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- a case study at SKF Gothenburg

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## Abstract

For a machine dependent company like SKF every minute of unplanned machine stops is a large cost. Correcting machine failures quickly is therefore extremely important and to achieve that the corrective maintenance is a vital process. With the purpose to improve the corrective maintenance at SKF Gothenburg, this thesis was performed as a case study at the company.

To be able to evaluate the processes of corrective maintenance a model was created. This model was then used together with data gathering, observations and interviews to evaluate how the maintenance was performed at SKF Gothenburg. Based on the outcome of these, three improvement areas were found; Goal setting, Resource planning and Communication. Also nine different recommended measures for SKF to take within the three areas are presented. If these measures are taken, corrective maintenance at SKF Gothenburg will become more efficient and the total repair time will decrease.

Key words: Maintenance, Corrective maintenance, Corrective maintenance evaluation

## Acknowledgements

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To perform the study observations were made together with the technicians. The shift team that spent a week teaching, explaining and demonstrating the maintenance processes deserve special thanks. Without your openness it would have been almost impossible to understand the complexity of your work. Also a warm thank you goes to all the interviewees that took time from their busy schedule to speak with us and answer all our questions.

Performing this thesis has been a valuable learning experience for both of us, in terms of corrective maintenance but also about SKF as a company.

Again, thank you!

*Gothenburg November 2011*

Erik Adolfsson Tuvstarr Dahlström

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## Definitions

| | |
|---|---|
| Central maintenance unit | The unit under FSM that is responsible for the corrective maintenance. |
| Corrective maintenance | Is done to return the equipment to working condition after breakdown or after perceived deficiences that are severe enough to cause a stop in production. |
| D, RK, E, H-factory | The different factories in the SKF Gothenburg site. |
| Downtime | The total time the machine is standing still in production due to an error. |
| FSM | The Facilty and Service Management is the department within SKF Sweden where the maintenance sub department is situated. Other FSM sub departments are technical support, property management and energy systems. |
| Functional maintenance unit | The units under FSM responsible for the preventive maintenance. |
| MIS | Maintenance information system. |
| Order accepting | Is what the technician does when he/she starts working with the order. It is done through the maintenance information system. |
| Planned maintenance | See preventive maintenance. |
| Predictive maintenance | Using technology to diagnose items or equipments condition duing operation. |
| Preventive maintenance | Is carried out regularly or after inspection in order to keep the equipment in working condition. In litterature also refered to as planned maintenance. |
| Repair time | The time from that the corrective maintenance order has been accepted by a technician untill the machine is running again. |
| Response time | The time between that the corrective maintenance order is put in and when the order is accepted by a technician. |
| Technicians | The staff that perform maintenance. |
| Total repair time | The total repair time is the sum of response and repair time per order. |

# 1 Introduction

*In this chapter the master thesis subject is presented as well as the problem analysis and the purpose of the thesis. Also the research questions and the delimitations are presented.*

## 1.1 A brief introduction to maintenance

The competitive pressure on the market is forcing companies to explore every possible competitive advantage with the goal to find the potential in every single process (Pintelon and Pinjala 2006). A high performing production system is not only dependent on an operational design but also on the processes of taking care of the system. This includes maintenance that aims to keep the system in an operational condition or bring it back to an operational condition after a break down (Blischke and Murthy 2003).

The cost of maintenance in Sweden is estimated to be 6.2 % of the industry turnover every year. As much as one third of the maintenance cost is estimated to exist due to bad planning, badly performed preventive maintenance and overtime costs which leads to unnecessary increased production costs (Salonen och Deleryd 2011). With a correct maintenance strategy the downtime and the maintenance cost can be radically decreased (Pintelon and Pinjala 2006).

Corrective maintenance, sometimes called break down maintenance, is used when a system or machine fails. It includes repair and replacement of failed parts to create a successful operation again. The corrective maintenance actions are, in contrast to preventive maintenance actions, not schedulable (Blischke and Murthy 2003). This makes them harder to plan and more costly to perform.

## 1.2 SKF background

SKF is a bearing manufacturing company founded in Gothenburg in 1907. In 2010 it had a turnover of 61 029 million SEK, over 140 manufacturing and operational sites and over 44 000 employees in 32 countries. SKF does however not only provide its customers with bearings but also seals, mechatronics, services and lubrication systems.

In Gothenburg, SKF has its main office and four factories producing bearing parts and whole bearings in the medium to large segment. Also, SKF's bearing analysis centre, laboratories and a research centre for process development are situated in Gothenburg.

## 1.3 Maintenance at SKF

As discussed above, maintenance is a very important area for providing an efficient production and the corrective maintenance is in fact, if utilized correctly, a cost saver. This is of course also true for SKF where a stop in any machine is a large cost. When an event of this kind occurred, it is of great importance that the error is corrected as quickly as possible so that production can continue. At SKF the corrective maintenance is called in when a machine is producing too low quality and has to be stopped or if the machine stopped on its own of some reason.

The purpose of the corrective maintenance was to assist the production by keeping the availability of the machines as high as possible to ensure high productivity. The focus of the central maintenance unit, who produce the corrective maintenance at SKF, was therefore to have as short response and repair time, i.e. total repair time, as possible while keeping the costs down.

The previous five years, the corrective maintenance at SKF gradually had been separated both geographically and organizationally from the preventive maintenance. This was done to create better control of the maintenance. The preventive maintenance was moved closer to the operators while the corrective maintenance was kept as a central resource. By doing this technicians could also get more specialized in the different fields of maintenance. The preventive maintenance units and the central maintenance unit could thereby specialize in their type of maintenance.

## 1.4 Problem analysis

SKF had a goal of decreasing the time used for corrective maintenance in relation to preventive maintenance, for financial reasons. At the time of the thesis the actual situation was roughly 40 % corrective and 60 % preventive maintenance while the goal was 20 % corrective and 80 % preventive maintenance.

When looking at corrective maintenance the total repair time, defined as the time from when a corrective maintenance order was received until the machine is fully operational, was the main focus but it could be divided into smaller parts. The response time, for example was one sub part defined as the time from when the corrective maintenance order was received to when a member of the central maintenance team was on site. According to SKF the response time was on average one hour, but varied between a few minutes to ten hours. What the variations depended upon was not fully understood. The dimensioning of the staff was at the time therefore mainly done based on experience and "gut feeling". An interesting example was during the recession in 2009 when some of the staff was moved from the central maintenance unit, but the expected effect on the response time was negligible according to the maintenance manager and the reasons were not self-evident.

The central maintenance unit, where the corrective maintenance was done had two more goals. One goal focused on response time; maximum 10 % of the response times were allowed to be over one hour. This goal was set to reduce total waiting time in the production. The other goal SKF had was to become more consistent in the reporting in the maintenance information system. This goal was also supposed create a structured way to share information between the central maintenance team, the operators and the preventive maintenance teams. Earlier, when all the maintenance technicians were stationed in the same building the communication was more informal.

SKF was aware that different improvements could be done to reach these goals on all levels of the organization. To see if there were any general improvement possibilities on the operational level, the machine or channel level, with aim to improve the preventive maintenance an internal report was made (Ohldin 2011). The report was based on corrective maintenance reports from five and a half years in one of SKFs factories in Gothenburg and showed that there were a few general improvement possibilities in different areas. For example there were needs for better handling of spare parts, better control of machine drawing and a better structure for using the maintenance information system. Another conclusion was that the sensors in the machines were a reoccurring problem that could be handled by changing the sensors to a "plug and play" model that the operators themselves could change (Ohldin 2011). All of these improvement ideas were not on the strategic or tactical levels but in its context for operation it showed that there were a lot of things that could be done.

Even though there were goals on a strategic level and the managers were following up on how the unit was doing in respect to these goals, the development of the corrective maintenance could have been better since it was not reaching its goals. To provide an effective central maintenance unit, potential areas of improvement could be found to focus the efforts in order to achieve a direct and positive development. This would lead to better planning of the work force and better utilization of the resources that in this case was the maintenance technicians in the central maintenance unit.

## 1.5 Purpose

The purpose of this master thesis is to analyse the corrective maintenance at SKF Gothenburg to find areas that can be improved to facilitate a more efficient service.

## 1.6 Research questions

Based on the purpose and the problem background, four research questions (RQ), which to a large extent are building on each other, was formulated.

To be able to understand how an organisation dealing with corrective maintenance is working, a model for describing and analysing was developed.

> RQ1: Develop a model that can be used to describe and analyse a corrective maintenance department.

Further, the general model could be used to describe the situation at SKF and thus providing an empirical base for the thesis.

> RQ2: How does SKF Gothenburg work with corrective maintenance?

To fulfil the purpose the potential areas of improvement had to be identified.

> RQ3: Which are the major potential improvement areas in the central maintenance unit?

The stated improvement areas then had to be analysed from the perspective of reducing the aggregated total repair time and increasing the customer value and thereby improve the maintenance service. The effects and risks of potential changes were also of importance.

> RQ4 What changes can be made to improve the areas identified in RQ3?

## 1.7 Delimitations

SKF is a global company, but the central maintenance unit in Gothenburg does not have direct links to other maintenance departments at other sites. Therefore, the thesis is geographically restricted to only investigate the Gothenburg site.

There was a large forthcoming change in the factories in SKF Gothenburg that had to be taken into concern when writing this thesis. The H factory had been sold to another company since it was not seen as a core competence any more, but SKF would continue to handle the corrective maintenance for short period of time. To be sure that the figures were accurate, in terms of for example resource utilisation, the factory was included in the research, but when discussing the future and making prognoses the H factory was excluded.

In this thesis a lot of data from the maintenance information system was used to answer the RQs. In the current system data was available from 2005 but older data, between 2000 and 2005, was also available from another system. To have a large enough amount of data to be representative, going back five years were decided to be enough. Another reason why five years seems appropriate was that there had been a lot of changes in the central maintenance unit historically. And as older data was less representable for the department's present state it could give less accurate results.

Another limitation was regarding the maintenance information system data. Every summer SKF shut down the production in the last two weeks in July. The two weeks before and after that, the maintenance was not working as usual due to holidays for the staff and that the production was not running at full speed. This made the data from July and August misleading for any maintenance done in any of the factories. Due to this, these two month every year had been excluded from the data.

# 2 Methodology

*In this chapter the methods used throughout the work with this master thesis is discussed. First an overview of the methods in correlation the research questions are presented and then the reliability and validity of the findings are discussed.*

This master thesis was conducted at SKF Gothenburg where the maintenance of machines and equipment with focus on the corrective side was studied. The thesis report was structured and presented as a case study with a deductive base. The case study is an appropriate method to use when studying a specific process in reality and it is a good way to study a limited area (Ejvegård 2009). But it is also important to keep in mind that the results from a case study are possible to apply to other situations (Ejvegård 2009; Bryman and Bell 2005). This disadvantage can be seen as a trade-off between the usefulness from an academic viewpoint, and possibility to be able to give good recommendations to SKF Gothenburg. But by having used a thorough literature study as a basis for a model handling the overall topic of corrective maintenance, this part is believed to be usable in other semi-automated producing companies as well.

A case study is also a good research method to use together with other methods (Ejvegård 2009). In order to fulfil the purpose and answer the RQs different methods was used. Figure 1 below illustrates what methods were used to answer the research questions.

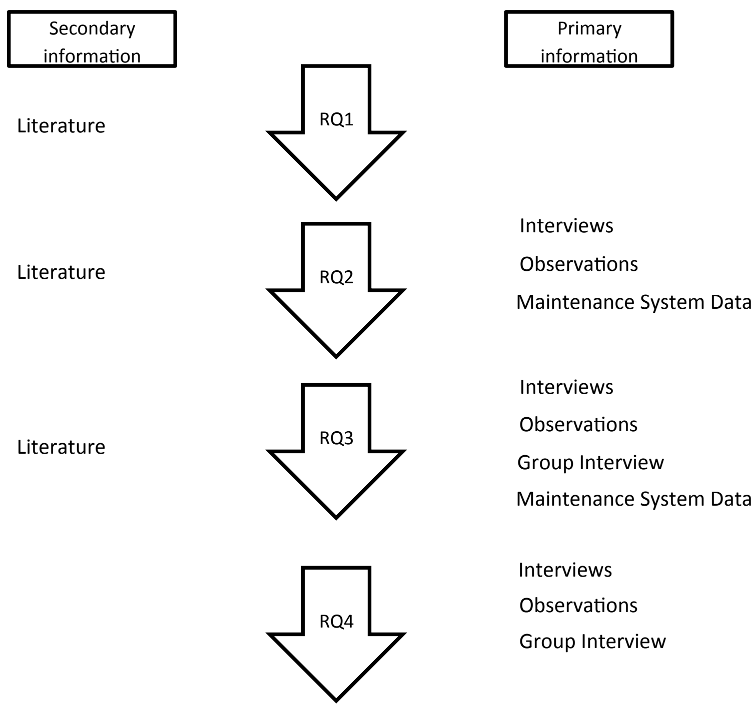


**Figure 1 Methods used linked to the RQs**

RQ1, Develop a model that can be used to describe and analyse a corrective maintenance department, was answered through literature studies in the area while RQ2, How does SKF Gothenburg work with corrective maintenance, mainly was answered by several observations and interviews, informal as well as formal, with concerned persons at SKF. Data from the maintenance information system was also used to give a thorough picture of the state of the corrective maintenance. To make sure that the right areas were covered academic literature was used.

The information gained to answer RQ2 was used to answer RQ3, which were the potential improvement areas in the corrective maintenance unit. The answer to RQ3 was of course used as a basis for the answer to RQ4, What changes can be made to improve the areas identified in RQ3, together with the model created in RQ1, interviews and observations.

The different methods used are further described below, were they also are divided into primary and secondary data as in Figure 1. After that, validity and reliability of the data and the results are discussed.

## 2.1 Secondary information

Secondary information is information that has been produced for another purpose than the forthcoming study (Björklund and Paulsen 2003). In this thesis the secondary data consists of information from literature studies.

### 2.1.1 Literature study

An academic literature review regarding maintenance was conducted and worked as a basis for the thesis. After an overview of maintenance, the focus in the literature review was turned to corrective maintenance. The literature was used to find a model for analysing the maintenance management discussed below. The literature study was mainly performed in the beginning of the thesis work but was followed up and expanded throughout the process.

The literature used was in form of academic articles, handbooks and books. To find the appropriate literature multiple search engines was used such as Chalmers library, Google scholar and the databases made available by Chalmers (for example Business Source Premier and Emerald Library). The searches were based on the following key words: maintenance, corrective, planning, preventive, maintenance management, framework, criteria, lean and different combinations of these.

The field of corrective maintenance has not had a lot of academic attention and most of the literature found focused preventive or overall maintenance.

### 2.1.2 Development of the Corrective maintenance model

The literature review ended with a transition towards finding existing frameworks in corrective maintenance. As mentioned, corrective maintenance has not received much attention in literature and the existing literature mostly described parts of the corrective maintenance in relation to preventive maintenance. This was also the case for the existing frameworks. In order to fit a theoretical framework with reality and to have a relevant analysis a new model was needed.

