn their commitment and obligations.

The fact that this is an absolute necessity makes this the first priority on the journey for improved performance.

The results also show that there are two recurring limiting factors present in nearly all elements of the maintenance function. Namely a properly integrated and functioning CMMS, and properly functioning lines/routines of communication.

The design and implementing of a proper CMMS is a laborious and time-consuming effort. This, in conjunction with the critical need of this to be in place to achieve the desired increase in performance, makes it important to start this task as soon as possible in the process. The results of this thesis tell nothing about the limitations of the systems in use. A new system may not be needed. The possibilities of customizing and improve integration of the systems already in place need to be considered first. For the reasons mentioned above this effort is given the second priority in the improvement process.

The implementation of most of the improvement measures described in chapter 4 requires good collaboration between several employees in different areas of the function. A prerequisite for this to be a smooth effort is to have properly functioning communication throughout the function. This is the reason why the sorting of communication issues is given the third priority in the improvement process.

The other potentials for improvement are of a lesser significance, and not spanning the entire function. No special prioritizing of these measures will be given, but it is important that the responsibilities are sorted out as early as possible, and that the process is initiated to be able to mature throughout the maintenance organization.

During the process it is very important that responsible and managers show good leadership, determination, patience, and are goal-oriented. A prerequisite for the success of the improvement effort is that it is accepted in the staff. To obtain this it is important to communicate the aims properly, and to include as much as possible of the staff in the process to gain ownership from the staff.

Chapter 6

Conclusions

This thesis has proven that the Maintenance Loop is an effective tool to assess the maintenance function of land-based manufacturing companies.

The importance of CMMS and good communication has been extensively proven.

It has also been proven that achieving a high level of maintenance performance does not come at a bargain over night. It demand hard work, resources, patience, and commitment.

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