In the literature, four main frameworks were found that described maintenance in different ways. These were merged into one model that could be used to describe and analyse corrective maintenance. The model was then discussed from different viewpoints, dissembled and reassembled again to ensure that the model communicated what the authors had intended.

## 2.2 Primary information

Primary information is information that is collected for usage in a specific study. Gathering primary data is important to in order to create an understanding of a specific research object (Björklund and Paulsen 2003). The primary data for this thesis has been collected through observations, interviews and from the maintenance information system.

### 2.2.1 Observations

Observations were conducted as a way to establish how the maintenance work was conducted at SKF. The observations were used to get an understanding how maintenance were produced at the company and the behaviour of the people involved. Nine days of observations were performed at different parts of the maintenance organization at SKF in the Gothenburg plants.

According to the literature, observations can be a very time consuming, but can also give more objective data (Björklund and Paulsen 2003). When conducting an observation, what is observed is what actually is done and not what is said to be done, although time is usually a concern. Through planning the observations became time efficient enough to be considered and observations were therefore used in the study.

Observations can be conducted differently depending on the purpose of the observation. The observers can be participating in the activity observed or just observe it from distance. Another option can be to inform the participants that they are going to be observed in forehand, direct observations, or to do the observation secretly, indirect observations (Björklund and Paulsen 2003). To be able to follow the maintenance teams in the plants the authors had to arrange an appropriate time with the teams and when the authors arrived they were presented to the persons they were to follow, hence the observation style was direct. The observations carried out did not include any measurements of performance; instead they focused on gathering information about the processes and the resources. This meant that a participative observation style could be beneficial in order to gather as much information as possible. Further, the observations were also meant to find improvement factors that could be found either by observing what is done and what is not done or by having a dialogue with the participants during the observation. For the thesis it was concluded that a participative observation method were to be adopted. However, it is the belief of the authors that a non-participative observation method could have worked just as well if combined with additional interviews.

To fully understand the processes within the corrective maintenance performed at SKF, it was important to have knowledge about how the preventive maintenance was planned and executed and not only the corrective maintenance. It was also important to get a feeling of how the central maintenance unit and the functional maintenance team communicated. In order to gain that understanding, observations of the functional maintenance teams were carried out. After these observations the focus was shifted to the corrective maintenance where more extensive observations were conducted.

### 2.2.2 Maintenance System Data

The maintenance information system at SKF was called the API system. API stands for Analysis, Planning and Information. In the system data for both the planned and the corrective maintenance was included. At SKF the API is a central source of data for example when regarding how the variations in response and repair time were distributed over time. Also data regarding what types of errors and how they vary over time were collected from this system.

Information from the API system was used to answer the research questions in different ways. The academic literature proposes different measures to see how well the maintenance organization was performing; those values were found in the API system. When specific data were not available in the API system, additional information was collected from maintenance managers. These measures were used in RQ2 to see how the organization was working and in RQ3 and RQ4 to exemplify how the discovered factors affected the performance of the department.

### 2.2.3 Interviews

An interview is commonly done with one or more interviewers and one interviewee. There can also be more than one interviewee; this is specified as a group interview which is different in many ways with a regular interview. An interview is done as a conversation between the two parties where the interviewer has prepared questions. An interview is a good way to gather information that otherwise could be hard to get through other methods, such as questionnaires or observations (Esaiasson, et al. 2009). In the study, six interviews were carried out with production representatives, see Appendix A. Further, additional interviews with Christian Moldén and David Berndtsson were done repeatedly during the time of the thesis. The main goal was to gather opinions and ideas from the people working with or close to maintenance or to get an understanding of different processes.

Interviews need to be documented in some way. The best way according to Eliasson (2010) is through recording. However, in some cases it might be more suitable to take notes instead. In the study taking notes were considered appropriate since there was a risk that the interviewees would be very careful with their answers if they were to be recorded. However, there are two important drawbacks with taking notes instead of recording that needs to be considered. The first one is that it is difficult to correctly quote the interviewee. The second drawback is that it can be difficult to actually prove that specific information has come from the interviewee (Eliasson 2010). These drawbacks were considered to be less important than getting authentic opinions from the interviewees, and were dealt with by having good documentation.

There are three types of interviews: non-structured, semi-structured and structured (Eliasson 2010). The non-structured can consist of perhaps only one question to the interviewee, who then gets to speak freely about the subject. The semi-structured contains a few more questions than the non-structured. This allows the interviewer to control the interview to a higher degree. The interviewer can thereby cover more areas or go in depth into a specific area. The structured interview is the easiest to document and can even be used for quantitative data gathering. However, it is most commonly used to cover a predetermined set of questions for a specific use. The interviewer can have difficulties with going in depth into an area. For the scope of the study a semi-structured interview type was used. The semi-structured approach allowed the interviewers to ask specific questions but at the same time allowed the interviewee to freely express ideas and thoughts. The list of interview questions used can be found in Appendix A.

Interviews are not the prefered method to use for finding quantitative data and should therefore be complemented by other suitable metohds in order to find specific data (Eliasson 2010). This information was found through the MIS.

***Group interview***

During the latter part of the study a group interview was conducted (discussed topics can be found in Appendix B). A group interview is an interview with more than one interviewee and can be used for different purposes; in this case there were five interviewees. One common purpose of group interviews is to investigate group creativity (Björkman 2004). According to Frey and Fontana (1991) a group interview can also have the goal to generate hypotheses or respond to scenarios. At the same time Frey and Fontana (1991) argues that group interviews can be used to interpret results. Eliassion (2010) further argues that interviews can be used to validate theories when information is difficult to find. The goal with the group interview was to discuss the preliminary findings with the people responsible for the different maintenance units in order to validate the areas of improvement and to explore opportunities for further improvements. An option would have been to test different improvements areas but as this would be beyond the scope of the study and it would require additional months to finish, the option was discarded. A group interview methodology was thereby the given choice to achieve both validation and to seek opportunities, due to its advantages in producing constructive ideas while keeping an open discussion. The interviewees consisted of the head of the different branches within the maintenance department and the head of the entire department. The group was chosen because of its knowledge, its ability to take decisions and its ability to implement changes.

One disadvantage with the group interview was that the discussion could have been affected by hidden social or hierarchical factors. One major advantage, however, was that there could be one discussion between all involved parties where ideas could be explored and consensus could be found. The disadvantage was considered but both due to the importance of the discussion and because of the lack of other viable methods it was decided to use the information gathered during the session.

## 2.3 Reliability and validity

When doing research there are some terms used to value the outcome, making sure that it is trustworthy (Eliasson 2010). Reliability and validity are two terms used meaning in what extent the results of the study are reliable and valid (Bryman and Bell 2005).

### 2.3.1 Reliability

Reliability means to what extent the result of the research is repeatable. In other words, if it were done again would the result be the same (Bryman and Bell 2005). According to Olsson and Sörensen (2007) the reliability of a study is ensured for example through having a high data quality.

The data used in the study came from the maintenance information system, API, at SKF. Technicians and operator entered this data when handling the specific orders. The way that the information in the orders was entered had just been standardized at the time of the study and the quality was improving. This was handled in the way that the old data was seen as an indicator of the development and the later data was used when looking at the potential future changes.

There were some obvious errors in parts of the reporting. For example the downtime reported from the operator and technicians were not correlating which was an indicator that the actual data quality could be higher. Also managers believed that the time reporting in some units were a slightly incorrect from the functional maintenance side. Apart from using the most recent data as a base for the analysis also the interviews and observations had been a basis for the analysis and were used to back up the numeric information.

The interviews were conducted in a semi-structured way, which opened up for follow up questions. Other interviewers might ask different follow up questions and thereby get partly different results but since the interviewees had strong opinions on the topic the general results and input would be the same. During the interviews one of the authors was responsible for note- taking and the other was asking the questions. After each interview the notes were gone through and discussed together and transcribed to make sure that nothing was missed. Recording the interviews could of course have been another good option but the authors were asked to not record anything from any employee at SKF. The authors also performed several interviews and together with observations that supported the opinions the results are thought to be reliable.

When doing observations the results can vary depending on who is observing. The attitudes and processes could of course vary based on the relationship the observed have with the observers. The authors tried to be as objective and responsive as possible during the observations and if the observations would be done again in the same way the same results would most probably be obtained.

### 2.3.2 Validity

Bryman and Bell (2005) divides validity into internal and external validity. External validity is whether the results of the research is generalizable or not and the internal validity is defined as if the measures used really measured what was intended (Bryman and Bell 2005).

Since this thesis was performed as a case study the thesis is to a large extent not externally valid. Some parts are, however, believed to be generalizable such as the Corrective maintenance model discussed below and the general literature review.

To make sure that the model developed was not only a product of academic papers but also had significance in reality it was validated by Christian Moldén, the manager of the maintenance department at SKF. The background information in terms of literature that made out the basis for the new model was presented to Mr Moldén in written form and through a short oral presentation. After this, the new model was presented in the same manner. Also the indicators, both currently used and the ones suggested in the academic literature, were discussed to make sure that the model was usable in reality. Mr Moldén considered the different aspects and found the model useful.

Other methods for validating the Corrective maintenance model could also have been taken, for example by having academic experts in the field of corrective maintenance analysing it. However the model was developed based on an extensive base of theoretical academic papers and can thereby be regarded as valid from that perspective.

When the improvement areas in RQ3 were identified, a group interview was held to validate the findings. The five attending individuals were representing different parts of the maintenance organization. For more information about the structure of the meeting please see 2.2.3 Interviews. Background information was presented and different areas were discussed during the discussions. In the meeting the areas were discussed and accepted by the group. Also some solutions were mentioned and discussed by the attending.

# 3 Frame of reference

*In this chapter a literature review in the area of maintenance is presented. The aim was to create a theoretical foundation to be used to analyse the state of the corrective maintenance and the effects of possible future changes at SKF for the central maintenance unit. Since the focus of the thesis is corrective maintenance, this is the focus of this chapter as well. Since corrective maintenance is very closely related to preventive maintenance that will briefly be handled when needed.*

## 3.1 Definitions of maintenance

Maintenance is an important organizational function that is needed to support production related processes. Breakdowns in production directly affect the output of the processes and thereby the profitability. Companies have different views on how maintenance can be used. Traditionally it has been seen as a necessary evil and that maintenance have complex relationships to other functions in the company (Ben-Daya and Duffuaa 1995). Further, Ben-Daya and Duffuaa (1995) argues that:

> *"In general terms, equipment which is not well maintained and fails periodically experiences speed losses and/or lack of precision and, hence, tends to produce defects. More often than not such equipment drives manufacturing processes out of control. A process that is out of control produces defective products and therefore increases the production cost which amounts to less profitability which endangers the survival of the organization."* (Ben-Daya and Duffuaa 1995)

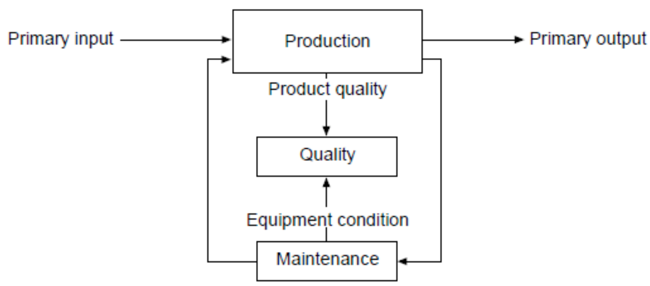


**Figure 2 Relationship between maintenance and quality (Ben-Daya and Duffuaa 1995)**

The quotation and Figure 2 above show the relationship between production output and maintenance. Ben-Daya and Duffaa (1995) clearly express the importance of maintenance in relation to quality where other literature (Salonen and Deleryd 2011; Dhillon and Liu 2006) focus more on the direct costs and profitability. Quality can express different things, two of the most common definitions are: *The features of a product that meet customer demand* and *Free from deficiencies* (Juran 1998). Regarding maintenance, the definition of quality: *Free from deficiencies* is perhaps the most fitting but it can also be argued that the customer aspect is just as important in maintenance as in any other department. However, the customer of maintenance might not be the consumer of the finished product, but another department or company.

Dhillon and Liu (2006) separates maintenance and catogorize them as: preventive, corrective and predictive maintenance. Preventive maintenance is often reffered to as planned maintenance and is carried out regularly or after inspection in order to keep the equipment in working condition (Dhillon and Liu 2006). Corrective maintenance is done to return the equipment to working condition after breakdown or after perceived deficiences (Dhillon and Liu 2006). Lastly Dhillon and Liu (2006) describe predictive maintenance as using technology to diagnose items' or equipments condition during operation. Predictive maintenance can also be the process of gathering information about the state of the equipment (Niebel 1994). The information gathered is then used to plan and schedule maintenance.

Preventive and predictive maintenance is closely related and are because of this often treated in a similar way, which is also the case in the literature that have been used in this report. According to Salonen and Deleryd (2011), preventive maintenance can be regarded as value adding while corrective maintenance is regarded as waste. This relates to the fact that facilities and machinery need regular maintenance to function in an optimal way. However, stops due to breakdowns can relate to lack of preventive maintenance, human error or other kinds of problems that can be avoided and hence are considered as waste. More specifically the following model (Figure 3) can be used to categorize maintenance:

| | Corrective maintenance | Preventive maintenance |
|---|---|---|
| Cost of Conformance | Indispensable corrective maintenance:<br>Corrective Maintenance due to:<br>- Failures with random distribution and no measurable deterioration<br>- Failures which are not financially justified to prevent | Valid preventive maintenance:<br>Preventive Maintenance, necessary to uphold necessary dependability<br>Improvements intended to increase the reliability of equipment |
| Cost of Non-conformance | Non-accepted corrective maintenance:<br>Corrective Maintenance due to:<br>- Lack of preventive maintenance<br>- Poorly performed preventive maintenance<br>- Poor equipment reliability | Poor preventive maintenance:<br>Unnecessary Preventive Maintenance<br>Poorly performed Preventive Maintenance |

**Figure 3 Cost of conformance/non-conformance in relation to maintenance type (Ben-Daya and Duffuaa 1995)**

Corrective maintenance is more costly than preventive since preventive can be planned and therefore be executed at a preferred time and date (Campbell and Jardine 2001). Corrective maintenance also implies that a company needs to quickly find material and personnel for reparation which, according to Campbell och Jardine (2001), increases the cost. Campbell and Jardine (2001) present a rule of thumb where corrective maintenance in general cost 50 % more than planned stops and breakdowns cost 200 % more than planned stops. The cost aspect is a driving factor for producing companies to shift from corrective to preventive maintenance.

The ideal state is to only have preventive maintenance when considering the numbers from Campbell och Jardine (2001), but as Salonen and Deleryd (2011) shows in Figure 3 it is not always justified to do so. To create a well working maintenance organization, both preventive and corrective is important (Dhillon and Liu 2006). Preventive maintenance should be carried out to ensure a satisfying working condition while corrective maintenance should handle random distributed errors and failures that are not financially justified to prevent (Salonen and Deleryd 2011). Hence, both types of maintenance are equally important parts to have in a sound maintenance organization.

### 3.1.1 Division of maintenance work

How large percentage of the total maintenance work that should be corrective maintenance is debatable. Jonsson (1997) states that corrective maintenance is not supposed to go over 30-40 %, however, in the study presented 50 % of the time is spent on corrective maintenance. According to Ben-Daya, et al. (2009) an effective maintenance organization has 80 % or more preventive maintenance, which leaves 20 % or less for corrective maintenance. Also Kelly (2006) uses 20 % as a good aming point. A different distribution signals a lack of control of the manufacturing equipment. However, Nyman and Levitt (2010) states that only a proactive maintenance organization can reach such low numbers in corrective maintenance. A reactive organization can, however, have up to 55 % corrective maintenance.

Nyman and Levitt (2010) argue that in a proactive maintenance organization, there should be a specific division of work. Group one works with routine jobs, such as planned preventive maintenance. Group two works with jobs that are less critical but still need to be carried out. Group three handles urgent or emergency jobs (Nyman and Levitt 2010). The emergency group is sized properly if they can handle almost all emergency jobs, and are not to seek help in more than 10 % of the cases (Nyman and Levitt 2010). When help is needed, staff from group two are to be called in, not from group one. This type of maintenance setup is closely related to only having preventive and corrective groups where the preventive teams handle all scheduled work including non-critical jobs.

### 3.1.2 The maintenance structure

How the maintenance is structured is often based on the specific situation of the company. Alternatives are to outsource the entire process or parts of it, centralize it, decentralise it or any combinations of these.

In smaller or medium-sized organizations where all production is housed in one structure, centralized maintenance is often the most beneficial and naturally most common (Niebel 1994). But, centralized maintenance is also very useful when the machine operating staff is responsible for the majority of the preventive maintenance (Niebel 1994). Ben-Daya, et al. (2009) and Niebel (1994) discuss the advantages and disadvantages of a centralized maintenance organization. Table 1 below summarize the opinions:

**Table 1 Advantages and disadvantages of a centralized maintenance organization**

| Advantages | Disadvantages |
|---|---|
| Flexibility and efficiency | Time to get to and from jobs |
| Less staff is needed | Less specialization in individual equipment |
| Allows more effective training | Cost of transportation connection |
| More effective line supervision[1] | Less effective work supervision due to the remoteness of maintenance |

In a decentralized maintenance organization, different maintenance groups are assigned to different areas, departments or units. One of the major reasons for decentralization is to come closer to the actual demand of maintenance. This will decrease the travel time between the office and the point of need but perhaps more importantly; it will create bonds to the operating staff as well as making the maintenance personnel more specialized on the equipment (Niebel 1994). The major downside of decentralization is less flexibility, lower manpower utilization and a lower range of available skill (M. Ben-Daya, et al. 2009). If machine operators are to take responsibility for preventive maintenance, as discussed in centralized maintenance, the benefits of the decentralized organization are lost which indicates that centralization is best used in large organization (Niebel 1994).

In large enterprises a combination of centralized and decentralized maintenance organizations can be used to reap the benefits of both while reducing the effects of the disadvantages (Niebel 1994). One combination is what Ben-Daya, et al. (2009) describe as a cascade system, where a centralized unit take care of work that exceeds the capacity of the decentralized units which creates a flexible system with a good utilization rate.

In complex production environments the staff has to specialize in certain areas which leads to decreased flexibility. In that case outsourcing can be favourable if additional training is too demanding, but the contract issue can be complex. Outsourcing also seems to be more common in small firms (Jonsson 1997).

## 3.2 Planning strategies

To be able to perform effective and efficient maintenance, maintenance planning is important.

### 3.2.1 Forecasting

The critical aspects of maintenance capacity are the number and skills of the personnel (M. Ben-Daya, et al. 2009). To control that the right skills are present in the maintenance department, training and hiring new people can be useful. However, having the right size of staff is much more difficult when dealing with corrective maintenance, due to the corrective maintenance load is uncertain (M. Ben-Daya, et al. 2009). The uncertainty stems from that maintenance work has on average longer cycle time than other

[1] Line supervision becomes better, according to Niebel (1994), due to one individual is responsible for all maintenance (if assuming one individual). This individual is usually more highly selected and trained than any counterpart in a decentralized organization.

manufacturing operations, most maintenance is specific and non-repetitive and the conditions and operation times vary greatly (Niebel 1994). Because of the uncertainty, Ben-Daya, et al. (2009), argue that forecasting is important. At the same time organizations tend to reduce the number of available personnel to increase the utilization rate, this can, according to Ben-Daya, et al. (2009), create a backlog of unfinished work. To assist in the forecasting the maintenance information system, discussed later in the thesis, can be used.

Forecasting can be based on either qualitative or quantitative data. Qualitative forecasting is often used when there is absence of historical data and experts' opinions play therefore a major role. Quantitative forecasting is used when historical data is accessible, precise and contains the right information. Ben-Daya et al. (2009) suggest the following steps to follow when designing a quantitative forecasting model:

1. Define the variables and identify the causality.
2. Collect and validate data.
3. Search for major trends such as seasonality.
4. Propose different forecasting models.
5. Validate the models and select the best one.
6. Improve the performance of it.

In a medium ranged planning, a mixture of the two methods, quantitative and qualitative forecasting, can be used.

### 3.2.2 Long term strategic planning

Maintenance capacity planning is of a highly strategic nature as the main resource is people and the planning is therefore often on a long or midterm horizon (M. Ben-Daya, et al. 2009). The level capacity is highly sensitive to errors, where a too high capacity results in low utilization and too low capacity can create stoppage costs as well as shorten the lifecycle of the equipment. To determine the capacity that is needed over time, different capacity strategies can be found in literature. Two of the common strategies are shared with other manufacturing capacity planning strategies; namely chase strategy and levelling strategy. The chase strategy is characterized by utilizing flexible resources and thereby changing capacity to meet the exact current, and possibly fluctuating, demand (Jonsson and Matsson 2009). Levelling strategy is the opposite of chase, where a company decides on a constant resource level and will then be forced to cut peaks and deal with that in times with less demand (Jonsson and Matsson 2009).

Moreover, Ben-Daya, et al. (2009) present two additional strategies: Demand management and subcontracting. Demand management is where preventive maintenance is schedueled equally among all periods and thereby lowers the demand for corrective maintenance. Subcontracting is a strategy which uses the skills of the employees that are working with the machines by having them do maintenance on a fixed amount of time during each month. Any additional maintenance needed are bought in from an external part (M. Ben-Daya, et al. 2009). These four strategies are often not used individually, instead they are mostly combined (M. Ben-Daya, et al. 2009).

***Sizing the maintenance staff***

Sizing the staff is a long term planning decision. As discussed above the corrective maintenance load is uncertain which makes the staffing very complex. Also Kelly (2006) states that the corrective maintenance needs are difficult to schedule after, since the occurrence is random. So in the literature there are no clear answers to the question of how the sizing of the staff should be handled.

What can be measured is the average work needed in this category of maintenance. But in companies this is not often attempted and together with low levels of shift-supervision it easily leads to over-staffing the teams that deal with corrective maintenance. The best measure for this is the demanded maintenance and the man-hours available per shift (Kelly 2006).

### 3.2.3 Short term

Maintenance planning on a short-term basis can be called scheduling. Scheduling is done for one day up to one week where resources are matched with demand (M. Ben-Daya, et al. 2009). In corrective maintenance it is often difficult to schedule the work in the future, so other guidelines become useful. Ben-Daya, et al. (2009) argues that the following guidelines are to be used: arrange orders by priority; 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 they create a sort of guidance in the matter.

However, when dealing with corrective maintenance only, most orders are very urgent and can therefore not be prioritized further in terms of importance (Nyman and Levitt 2010). Instead, other priority rules may be more suitable such as lowest estimated repair time first. Moreover, Ben-Daya, et al. (2009) stresses that it is desirable to have different teams with the same capabilities which would make it possible to handle similar jobs at the same time. Further, Ben-Daya, et al. (2009) express the usefulness of having teams of different capabilities that could work together on jobs that requires different kind of skills. These jobs should be prioritized for both teams because if only one team finish its part, the machine or equipment will still not be functioning until the other team finishes the second part.

## 3.3 Information system

A maintenance information system (MIS) can, according to Kelly (2006), be defined as a formal mechanism for collecting, analysing, storing and reporting maintenance data. It can contain many different modules including a technical information base, maintenance schedule and shutdown work planning and control (Kelly 2006).

It is in the MIS that maintenance orders are entered. Kelly (2006) describes the processes as follows: A work order comes in containing information about for example the site and person that are requesting the job and a description and estimated time to perform the task. The work order becomes a work request that goes in to the work catalogue. In the catalogue preventive and corrective maintenance are divided into different files. The next step is the planning where the corrective work orders are planned according to the specifications of that specific plant based on how it is organized. The allocation board in the MIS shows the short term planning of orders to be dealt with each day. The MIS can also have modules that have control over stores, top ten reports, cost reports, evaluation measures and many more (Kelly 2006).

The MIS control module should be utilized and according to Kelly (2006) as a minimum be able to provide failure dates or hours operated to failure, duration of failure, production/quality losses, item/component affected and probable cause of failure.

## 3.4 Deduction of literature

To summarize, an effective maintenance organization is not the same as having different optimized groups that work with preventive and corrective maintenance respectively. For total maintenance effectiveness, the different parts need to be integrated. The step from having two separate parts to working together is a big step from going from what Nyman and Levitt (2010) means with reactive to proactive maintenance. The goal of only having 20 % corrective maintenance (Kelly 2006; Ben-Daya, et al. 2009) needs to be supported by the means to get there. A suitable setup in the maintenance organization needs to be combined with an effective planning and scheduling or with clear prioritation rules. Any universal rule does not exist, instead each organization has to consider the different alternatives and choose the most appropriate one.

## 3.5 Theoretical frameworks

To be able to evaluate and analyse the maintenance organization, frameworks are important tools. Four frameworks have been chosen based on their relevance to the topic, their distinctiveness and their applicableness. They are discussed and described below and then merged into one single model.

### 3.5.1 The Jonsson framework

This section presents a framework for describing and analysing the maintenance management in manufacturing firms created by Jonsson (1997). This framework consists of five parts; Goals and strategy, Organization, Tools and techniques, Support mechanisms and Human aspects. The effectiveness in the maintenance management is, according to the author, dependent on both how well these parts are connected as well as how they work individually (Jonsson 1997). If nothing else is stated the information in this subchapter is based on Jonsson (1997).

The first component in the framework is goals and strategies. Just as incorporating manufacturing strategies with the corporate strategy has been proven to be a success factor, coordinating maintenance goals with the goals of manufacturing and corporate strategies can create advantages for the company. Similarly, Nyman and Levitt (2010) states that both organizations and individuals perform better, and accomplish more, by having well communicated expectations that are challenging yet fair. Goals and strategies are important parts of making the maintenance a companywide issue.

According to Jonsson (1999) few companies have a clear goal for their maintenance even though it is seen as a prerequisite for achieving efficient maintenance. It is not enough to just have a formulated strategy (Jonsson 1999). To make the entire production system as efficient as possible communication between the maintenance and production is essential and management has to see the potential profitability in maintenance and give it more attention.

The second component is the organization. A maintenance organization can be constructed in various ways and depend upon the organization philosophy, maintenance load, size of the plant and the skill of the personnel (M. Ben-Daya, et al. 2009; Jonsson 1997). These factors together decide whether to have a centralized or decentralized organization, which gives different possibilities to the organization. Kelly (2006) further argues that, the single most important influencer of these, in shaping the maintenance organization, is the workload.

Tools and techniques for maintenance include the different types of maintenance, as described earlier, and is the third component in the framework. In many cases, preventive maintenance is not used as much as it could be, but there is a trend of having increased percentage of preventive maintenance (Jonsson 1997). One reason for this is that, as mentioned above, the cost of corrective maintenance is on average three times higher than if the same repair were made within the preventive maintenance. Also the corrective maintenance force often works at a low capacity utilisation rate due to lack of planning (Jonsson 1997). To gain high capacity utilization and decrease the cost of maintenance, different types of planning can be efficient. In simple terms the function of planning is to ensure that the right resources arrive at the right place at the right time to do the right job in the right way (Kelly 2006).

The human aspect is the fourth component in the framework and is the basis for continuous improvement. Human error causes more than half of all the failures in a system and a large part of these require action by management. Competence, information, responsibility and motivation are important prerequisites for effective maintenance and job satisfaction (Thilander 1992; Kelly 2006). To achieve an efficient maintenance organization both a good working environment and sufficient training are important, as well as an adequate work status (Jonsson 1997).

The fifth and last part of the framework is support mechanisms. These are important to make the flow of information between maintenance and production easier and make efficient communication between departments possible. In this category a MIS is very important. Since maintenance data is a basis for, for example, spare part provisioning and capital investments the MIS should be integrated with the overall information system. The systems have to be seen as complementary to be able to get the most out of them.

This framework is not specialized on corrective maintenance but covers all types of maintenance in a manufacturing company and thereby covers corrective as well. This is however something that has to be considered when applying the framework to this case study.

### 3.5.2 The Ben-Daya et al. framework

Ben-Daya et al. (2009) presents a handful of important factors to use when evaluating and measuring maintenance productivity. These factors together create a system that needs to be incorporated with the strategy at different hierarchical levels in the organization in order to create a comprehensive picture. This section is a description of the system and the links to strategy and the text is based on information from Ben-Daya et al. (2009) if nothing else is stated.

The system consists of six parts: Value created by the maintenace; Allocations of resources; Health, safety and environment; Knowledge management; New trends in operation and maintenance strategy; and Changes in organizational structure. These are to cover the most important part of the maintenance productivity, but it is important to remark that they do not cover all aspects.

1. *Value created by the maintenance*. This is stated as the most important factor because of its business relation. In all businesses there is a need for creating value and if a department is not adding value it needs to be restructured.
2. *Allocations of resources*. The resources are the foundation of maintenance and the focus here lies on the effectiveness of the resources. To evaluate if the right resources exists and if they are used in the right way, the allocation of these are important to look at. Perhaps more investments are needed or the wrong investments have been made.
3. *Health, safety and environment*. An organization should not only be productive in terms of production output but should also look at health, safety and environmental factors. An efficient organization should incline a low number of incidents and accidents.
4. *Knowledge management*. Today's business is using more technology and information and communication technology (ICT). To handle the change, the knowledge that exists in a company needs to be taken care of, even though operations become more automatic. And there is a need for a systematic approach for knowledge growth.
5. *New trends in operation and maintenance strategy*. Companies need to adjust their strategy to the changing environment and quickly respond to new demand. This is also a step for having continuous revision of the strategy.
6. *Changes in the organizational structure*. The productivity measurements need to reflect the focus of the organizational structure. The focus at individual organizations can be very different and the used measurements can and should therefore vary for different actors.

The presented factors gives an indication of what to look at, but as stated earlier the strategies at different levels of the organization are also important to consider. Ben-Daya et al. (2009) gives a few examples of typical measurements used at different levels in Figure 4 below.

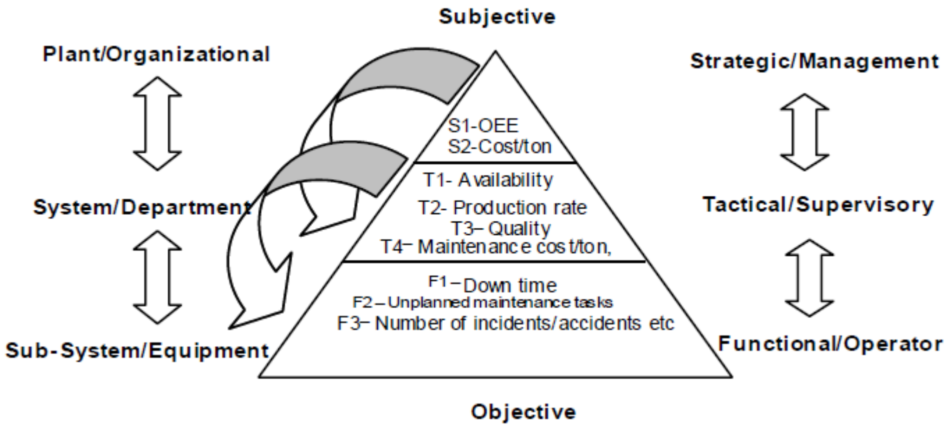


**Figure 4 The hierarchical levels (M. Ben-Daya, et al. 2009)**

What also can be seen in Figure 4 is the connection between the levels. Not only should the different hierarchical levels be considered when designing measurements but they should also be connected to each other. In Figure 4, downtime is at a functional level, availability at a tactical level and OEE at a strategic level. All of the measurements can be used at each level but the value is higher if the right measurement is used at the right level.

### 3.5.3 The Parida Framework

In many industries it is critical to ensure an effective and efficient maintenance organization. A way to achieve this is by using performance measures. Many general frameworks for performance measuring exist, but still not much literature is available in this specific area of maintenance performance measurements (Parida 2006). Parida (2006) proposes a framework that is based on factors that are influencing the maintenance effectiveness and originates from a theoretical frame of references. If nothing else is stated the content of this subchapter is based on Parida (2006).

The maintenance performance measurement framework presented is, as the model by Ben-Daya (2009), divided into three hierarchical levels; strategic (top management), tactical (middle management) and functional (operators). This is done to ensure that the information flows smoothly within the organization and thereby creates an automatic evaluation of the measurements, see Figure 4.

Based on interviews and literature research Parida (2006) identified important factors and divided those under seven criterions. The criterions are; Equipment, Cost, Maintenance related tasks, Learning and innovation, Customer satisfaction, Health safety and environment and finally Employee satisfaction. One example of factors connected to the criteria Equipment is the availability of the machines. Maintenance task factors can be the number of corrective maintenance tasks done during a specific time period. In Figure 5 the factors proposed by the author is presented under each hierarchical level.

| Hierarchical LEVEL OF MPIs / MULTI-CRITERIA OF MPIs | Level I *Strategic/Senior Manager/ Plant* | Level II *Tactical/Middle manager/ system/ subsystem* | Level III *Functional/ Operators/ Equipment/ item* |
|---|---|---|---|
| *Equipment/ Process related* | 1. OEE (Total production) | 1.Availability<br>2.Downtime(hours)<br>3.Performance speed<br>4.Impact of quality | 1.No of stop<br>2.Downtime(hours) |
| *Cost-related/ Financial* | 2.Maintenance cost per ton<br>3.Production cost per ton | 5.Maintenance cost<br>6.Production cost/ton | |
| *Maintenance Task-related* | | 7.Change over time<br>8.Planned maintenance tasks<br>9.Unplanned tasks | 3.Change over time<br>4.Planned maintenance tasks<br>5.Unplanned tasks |
| *Learning & Growth/ Innovation* | 4.Number of new ideas generated<br>5.Skill improvement & training | 10.Number of new ideas generated<br>11.Skill improvement & training | 6.Number of new ideas generated<br>7.Skill improvement & training |
| *Customer Satisfaction related* | 6.Quality complaint numbers<br>7.Quality return | 12.Quality complaint numbers<br>13.Quality return | 8.Quality complaint numbers<br>9.Quality return |
| Health, safety & environment (HSE) | 8.No of accidents<br>9.HSE complaints | 14.No of accidents or incidents<br>15.HSE complaints | 10.No of accidents or incidents<br>11.Environmental standards/ complaints |
| Employee/ Satisfaction | 10. Employee complaints | 16.Employee complaints | 12.Employee complaints |

**Figure 5 The maintenance framework (Parida 2006)**

There are no standard references for the performance measures Parida (2006) proposes. Instead it is up to each company to set their own goals and follow trends in the measurements over time. This is a basis for continuous improvement in the organization.

Parida (2006) also states in the case studies made with the framework that it has to be adapted to fit the specific company and situation. The framework covers maintenance as a whole so some adaptations might be needed to fit the corrective maintenance specifically.

### 3.5.4 Campbell and Jardine Framework

This framework is based on the major categories that Campbell and Jardine (2001) express as the most important to be measured when striving to reach the maintenance departments overall goals. Just as in Ben-Daya et al.'s framework, there are also other categories or factors that are not considered, instead only the most important ones are considered. The source of the information comes from Campbell and Jardine (2001) if nothing else is stated.

In the framework, called *the Broad strokes,* there is different categories which all contain different measurements. There are six main categories where five of them are more specific and a sixth one which is more general. The categories are: Maintenance productivity, Maintenance organization, Efficiency of maintenance work, Maintenance costs, Maintenance quality, and Overall results.

1. *Maintenance productivity*. The productivity should measure the different resources, such as: labour, materials, contractors, tools and equipment. An example of a specific measurement is manpower utilization or cost of material usage per order.
2. *Maintenance organization*. The maintenance organization measures the effectiveness of the organization and the planning activities. Ratio between planned and emergency work orders and planning time per employee are common measures.
3. *Efficiency of maintenance work*. This measures different aspects of how the maintenance keeps up with the workload. The work order turnover, response time and backlog are the major indicators.
4. *Maintenance costs*. This is a commonly used category when evaluating maintenance as it, as mentioned in 3.1, has traditionally been seen as a cost. It is important to note that driving the cost of maintenance down can be counterproductive for the company as the cost of production stops and new equipment will increase as a direct result of a maintenance cut-down.
5. *Maintenance quality.* The quality of maintenance is often overlooked but is very important to understand if the maintenance are doing things right. Flaws in maintenance quality could indicate a need of training or need for new skills. Repeat jobs and breakdowns and stock-outs can be measured.
6. *Overall maintenance results.* This category has a more strategic focus and relates to measurements that are used in Ben-Daya et al. (2009) and Parida (2006) under strategic or tactical levels.

# 4 The Corrective maintenance model

*In order to have one framework that is appropriate to the thesis a new model has been created, which is a product the four frameworks discussed in Chapter 3 by Jonsson (1997), Ben-Daya et al. (2009), Parida (2006) and Campbell and Jardine (2001). This was needed because the frameworks overlapped each other in many aspects but also covered different levels in the maintenance organization and, thereby, had different intended areas of use. Also the focus of the frameworks was overall maintenance and not corrective maintenance specifically, which is the focus of the thesis. These issues were taken into consideration when constructing the Corrective maintenance model.*

The five Evaluation areas is the core of the model. Four of the areas are supporting the fifth, the goals, which are set for the department. To evaluate how the maintenance department performs, many different indicators can be used.

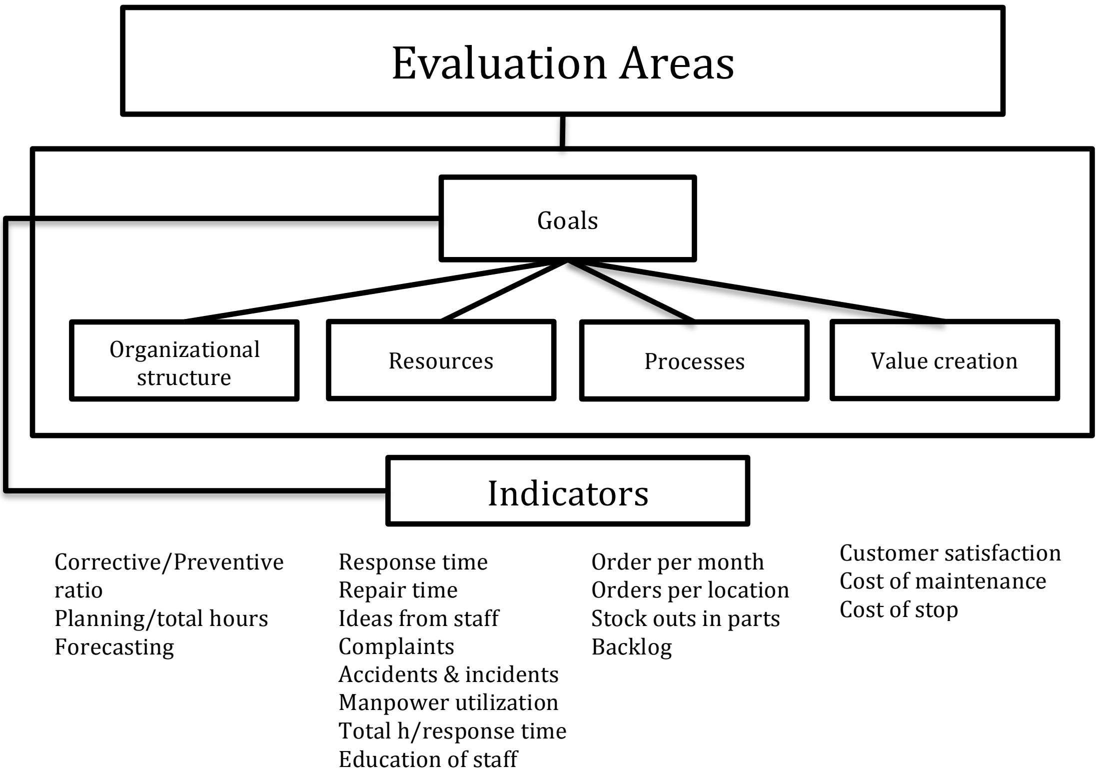


**Figure 6 The Corrective maintenance model**

## 4.1 Evaluation areas

The corrective maintenance organization can be described through five different areas that together create a dynamic environment. Figure 6 shows the maintenance organization in two levels, where goals are above the other areas. The reason for this is that the goals are supposed to be achieved through the four different areas. However, this does not mean that the areas are subordinate of the goals.

### 4.1.1 Goals

The goals are an important element in the organization as it steers the direction of the company as well as focus efforts in order to achieve better results. The goal setting is very important, as the goals are to be relevant, challenging and achievable. Furthermore the goals should be connected to other departments and not only maintenance or corrective maintenance. Overall company goals and manufacturing goals should both be supported through maintenance goals.

Continuous improvement and development of the organization are other aspects of the goals. These are important for the organization in the sense that it keeps the organization evaluating and critically questioning the methods, which supports the development. Also, a concrete plan for reaching the goals is essential for the realization of the goals.

### 4.1.2 Organizational structure

Each organization has a specific structure that is set to support its activities. The structure should also support the goals but the goals can of course also be set after the structure. In Chapter 3 Frame of reference, a description of different structures are presented and it is concluded that a maintenance organization can be centralized, decentralized, outsourced or a mix of both. Further, the operator role can vary greatly when it comes to maintenance, from being participative and execute the maintenance themselves to only report the need for maintenance.

Communication is often crucial in any type of organization or department, which is true in this case as well. Communication channels between the right people and positions are essential for the work to be done in a satisfying way, not at least to be coherent with the goals.

### 4.1.3 Resources

The resources in the maintenance organization mainly consist of people with certain knowledge and competencies. However, knowledge does not necessary need to be connected to a specific employee. Knowledge can be shared in the organization and needs to be taken care of, and therefore knowledge has its own part in the resource category.

The competencies that technicians in the maintenance organization have can vary greatly. One technician might have many years of experience when it comes to a lot of machines while a newly hired technician may lack the broad knowledge, but instead have specialist expertise about a certain machine type. These different competencies can be equally important or be totally different when it comes to planning the resources. It is therefore crucial for the maintenance organization to handle the resources and balance them. When a certain competence is missing three options are available. Training the staff could be an option, hire new employees with the knowledge are another option and a third is to outsource the tasks to an external actor. A combination is also a possibility. These three are some examples of competence related questions that are important in a maintenance organization.

Safety and work environment are very important issues for the people working in the maintenance department but also for the organization itself. With a good working environment with no accidents or incidents the organization can expect better results and more satisfied employees. Fulfilment, however, may come from elsewhere, such as the possibility to influence the working condition or to come with ideas.

### 4.1.4 Processes

The processes are the key activities that are done in the maintenance organization and the supporting activities that facilitate the actual maintenance work. Many aspects of day-to-day activities for maintenance technicians can be described as part of the processes. The process can also be seen as a series of actions performed by operators and technicians from when a breakdown occurs until the equipment is back in working condition.

Related to the activities carried out by the maintenance staff is the support function of the MIS, which can either be a separate system or connected to other information systems.

The planning stages are another part of the processes that is considered when evaluating this area. The forecasting methods and the scheduling and other planning tools are essential to support the structure of the organization and thereby the goals.

### 4.1.5 Value creation

The maintenance organization should create value for the manufacturing and, hence, the whole organization. Many departments in an organization, such as maintenance, are built around the core activities in order to maximize the output or likewise. Maintenance itself does therefore not generate its own profit, instead it shields the company from making high losses in production. Because of this situation, it is easier to calculate the cost of the maintenance than the profit. However, the profit can be evaluated by looking at the alternatives to maintenance (more frequent investments in machines, more downtime etcetera).

When creating value, the maintenance should satisfy the expectations from the customer. The customer of maintenance can either be the production, the operator for the failing machine, or the end customer, depending on the perspective. In the Corrective maintenance model, the production department is seen as the customer.

## 4.2 Indicators

Indicators are used to evaluate the performance of the corrective maintenance organization. The indicators have no previously set optimums, but are instead used as relative measurements. The goal values coupled to each indicator has to be set internally by the organization and can thus only be used to compare with previous results or to the fixed goals. The indicators should give guidance to the management and show how well the organization fulfils its goals. When implementing changes for example the indicators could show how successful the changes were.

The indicators shown in Figure 6 are possible indicators for each evaluation area. All are not needed in all situations and have to be adapted to the specific company. Another interesting possibility with the indicators is its usefulness as a tool in motivating the technicians since they can give a picture of how well the organization is doing as a team and how far it is to reach the goals set for the department.

# 5 Empirical findings

*The aim in this chapter is to create an empirical basis to analyse further. The findings at SKF in regard to the purpose of the thesis and the research questions will be presented. First general information about the SKF factories in Gothenburg is presented. Then the overall maintenance organization at SKF is described. After this, the central maintenance unit that performs the corrective maintenance is described through the Corrective maintenance model presented in Chapter 4.*

## 5.1 SKF Gothenburg in general

In the Gothenburg site SKF manufacture different types of roller bearings. The Gothenburg office is also the SKF headquarter, which means that there are other functions than manufacturing at the site. At the time of the thesis, SKF Gothenburg consisted of four separate manufacturing factories. The four plants produces different parts of the bearings; one was producing cages, one was producing rollers, and two were used to manufacture the finished bearings (one plant for large and one for medium sized bearings). In the production sites there were between 800 and 900 operators.

## 5.2 SKF Gothenburg maintenance

The maintenance at SKF Gothenburg, both preventive and corrective, was a part of the Facility Service Management organization. As seen in Figure 7 it was organized together with for example property management and energy systems. The maintenance department in itself was organized in three separate units. There were two preventive maintenance units, called functional maintenance units, and one central maintenance unit. The preventive units were situated at two of the producing factories, RK and D. The unit at RK was also doing the preventive maintenance for the E factory. These units consisted of mechanics and electricians who planned and executed the preventive maintenance in RK, E and D respectively. Even though the maintenance sub-department was centralized the preventive maintenance units were geographically decentralized, as they were located in the different factories. The centralized maintenance unit was a central function both geographically and organizationally of SKF Gothenburg, responsible for the corrective maintenance in all factories.

In each of the three maintenance units (RK, D and the central maintenance unit) maintenance engineers were responsible for that the maintenance related goals were met. The maintenance engineers were also responsible for planning long-term equipment dependability. Each unit also had a manager who was responsible for staffing and administrative tasks.

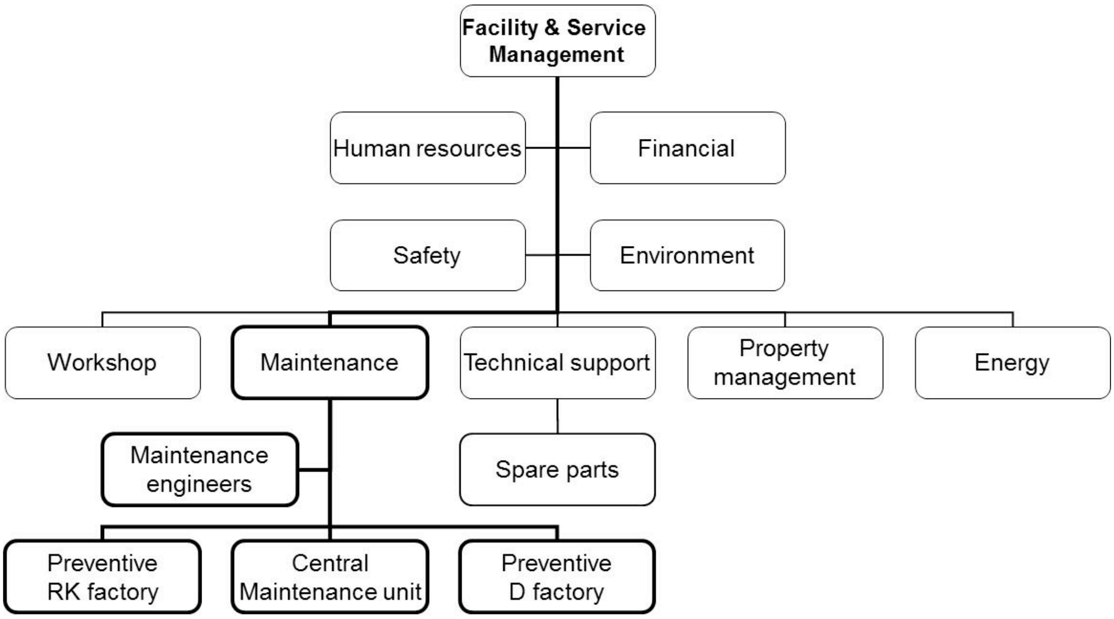


**Figure 7 Facility service management at SKF Gothenburg**

The H factory was sold in April 2011 and the corrective maintenance were contracted to continue for 18 month. As SKF sold the factory all the preventive maintenance stopped, which led to a higher degree of corrective maintenance needed. It was the opinion of the technicians working with corrective maintenance that the work put in to this factory was larger than the other factories. This means that there were likely to be less work for the central maintenance unit after the maintenance contract ended which could potentially mean having an oversized central maintenance unit.

The forth factory, E, was only running to a certain degree as parts of the factory was under construction. It was at the time of the thesis not yet decided how the preventive maintenance was to be handled in the factory in the future. However, the corrective maintenance was already handled by the central maintenance unit and when the factory was fully operational the corrective maintenance load would most likely increase. A general opinion was that the amount of corrective work previously done in the H factory could be transferred to E and thereby there was an opportunity to make use of the existing and available resources to meet the new demand.

## 5.3 SKF Gothenburg corrective maintenance

This subchapter is divided into five parts: Goals, Organizational structure, Resources, Processes and Value creation. These are the five areas in the Corrective maintenance model. The subchapter will focus on corrective maintenance at SKF Gothenburg.

### 5.3.1 Goals

SKF Gothenburg had three major goals concerning the corrective maintenance. The first one concerned the ratio between corrective and preventive work orders. The goal stated that no more than 20 % of the work put into maintenance should be corrective, the remaining 80 % should be preventive. The time spent on corrective maintenance had been decreasing and in October 2009 it reached the lowest point at 35 %. After that a slight increase occurred and in Mars 2011 the ratio was 45 %. The goal of 20 % had been set because it had appeared to be corrective orders that should be handled as preventive work and at the same time it seemed to be a realistic goal that was possible to achieve.

On a machine level it was clear that some machines required more hours and more frequent corrective maintenance. Eight machines were responsible for 10 % of all corrective maintenance hours between 2010-09-01 and 2011-08-31. In Figure 8 below, the total amount of corrective maintenance hours spent on each machine is displayed.

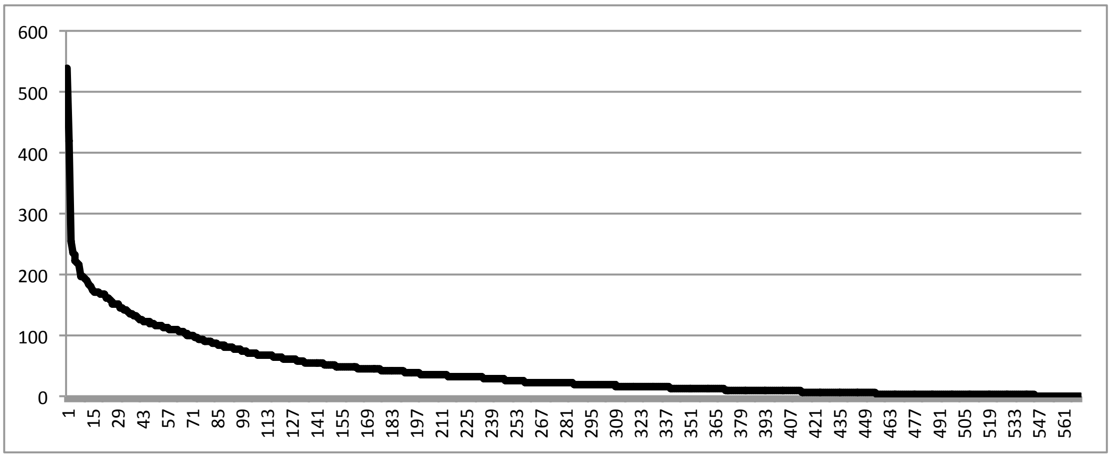


**Figure 8 Corrective maintenance hours per machine between 2010-09-01 and 2011-08-31**

The second goal stated that 90 % of the maintenance orders should have less than one hour response time. The response times usually varied between a few minutes up to several hours, averaging on one hour and with a median of 30 minutes, see the distribution in Figure 9. The one hour guideline was set as a recommendation in order to have a certain service level to the manufacturing. However, there was no goal regarding the repair time or the total repair time, which means that the total downtime for the manufacturing was not addressed through this goal. The reason for this was that the repair time could differ depending on the type of error, the staff available and other factors. However, long repair time gave longer response time due to the technicians had more actual repairs to do. Therefore the response time also indicated the state of the repair time, even though it was not a direct measurement.

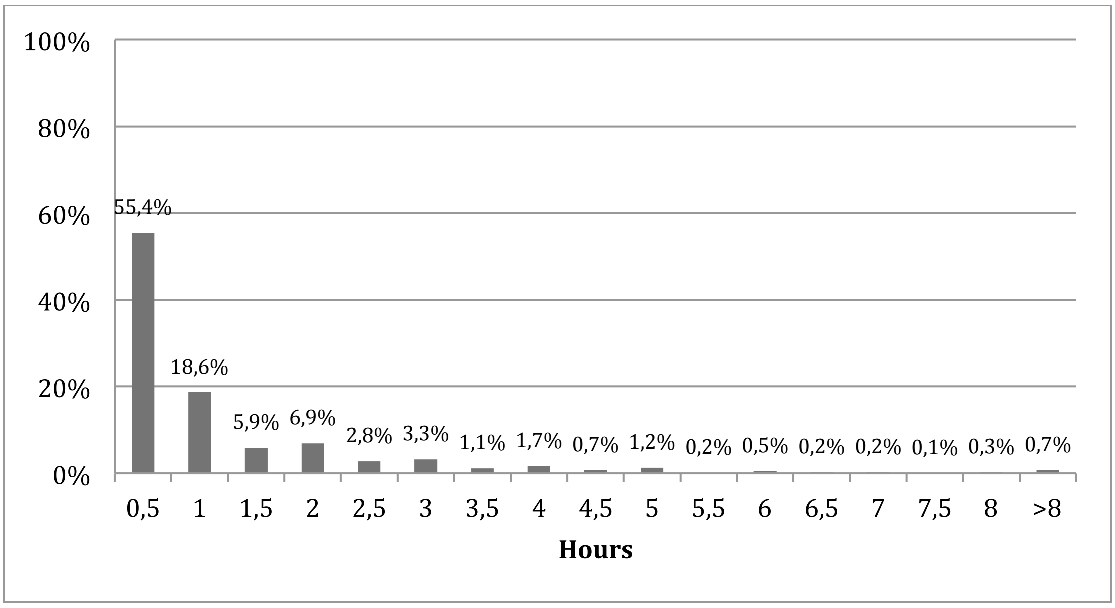


**Figure 9 Distribution of response time between 2011-01-01 and 2011-08-31**

The figure above shows that SKF did not reach the goal of having a response time less than one hour for 90 % of the orders. For the period investigated, 74 % of the orders had less than one hour response time. And 90 % of the orders had less than 2,5 hours response time.

The last goal in the corrective maintenance unit dealt with how to report back after finishing a repair order. According to set guidelines the technicians should report the symptom, the cause and the measures taken for each order. This was however not fulfilled in all cases, and the management decided to set a goal in order to improve this. The goal stated that at least 50 % of the maintenance reports should include the symptom, cause and measures taken. The information was valuable for the organization and it was therefore preferable to have a structured way to communicate it.

### 5.3.2 Organizational structure

The central maintenance unit normally carried out the corrective maintenance at SKF Gothenburg. However, in July and August every year there were weeks where there was no preventive maintenance planned because of summer vacations. The workforce from the preventive maintenance in those periods helped with the corrective maintenance in order to even out the workload. This strategy was the same for all years that were used in the study.

The central maintenance unit was not situated together with any of the other maintenance units. Instead, the central maintenance unit was situated in a building between the factories while the preventive maintenance was situated in their respective factories. This implied that the technicians from the different units did not regularly meet even if they maintained the same machines or equipment. On a higher hierarchical level both the maintenance engineers and the managers had regular meetings for planning purposes and to exchange information.

SKF Gothenburg changed its machine park and production channels regularly and was planning to continue doing so in the future. This was evident as the E factory was being expanded during the time of the study. Also the production in many channels in the factories was going up to a five-shift strategy instead of the normal four-shifts. This would presumably affect the central maintenance unit and possibly mean that they have to change the existing shift system to be able to have full time availability during the weekends as well.

### 5.3.3 Resources

The central maintenance unit had a total of eight mechanics and twelve electricians in the four teams. Some of the technicians are trained in both areas, but the majority of the technicians were only educated in one of the professions. There were previously one more electrician and one more mechanic in each team but in April 2009 they were laid off or transferred to other jobs due to the economic crisis. During daytime the mechanics were also supported by extra staff.

As stated previously, the corrective maintenance was carried out from the central maintenance unit as seen in Figure 7. The unit needed to be available during all hours when production took place. Therefore, the corrective maintenance needed to be staffed 24 hours a day for 5 days a week and 12 hours per day during the weekends. The reason for not having around the clock staffing during the weekends was mainly financial and some problems with reaching an agreement with the unions, since the production had already had expressed a need for a round the clock service. The preventive maintenance staff, in comparison, worked day time, eight hours per day, five days a week. The central maintenance unit had a four-shift system with two mechanics and three electricians in each team. Each team worked eight hours then changing over to the next team. Every 24 hour period, three different teams were active. During the weekend there was only one team working both days. Every week three teams worked and one was free, and this rotated every week. The teams did not have fixed breaks and all hours were counted as working hours. Even though there were five technicians in each shift the amount of orders coming in varied greatly, see Table 2. The night shift between 22 and 06 had just over half the amount of orders compared to the day shift.

**Table 2 Distribution of orders during the day between 2011-01-01 and 2011-08-31**

| | 22-06 | 06-14 | 14-22 | Total |
|---|---|---|---|---|
| **Number of orders** | 1084 | 1921 | 1437 | 4442 |
| **Percentage of number of orders** | 24 % | 43 % | 32 % | 100 % |
| **Median response time** | 30 min | 30 min | 30 min | 30 min |
| **Average response time** | 51 min | 1 h 6 min | 1 h 8 min | 1 h 3 min |

The decision to have two mechanics and three electricians in each team was based upon the ratio between mechanical and electrical orders. When combining the different factories 60 % of the orders was electrical, but measured in actual work time the ratio between mechanical and electrical was 50/50 and these numbers were also very stable over time. Per factory the aggregated total repair time was varying a bit more, but since the corrective maintenance unit was a central resource it was the aggregated level that was important in this case.

The resources of the corrective maintenance also went beyond the organizational boundaries of the central maintenance unit. SKF Gothenburg used operator maintenance to some extent, mainly for troubleshooting. However, some of the operators had enough knowledge of the equipment to correct specific errors by themselves. Also in some cases the functional maintenance teams did corrective measures. The functional maintenance teams did at the time about 4 % of the corrective orders and the trend was increasing. What was interesting was that the orders the functional maintenance teams performed took longer time to complete and varied a lot more than the ones the corrective maintenance teams handled. Here there were slight differences between the factories. D, E and RK were increasing while H has been doing a more or less constant amount the previous five years both in time used and in actual number of orders.

As mentioned before each corrective shift team consisted of three electricians and two mechanics. Figure 10 shows the resource utilization in terms of the amount of time used for corrective jobs in relation to the time available both for the mechanics, the electricians and the total per cent used.

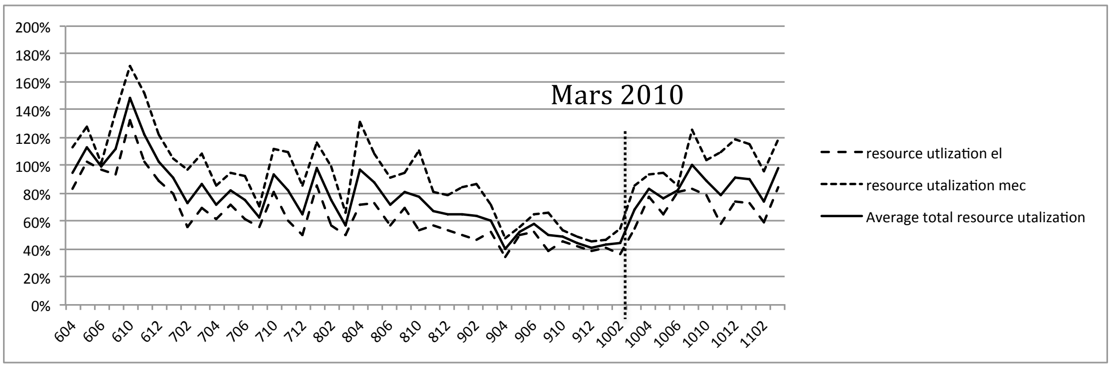


**Figure 10 Resource utilization solely in the shifts 2006-04-01 and 2011-03-31**

Until Mars 2010 the trend was moving towards lower resource utilization. The next month the cut-backs in staff were made and it is clearly seen in the data where the resource utilization increased rapidly. However the changes made in 2009 also meant that there were extra mechanics working daytime that were not included in the shifts. That is why it seems as if from June 2010 and onwards the mechanical technicians have been working more than 100 %. The electrical staff, however, did not change the shift structure.

### 5.3.4 Processes

All the way from the moment when a machine broke down until the corrective maintenance was performed there was at SKF an elaborated plan for how the processes were supposed to work, as seen in Figure 11. First the operator noted the time when the machine broke down to later be able to calculate the total downtime. The downtime in the maintenance process is however calculated from when the order is put into the MIS until the machine is operating again and the order is closed. Between 2010-05 and 2011-05, 42 % of the downtime due to corrective maintenance was electrical and 54 % was mechanical. The 4 % missing is due to the way that the downtime was reported in the factories, which was not correlating with the way downtime was reported by the maintenance technicians into the system. The average total downtime per month in the factories the last year and the difference in reported total downtime and reported corrective work time are shown in Table 3 below.

**Table 3 Average downtime in hours due to corrective maintenance per month in the different factories between 2006-04-01 and 2011-03-31**

| | Corrective el | Corrective mec | Corrective total | Difference |
|---|---|---|---|---|
| D | 340,15 | 212,89 | 609,16 | 9% |
| E | 160,26 | 99,21 | 266,73 | 3% |
| H | 175,75 | 260,84 | 439,52 | 1% |
| Rk | 224,54 | 136,93 | 367,96 | 2% |
| Total | 900,69 | 709,87 | 1683,37 | 4% |

Depending on the level of competence of the operator he or she should start to troubleshoot the machine. After this the operator put an order into the API. The operator had to fill in where the machine was located, if it was a mechanic or electric problem, and whom the corrective maintenance technician could contact when he or she got there. Also additional information about the problem could be written into the order. After putting the order in the system the operator could call the central maintenance unit to receive additional troubleshooting tips and information about an approximate response time. The technicians were however very careful with promising a specific time for when they could start the future reparations, since they did not know how long time the orders scheduled before would take.

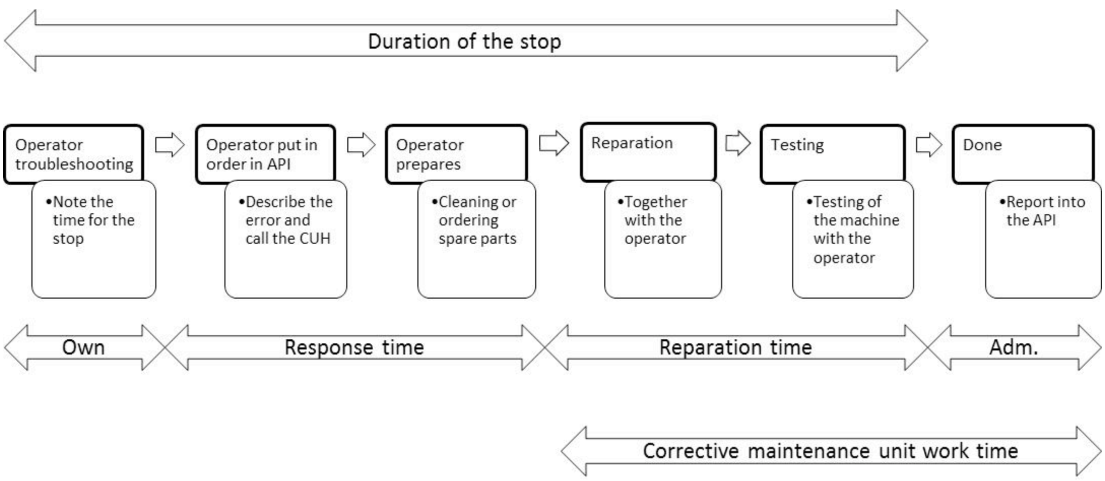


**Figure 11 The corrective maintenance processes for technicians and operators**

While waiting for the technician the operator could, if possible, prepare the machine for the maintenance by for example removing any protecting shields and cleaning the area. This was sometimes done and sometimes it was considered unnecessary due to the type of machine or problem.

When a technician was available he or she used API system to find corrective maintenance orders. The orders were shown in a list in the order in which they were prioritized. An order that the technician had the right competences for, mechanic or electric, was chosen. Afterwards the order was accepted and printed. The operators could all the time themselves use the API system and see how many orders there was before his or her order and the moment a technician had accepted it.

When the technician arrived the operator was contacted and together the problem was looked through. The idea was that the operator should learn more about the machine by working with the technician. Also the technicians could not operate all machines in all the factories, so the operator was needed of that reason as well. In reality the operator was not always present during the repair. Instead he or she mostly was present for giving a description of the error and for testing the machine after the repair.

To locate the error the technician often needed to get hold of the drawings of the machine. The drawings were kept in lockers in the factories and the technicians knew where to find them. The drawings were however not always up to date and correct which of course slows down the repair process. This was a problem discussed by the technicians but also was noted by Ohldin (2011) and seen in the observations.

Another thing that delayed the repair process was the spare parts. Even though there were only supposed to be spare parts in the main warehouse, this was not so in reality. The different channels had spare parts in the factories and the technicians themselves often had some common parts in their bags to decrease the amount of visits to the warehouse. The main problem seemed to be to physically find the spare part, how to search for them in the MIS and having control over them in the central warehouse. These problems had not only been seen through the observations but also been reported in an internal report (Ohldin 2011).

In some cases the technicians at the central maintenance unit did not have the necessary skills to complete the reparation of a specific machine. In those cases experts from outside SFK were called in to help. First the technician tried to solve the problem with phone support, but when that was not possible the experts came to the factory. The usage of external experts had increased since the middle of 2007 in all factories but the amount varied greatly from month to month. The H factory was singularly the largest user of external experts and it was believed that when the responsibility for repairing was changed over to the new owner the overall situation would stabilize.

When the problem in the machine was adjusted the operator tested the machine together with the technician to make sure that everything was working as it was supposed to. The technician in this stage often explained to the operator the cause of the problem and the measure taken, but this did not always happen.

After this the technician should write a report in the order in the API system and report the job as completed. Then the next job in the list could be accepted. The computers were available all over SKF so they did not have to go to their "home" workshop to do this, but the reporting was in reality not done at once. Often the technicians did all theire reporting together in the end of their shifts. The reason was that they believed that it was more efficient to do so. The technician also reported the total work time used for the specific jobs. That information was then used as a basis for invoicing the factories for the service provided.

The prioritizing of the orders in the API system was done according to FIFO, first in first out. Often only the production managers in each factory could make changes in the priorities of the orders, however, they could only change within orders from the same factory and the order they prioritize down will end up furthest down in the list. They could with other words not swap places on their own orders in the list but only delete and re-enter orders. To move the orders the production manager had to call the administrator at the central maintenance unit who could make the make the change in the system and thereby in the list the technicians worked after. The administrator did only work the day shift.

### 5.3.5 Value creation

There were several issues where there seemed to be a common view of the corrective maintenance situation from the different production sites but certain issues seemed to be more important for some than for other. A general issue mentioned during the interviews was communication in many different areas while the question of prioritizing orders seemed to divide the production. The increased amount of external help was not seen as a major issue for anyone.

The corrective maintenance unit had, organizationally speaking, a supplier- customer relationship to the production at SKF, even though they were both part of the same company. There was an internal billing process between FSM and the specific production unit who needed the corrective maintenance. The billing was based on a price per technician and hour. Each month the financial outcome for FSM was summed up and if there was a surplus it was given back to the production and if there was a loss the production had to put in money to even it out. According to the interview performed there was an opinion that the production did not overpay for the services provided but also that the FSM department did not have any financial risk which might mean that the organization did not have a financial motive to improve the efficiency of the provided services.

The technicians performing corrective maintenance and the manager's experienced that the production in some situations did not understand the complexity of the work they were performing. Production on the other hand referred to the corrective maintenance technicians as some type of internal "heroes" and claimed to have a high degree of understanding of the repair process. However the communication between the technicians and the operators or production managers was seen as inferior and that was causing problems. In some cases the technicians were seen to come and go and not updating the operators of what was happening. Also there was a problem when a repair was done and the technicians did not always communicate that it was finished, what was wrong and stayed to see that the machine was functioning again. This was done in the API but first in the end of every shift. Another example raised in the interviews was the way that the time used for corrective maintenance was reported into the API that differed between what the operators' reported and the technicians reported. The need for communicating directly was a common opinion in the interviews.

The understanding of the repair process and its complexity was high but the most important question for the production was the response time. When the operators and the managers did not have any implication of when the technicians were coming it was hard to plan the work that could be done while waiting. The need to call to see how long the technicians think it would take was seen as a problem from production but seen as a part of the ordering from the central maintenance unit's perspective. One person in production argued for example that if they call then everybody else would call as well and that would lead to that the response time would be even longer. The goal set by FSM to have 90 % response time less than one hour was not very useful according to the production; they rather have had a guaranteed response time. There seemed to be an opinion that a fixed maximum response time would be very good.

To decrease the response time the production saw different possibilities. One solution was of course to hire more staff in the corrective maintenance unit. There was an understanding regarding that this would increase the cost and that it was the production that decided how much FSM was allowed to spend, but as one production manager said; it could be a temporary solution until the preventive maintenance would work better. Another idea was to go back to an old system where one person on the corrective maintenance staff went directly when it a new order came to make a first assessment. This was perceived as a good idea since some of the problems was very easily handled or just needed the technician to fetch a spare part and the operators could then change it themselves. Another version of this idea that was mentioned was to allow the functional maintenance workers to make longer corrective work as well with the argument that they did know the machines well and should have a close relationship with the operators. Generally a close relationship between the functional maintenance teams, the channel operators and the corrective staff were seen as a prerequisite to have a low degree of corrective maintenance and efficient corrective maintenance when needed.

When it came to prioritizing orders the production managers had different opinions. Some said that having more prioritizing possibilities than during the time of the study would not work since everybody would think that their channels would be the most important. Others argued that it was really important that the factories should have an internal prioritization as well as the channels within those factories. At the time of the thesis it was often only the managers that could prioritize in formal or informal ways but there was an opinion that at night when the manager was not around the operators should be able to make a prioritizing decision within a channel as well. There seemed to be an issue of who had the mandate to decide what. Whether prioritization should be used or not was not for the central maintenance unit to decide upon. Instead it should be up to the production to localize the bottlenecks and decide to prioritize if they find it necessary.

Competences were another issue that came up. There was an opinion that the technicians were very good at what they did but had too broad competences and that it would be good to also have more front edge competences. An idea was to always send the technician with the deepest knowledge in the machine type for each order, however it was not discussed how this would work in reality and which effects would be expected. Which exact competence area that would have to be improved was not obvious but that it was a shared responsibility between the production and FSM was clear. Also, depending on which technician who took an order and met the operators influenced the result since they had different approaches. A positive approach from the beginning led to a more satisfying result.

How the communication was supposed to happen in different processes seemed to be a big issue. For example the interviews revealed that the production felt the need for the escalation model, for how to communicate when the reparations took long time, created some years ago to be used, while the FSM thought that the model was just a paper product that no one wanted. The issue for the production in many cases seemed to be that they had to go and search for information to get any. In some cases, the informal communication was working and then it was no problem. However, in other cases the problem was obvious. For example, the operators did not know whether a repair had been done or not or in one case the technician fixed the problem when the operators were on break, or in a case where a spare part was lacking and the technician went to the next order without informing the right person. The production realized that the need for clear communication routes also existed on their part so that the information would get forwarded to the right person.

Also a possible improvement area was the handing over between shifts. When a repair had to be handed over, the briefing took place in the home office of the technicians and not at the machine, which was perceived as a problem. If the transition to new people could have been handled in the right place, the new operator could also have been briefed together with the new technician and the communication would have been clearer to everyone. Another interesting point mentioned by many of the production managers were that they missed having someone from maintenance in the steering committees of the factories.

# 6 Analysis

*In this chapter the empirical findings will be discussed and possible explanations of why the state of the corrective maintenance was how it was. This is used to analyse what future challenges the unit stood before.*

## 6.1 Goals

As discussed earlier FSM had three major goals concerning the corrective maintenance. The first was that the ratio between corrective and preventive maintenance work should be 20/80. This goal was set based on what management thought the organisation was fit to achieve. According to the literature, see 3.1.1 Division of maintenance work, many different ratios could be used and 20/80 was one of the ratios mentioned. Thereby the goal seemed to be reasonable but the literature also stated that the goal should always be to have little need for corrective maintenance. At the time of the thesis the organisation had approximately 45 % corrective maintenance. This amount had been decreasing over the previous four years but then suddenly started to increase again in the end of 2009. The main reason for the increase was that the state of the economy had stabilized and the demand for SKFs products was increasing. This led to that the machines were driven harder to be able to deliver on time. As a result the wear and tear increased and the preventive maintenance in some respects might have been overlooked. In 5.3.1 Goals it was discovered that a few of the machines caused a high amount of labour hours for the central maintenance unit, for example stood 8 machines for 10 % of the total working time for corrective maintenance (both internal and external). If the need for corrective maintenance in these machines would have been lowered to half of the previous year's value by preventive maintenance, 5 % or 1200 hours less work would have been needed for the central maintenance unit. At the same time, this would also have meant that there would have been 500 hours of less stoppage in production. This kind of selective measure could have been helpful both to reduce costs and to reduce the corrective maintenance needed.

A second goal was to respond to 90 % of the corrective maintenance orders in less than one hour. When looking at the distribution of the response time it was clear that 74 % of the orders met the requirements of a response time less than one hour, which meant that the organisation at the time of the thesis was not reaching its target in this aspect. To approximately reach the 90 % target the response time was two and a half hours, which was considerably higher and it is also important to keep in mind that in most cases the machine was standing still during the response time.

The third goal was that at least 50 % of the reports made after a repair should contain information about the symptom, the cause of the symptoms and the measures taken. According Ohldin (2011) the information was getting better the more recent the orders were, but it was also hard to use it as a measurement. For example in some cases it was only a minor error that was not considered to need any additional information. Which percentage of the orders that needed information was therefore unclear and the measure was too variable to be usable. It was considered to be important to have an accurate and sharp reporting structure but a goal would have had to be clearer for it to work. Instead the reporting should be considered as a mandatory part that had to be done before the order could be finished.

The first two goals were connected in the way that historically if the corrective orders decreased, in work time and in numbers, the response time went down as well. So, one solution was of course to try to lower the amount of corrective maintenance. To decrease the response time and the ratio of corrective maintenance, a number of actions could have been taken. For example let the functional maintenance staff respond to all orders within 15 minutes to do a first diagnose and then leave or complete the order if it was estimated to take less than thirty minutes. One way for the corrective unit to decrease the response time themselves was by decreasing the repair time. That could be done by extensive training, more efficiently working organisational structure, control of the machine drawings or a better spare part system. If that seemed impossible the response time could be decreased by for example adding staff, see 6.3 Resources.

Another interesting point was that the goals within FSM seemed to be more or less unknown in the production. Since FSM provided a service where the production was customers, they should include the production in the goal setting to make sure that the service provided was fulfilling the needs. The MIS at SKF had all the possibilities that the literature described were necessary, see 3.3 Information system, and that included the possibility to create reports from all the data entered in the system.

## 6.2 Organisational structure

SKF had over several years tried both a decentralized and a centralized maintenance organization. At the time of the study the organisation was a combination of the two strategies by having the maintenance owned centrally but letting the functional maintenance be close to the channels in each factory. The corrective maintenance was however still centralized both geographically and organizationally. This was a way to try to capture the positive sides of both centralized and decentralized organisation. The functional maintenance was closer to the channels and had better knowledge of the specific machines. This was important when doing preventive maintenance where close communication with production was necessary. The corrective maintenance that was central was more efficient due to a shared pool of resources between all factories. The centralization also allowed more flexibility and when compared to the functional maintenance, the corrective maintenance staff had another set of skills that were more general and not as specialized. The combination of both specialized and general knowledge created benefits in terms of being complementary to each other. As discussed in 3.1.2 The maintenance structure, this was a solution that fit larger organizations well. When considering the option to again decentralize the corrective maintenance, planning of the work would become much more complicated. Internal data showed that the workload varied for each factory and over time. This would imply that a decentralized corrective maintenance unit would have had a highly varying resource utilization, which would result in long response time one day and excess of resources the other day. The variation that existed in the breakdowns at the different factories evened out over all the factories and time that suited a centralized corrective maintenance unit more appropriately. The downside of having such an organizational structure was that the corrective maintenance staff was separated from the production staff and processes.

The production expressed a need for having the maintenance closer to production. Closer could be geographical as discussed above or it could also be organizational or describing responsibilities. Starting with organizational closeness, the maintenance was a separate department from production and even though the personnel handled the same equipment and machines they had different incentives. This could have led to contradictions in goals, where production focused on having as high output as possible and the maintenance focused on internal measurements such as in this case the amount of orders that were reported in a specific way (cause, effect and measure taken). However, the separation put all services in the company in one department that could have other benefits. The development of such department was likely better since the staff could learn from each other to a much higher degree than they could have had done in a decentralized organization. It was also easier to implement changes in the processes or give new guidelines. Further, the responsibilities that were described as a concern by production were closely related to incentives. If the maintenance department was not directly affected by the output of the production where they operated it could potentially have meant that there was a lack of incentives for improvement and effectiveness. This concern had been expressed by a number of the production personnel. As any internal service organization it could have been beneficial to look for inspiration at external counterparts in order to benchmark the level of service they could offer and obviously how it was executed.

Between the production, functional maintenance units and the central maintenance unit there were different channels of communication. For example it could be direct communication between technicians and operators, reporting in the API or maintenance engineer meetings. As described by Jonsson in 3.5.1 The Jonsson framework, good communication routes between these parties were essential for the effectiveness and efficiency of the organization. When it comes to communication in terms of conveying information regarding response times to the production channels, the central maintenance unit still had some work to do. The major issue, expressed by representatives from production was the lack of communication between them and the central maintenance unit and not the actual repair or response time. The reason for this was that if the production knew that a repair would take many hours they could redirect the production flow or in other ways delegate new tasks for the affected operators. Two ideas that were brought forward were either to receive an approximate time of the technician's arrival when issuing and order in the API or to have a fixed time depending on which machine that has broken down. At the time of the study, if the operator wanted to know when the technician was arriving he needed to call either directly to the technician or to the central maintenance unit. However, if everyone would have done this, the technicians would spend a lot of their time answering the phone instead of repairing machines. During daytime there were other personnel available that could answer these questions but during the evening, night and weekend shifts there were no others that could support the technicians by informing the production. One of the interviewees described a system with fixed response time according to a priority list where the prioritized machines had 10 or 30 minutes response time and less prioritized machines had one or one and a half hours. Compared to SKF's case, the average response time could be the same but it would give the production channel a good understanding of when a technician could be expected to arrive at the scene.

When considered the relatively stable demand for corrective maintenance on an aggregated level, it became easier to forecast using historical data in the API system than it would have been if there were a lot of variations. In 3.2.1 Forecasting it is discussed that both a mix of quantitative and qualitative data could be used to forecast in a medium planning horizon. This could be used to investigate future demand of corrective maintenance considering the at the time on-going changes such as expansion of the E factory, the sales of the H factory and the increased production to 5 shifts. The first two changes would most certainly have required a review of existing resources that could have led to an increase or decrease of the staff. The last change could also have caused a need for an increase of staff but it would also have caused more frequent breakdowns of the machines. Add to this that SKF had a mix of older and new machines. When preparing for these changes, forecasting is a powerful tool that could point out important factors that need to be considered in the future.

## 6.3 Resources

Capacity planning within maintenance is an issue without any correct answer. There are different capacity strategies, see 3.2.2 Long term strategic planning, but which to choose is a question about cost, potential earnings and strategic decisions. At SKF they were using subcontracting as a way to both handle front edge competence issues and in some cases to meet the demand of corrective maintenance. This was combined with a levelled strategy, as discussed above, with even resources no matter how the maintenance orders were distributed.

The competence of the corrective maintenance staff was a question raised in the interviews with production managers that were afraid that some technicians lacked in front edge competences and were "too broad". As discussed in 4.1.3 Resources, the lack in competence could be handled in different ways like education and new hiring to complement the existing personnel. At SKF there were too many different machines to be able to have in house front edge competence on them all and so external help was called in when needed. The production managers did not see a problem with the external help used, even though it was more expensive.

The effect of downsizing the staff in April 2010 is clear in the data where an increase in resource utilization rate is visible. The change made the resource utilization increase, however not in a similar manner for both mechanics and electricians. Even if there were more electrical than mechanical orders, the repair time for electrical orders was shorter and the competences needed were 50 % mechanical and 50 % electrical. The decision made to have two mechanics and three electricians in each shift with support from daytime mechanics thereby seemed questionable. Also some of the production managers raised the issue of enlarging the corrective maintenance staff to reduce the response time, but the question was if it was not more efficient in the long run to put those resources on preventive maintenance to decrease the amount corrective orders and thereby creating a long term solution to decrease the response time.

To look at a potential future situation without the H factory, a graph without the orders from there is shown below in Figure 12. Since the E factory was supposed to be up and running in a near future this graph gives a hint on the resources needed.

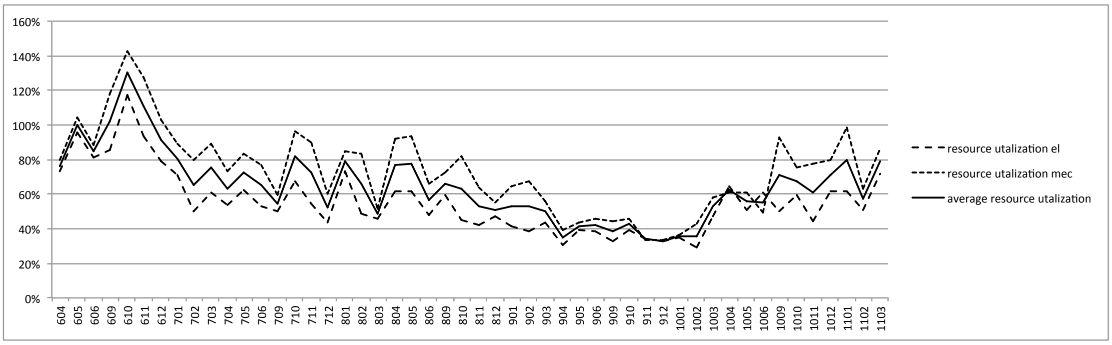


**Figure 12 Resource utilization without the H factory from 2006-04-01 to 2011-03-31**

The distribution of orders from the different shifts were also very interesting. The production was going at 100 % around the clock all weekdays and in some production sites also on the weekends so the division of orders should have been more or less even over the shifts. This was however not so where the day shift had almost twice as many orders compared to the night shift. This difference could not be explained by the labour division on the weekends where the night shift was not used or by the possible "saving" orders from Sunday night to Monday morning. Another interesting fact was that the median response time was the same on all shifts even though the amount of orders varied. The average response time however varied, which could imply that the really long response times were fewer in the night shifts. According to the maintenance engineer it was an "old truth" that the production worked better at night and no one really knew why. Possible explanations were that there were less people around to fiddle with the machine or that there were many other tasks that the operator had to do during the day so it was easier to just put in an order than to handle it themselves. Therefore, not only the number of technicians could be discussed but also the efficiency of the maintenance in the different shifts.

In the case of the functional maintenance teams performing corrective maintenance, the general explanation provided by the maintenance engineers were that if the functional maintenance teams did corrective orders it was because they were called in when the channel was "panicking" in a stop and desperately needed help quickly. These orders were generally more complex and took more time. Another explanation was that the functional maintenance was unused to troubleshooting. The question was if that was what the functional maintenance teams were there for and if their time could be used more effectively.

## 6.4 Processes

The actual processes of corrective maintenance were in most situations the same as the theoretical processes decided upon, but in some situations it differed. This was however not necessarily a bad thing for the efficiency of the work performed. There were also some parts of the process that could be improved to better fit the needs of the production. The lack of common understanding of how the processes should be carried out was something production managers emphasized the importance of. The key issue was to have good communication with the production and decide together how the processes should look and then stick to that so all parties knows what to expect.

When an order was put into the API the technicians answered the order as fast as possible. This time however could vary greatly and that made the planning procedures for production very hard. To reduce the time or to promise a specific response time was difficult since the response time to a high extent was depending on the repair time that could be varying greatly in every specific order. To reduce this time there were a few things that could be done. As discussed earlier personnel could be added to the corrective unit, but that might not be a good long-term strategic decision. Another solution could be to have the functional maintenance teams responsible for making a first assessment. At the time for the thesis they were allowed to look at the broken machine for 15 minutes but how often this possibility was used and what those 15 minutes were used for was not clear.

Another thing that could create longer repair times was the spare parts. Parts seemed in some cases to be hard to find and the processes of how to get the spare parts were not followed. Also according to Ohldin (2011) this could be an issue and the writer argued that the problem seldom was that there were no spare part but that the location of the spare part was unknown since they were spread out over the factories and not, as they should be, in the central warehouse. The occurrence of spread spare parts in the factories had happened because the channels did not want to go across the entire production site to get a small part because it was time consuming. The staff in the warehouse however stated that the total time to get a part would be faster if the processes for getting the part were followed.

The drawings of the machines, or the lack there of, were a problem taken up by Ohldin (2011), production managers and the technicians. The drawings were incomplete, not updated and not where they were supposed to be. This was also a problem that affected the repair time and thereby also prolonged the total repair time and in extension the response time.

Communication problems were also evident when looking at the reported downtime in the machines due to corrective orders where the time reported from the production and the maintenance technicians differed. This also correlated with that the technicians waited with the reporting of orders until the end of each shift, instead of doing it directly, to be able to respond to the next order in line faster. In some cases the production wanted to be able to see what had happened during the shift and sometimes they did not know if the machine was fully operational when the technician leaved or if he or she just were out to have lunch or fetch a spare part.

Some years previous to the study a process plan to use when a repair had to be escalated was drafted. It contained information of what to do when for example a repair has exceeded two hours or when external help had to be called in, to keep the production managers up to date on what happened in the channel. The technicians did at the time of the thesis however not use this plan because it was believed, both by them and the maintenance managers to be a paper product and not usable in reality. This view seemed not to be shared by all parties in the process and in some cases an escalation plan was requested from production.

The opinions of the need for prioritizing the orders differed widely in the organization. Some believed that it was of uttermost importance to increase the prioritizing list and have it updated from productions side every day with what factory and what channel that was the most important during the day. Others believed that all parts of the production were equally important in the long run and thereby no excessive prioritizing except from the hardening machines, should be done.

Literature did not provide a firm guideline in the subject of prioritizing in this area, see 3.2.3 Short term, since corrective maintenance cannot be scheduled. One argument was that the corrective orders were equally important and thereby cannot be prioritized by importance. Instead orders that were close to each other could be handled together or the order with the lowest estimated repair time could be handled first. It was however hard to know how long an order should take and it would be based on the information entered into the API and it would be a question of how the individuals interpret that information.

In reality informal prioritizing did take place in the factories. Both in form of the manufacturing manager calling in and changing the order of the orders in his or her factory and on channel level where the production manager spoke to the technician when he or she arrived and asked to take another order in the same channel first. This informal prioritizing worked on daytime when the managers were there, but the rest of the time there were no one with organizational mandate to change in the orders and that made it difficult.

## 6.5 Value creation

Corrective maintenance creates value for both the production and for the end customer, as discussed in 3.1 Definitions of maintenance. The corrective maintenance cannot be fully replaced by preventive maintenance at a reasonable cost, which leads to the conclusion that an effective and efficient corrective maintenance was needed at SKF. In 5.3.5 Value creation it was clear that the central maintenance unit could improve in some aspects and that these improvements affects the other areas in the Corrective maintenance model.

## 6.6 Improvement areas

In this subchapter, potential improvement areas for SKF Gothenburg are presented. Three areas are focused on, based on the most pressing needs found through the empirical study at the company. The corrective maintenance at SKF had potential improvement areas but also areas where the organization was well adapted to fit the needs of the production. The centralized/decentralized organisation was one example of an area where the organization had found an appropriate way to work gaining the benefits from, and limit the negative effects of, both strategies. The structure created both flexibility where it was needed and closeness to production. Also the competences of the corrective maintenance staff seem to be appropriate. The strategy to complement the broad competence of the technicians with external staff to meet the demand for front edge competences in specific machines and orders was an effective strategy that suited SKF.

But as stated earlier, there were also areas where the organization could be improved. Improvement areas that will not be addressed separately, due to their pervading character, but still were very important were standardization and common understanding of the processes. If production expects a certain routine or processes and it happens differently it could lead to friction between the departments. A similar view of the processes and standardized processes also helps to create an understanding of the other part even in stressful situations.

***Goal setting***

The first area is goal setting where the connection to the production as customers has to be clearer. None of the goals had a clear connection to evaluation regarding how good the unit was doing in reference to the production needs due to their internal nature. The decision on what goals to evaluate the organisation on, how the work to achieve those goals should look like and what resources should be used has to be taken together with production on a strategic level. The things that are important to the customer have to be important for the maintenance unit. But for goals to work they also need to be well anchored, both on the customer side and in the own department, from the technicians and all the way up. For everyone to believe in the goals, a focused effort had to be put in to improve the organization in the right direction and continuously measure how the work is improving and communicate it to all hierarchical levels.

***Resource planning***

Secondly the strategy of how to utilize the entire maintenance organisation staff the most as a whole is an area that can be further investigated. The routines that exists today, but are not always used, clearly states that functional maintenance can help doing corrective maintenance. This could be further explored in order to cut peaks in response time for the central maintenance unit. By allowing the functional maintenance teams to do a diagnose or to have them check the most common cause of stop in the machine when it stops both response time and total repair time could be lowered, this connects to what Nyman and Levitt (2010) discuss about having functional maintenance do 10 % of the corrective orders, see 3.1.1 Division of maintenance work. Further, it is shown that a limited number of machines cause a high amount of orders for the corrective maintenance unit. These machines should receive extra attention by the functional maintenance and the preventive maintenance routines for these machines might need an overhaul.

To further cut peaks in response time and queues the capacity planning could be changed. There is clearly a big difference in need of corrective maintenance during the different shifts of the day and there is also a need for a fifth shift. At the same time, having two mechanics and three electricians seems to be based on a different situation since the workload today is equal among the two functions. Together, these three separate situations create a possibility to even out the resource utilization during the whole week.

***Communication***

The third improvement area is the communication strategies on all hierarchical levels that need to be formalized and agreed upon with production. There were no clear directions regarding what should be communicated to whom and how information should be communicated. This was both during the reparations and after. For example with whom the technician should inform if external help is to be brought in or who needs to know what when a reparation has been going on for more hours than expected. This is a problem both on the production and the maintenance side. In most cases the informal communication routes and common sense is enough, but in some cases the information gets lost on the way to the right person, since it depends on individual relations. A common plan between production and maintenance is needed to make sure that the information production wants in different processes are communicated and that everyone knows what to expect.

# 7 Recommendations to SKF Gothenburg

*This chapter contains recommendations regarding improvements that can be made for the corrective maintenance at SKF. Both general improvements and specific improvements areas will be dealt with. The specific areas of improvement is connected to the indicators and to the Corrective maintenance model found in Chapter 4 The Corrective maintenance model. The general improvement is discussed under 7.4 General improvements.*

As can be seen in Figure 13 there are three specific improvement areas detected based on data analysis, literature review, interviews and observations. These are Goal setting, Resource planning and Communication. When improving these three areas different indicators will be affected and a more efficient organization will be obtained. Based on the specific situation of the organization at the time of the thesis, the nature of the improvement areas and the Corrective maintenance model six indicators has been selected. Improving one area can affect one or more of the indicators depending on for example what measure is taken.

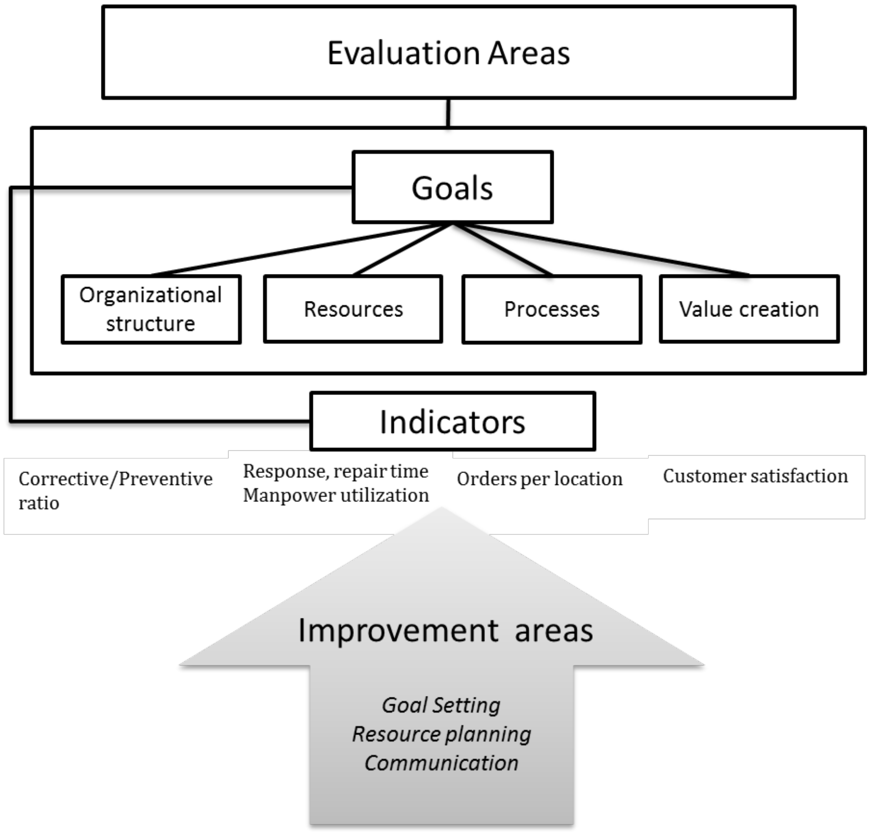


**Figure 13 Improvement areas affect the Corrective maintenance model**

What is common for all of the improvement areas presented, both specific and general, is the importance of making sure that there is a common understanding of the processes for all involved parties. If this is achieved any development or improvement thereafter will be empowered by having different functions heading in the same direction and thereby building on each other. The common understanding of the processes can be difficult to achieve, as it requires a certain degree of commonality. The reason for this is that there is a lack of established routines and standardization throughout the processes connected to maintenance. Instead each production channel or other stakeholder chooses to use maintenance in different ways. In some cases the differentiation can be beneficial as it fits different channels to have different services. However it is recommended that it becomes more clearly specified what the service offer consists of.

## 7.1 Goal setting

The goals can be seen as a statement of what is important for the organization, department or unit. What goals are set up also implicates what indicators are important and how they should be followed over time. A good example of a goal is to have a certain response time for a specific percentage of the orders. The organization can also have multiple goals with corresponding indicators that have to be followed up and worked with in different ways to gain results. In goal setting, there should be incentives for improving the performance; the maintenance department needs to improve its performance by setting clear goals together with production and also to develop and visualize means to reach the goals for the technicians. It should be further emphasized that setting goals together with production is the key for reaching the best results.

For any organization or department it is important to work for continuous improvements, as it is a driver for positive development. An organization without it can easily become comfortable in its situation and become less effective. In an internal service organization the risk is perhaps larger as it does not have any actual competitors. The maintenance department at SKF needs to investigate what incentives there are for developing the service offer. Comparing with the production channels, the channels have clear incentives as their output is sold to customers, which mean that more output results in higher profit.

In the central maintenance unit at SKF Gothenburg there were fixed goals, but the knowledge about the goals were very low both inside and around the department. Also the department was lacking a plan for how they should work to reach the goals. Since the corrective maintenance is so intimately connected with both the preventive maintenance and the production, a common goal and structured way to reach the goals prepared together would be appropriate.

Apart from having cross-functional goals, also communicating the goals and decisions taken on a high hierarchical level is of great importance. The operating staff that actually is performing the maintenance work has to realize that the goals are important and that their work matters in the quest to reach them. To further point out the importance of the goals and enable success in reaching them a continuous process for follow-up is important. For example there could be automatic reports in the maintenance information system that covered the goals and were updated every month. Further discussions about the communication are found in 7.3 Communication.

## 7.2 Resource planning

The resource planning is a key activity in a maintenance organization where the staffing should correspond to the customer needs. The maintenance department can change the planning in order to improve the manpower utilization, to change the corrective versus preventive maintenance hour ratio and to focus on orders per location or machine. The second of these was already used by the functional maintenance as an indicator, which makes it easier to work further with. Within resource planning there are three recommendations: plan the staffing according to resource utilization, use functional maintenance when needed to relieve pressure on the central maintenance unit and change shift at the site of ongoing reparations.

It is clearly shown in 5.3.3 Resources that the need for corrective maintenance has decreased compared to functional maintenance but the since late 2009 the decrease has come to a halt. However, there has not been any significant difference between mechanical and electrical functions in hours spent on repairing. Instead the need for the two functions has been equal. Considering this it is extraordinary that the resources are planned differently in the central maintenance unit. The mechanics had two technicians in each shift and extra staffing during daytime whereas electrical had three technicians in each shift only. Further, the number of orders was very different during the hours of the day, where the night shift has roughly half the orders compared to the day shift. This suggests that the electrical staff should be planned similar to how the mechanical staff is planned in the future. On top of this change there has also been an expressed need from the production to have a fifth shift in the central maintenance unit covering the nights during weekends. During the nights on weekends the need for corrective maintenance was not as large as other nights as not nearly all production channels was running, which indicates that this shift should not consist of as many technicians as other shifts.

One suggestion to improve corrective maintenance, that has been used in some of the production channels (see 5.3.3 Resources), is to use the functional maintenance as an extra resource. At the time of the study the functional maintenance did 4 % of the total corrective maintenance, however this was an average number which means that some of the functional maintenance teams did no corrective maintenance and some teams did perhaps twice the average or more. To build on the idea that functional maintenance could help, it could help when there is a long queue of corrective maintenance orders. In practice this would imply that if there is an incoming order and the central maintenance unit understands that they cannot respond to the order within an hour the functional maintenance should be called in to support. They could start with troubleshooting and perhaps fix the problem before the central maintenance unit can arrive. This suggestion implies that there would not be extra resources needed in the central maintenance unit but in some of the functional maintenance teams instead. This would also mean that these extra resources could help with preventive maintenance and perhaps training of operators. In the long term perspective for SKF it should be preferred to optimize the preventive maintenance than to sub-optimize by increasing the central maintenance unit staffing only.

Further when the production shift comes to an end there is unutilized time for reparation as maintenance also changes shift at the same time. During this time in the end of each shift the maintenance technician has to do the reporting of all the orders handled during the day. The reporting takes roughly 30 minutes and the technician will therefore not start on any new order during or closely before that time. The technician coming on the new shift will require some time before going out to start repairing, even if it is an existing order. This means that there could be up to one hour of no actual reparation in the factories between each shift. As there are three shifts during the day there are three unutilized hours. The reporting itself is not a problem but it creates a gap when done during an active order where the machine stands still for reparation. If the technician on the new shift were able to change over at the site of the machine the shift change would go smoother since both technicians would be there to fill in what had been done and what the potential problem is. This is only suggested to be done if there is an active order running during shift change. This also requires a change in reporting since if this would be implemented the reporting has to be done earlier. It is suggested to do the reporting each time the technician finishes an order.

## 7.3 Communication

Communication between the production and the maintenance units as well as within the maintenance units is a wide area that needs to be improved at SKF in Gothenburg on all levels. If the right information would reach the right person it can improve the customer satisfaction. It is also a big part in the other two improvement areas where the sharing of information is essential for reaching good results. This area is one that all the production managers have been discussing in interviews and many of them have referred to this as the most important area for improving the service. For example communication is of essence when following up on goals and creating a plan for how to reach the goals. Communication can be very abstract, however there are a few concrete recommendations discussed in this subchapter. The recommendations are: inform the operator about the technician's arrival, develop the escalation model about communication and incorporate service or maintenance representatives in the production steering group meetings.

At the time for the thesis communication, on most levels, was based on the individuals' personal networks within SKF. This made it easy for information to get lost on the way to the receiver. To tackle this problem, new structures for how to communicate and what information should be communicated could be created and implemented. On technician-operator level this could include a structure where the technician calls the operator when it is possible to give an approximate time for arrival at the site. This would make it possible for the operator to plan his/her time a bit better and would also be a way to try to meet the productions needs of a fixed response time for easier planning on the manager level. Also having a structure for making sure that the operator and the technician agrees over what has been done and that the repair is complete would be positive for the overall customer satisfaction since this sometimes is referred to as a problem.

Another important issue is what information should go upwards in the hierarchy and who should be responsible for that the information reaches that person in a corrective maintenance situation. One alternative is to once again create an escalation model dealing with how the technicians should communicate when troubleshooting a machine but without finding the error within a certain time. This is a communication improving action to take that demands production to have an active role in the creation of the model that also can lead to better shared understanding of the processes and needs. However, since there is an existing escalation model, it is recommended that the existing one is developed further for a new implementation of it.

On a high hierarchical level it would be valuable to incorporate service or maintenance representatives in the production steering group meetings. This is a possibility that would make the communication between the organisational departments much easier.

## 7.4 General improvements

During the thesis some general improvements were found that would decrease the repair time for the corrective maintenance unit and the amount of corrective orders. These improvements did however not lie under the corrective maintenance unit and are therefore addressed separately from the other areas. The general improvements are the spare part handling, updating machine drawings and focusing the work in the functional maintenance teams.

The first improvements is spare parts, where there clearly are room for improvements in terms of how to give the production and the maintenance as good service as possible when it comes to ordering, collecting and storing spare parts. Maintenance technicians are dependent upon having access to spare parts when needed, if the parts were easier to find the repair times would decrease as the technicians would not have to search in the main storage, the production channel storages or search in unused machines that might have the part needed.

Another general improvement that seemed to be known within SKF but not yet handled was updating and storing machine drawings. There was constant irritation regarding the drawings, whether they were non-existent, not in the right place or were not updated with changes made to the machine. To handle this problem it would require a focused effort during a shorter period of time, but it is expected to have significant positive effects on the repair time. Also, it is believed that if the drawings were correct and in order, people handling them would make sure they are put back into place and updated accordingly.

In the data it could be seen that some specific machines required extensive work from the central maintenance unit. On a bi-monthly or quarterly basis the total corrective maintenance hours spent on the machines during the time period should be investigated by displaying the top ten or twenty machines. These machines should get extra attention by the functional maintenance in order to reduce the risk of having unplanned stoppages due to breakdowns that requires corrective measures.

## 7.5 Summary of recommendations

The recommendations for the corrective maintenance department are separated into three areas: Goal setting, Resource planning and Communication. The areas are equally important for improving the department and can be improved simultaneously or one by one.

Within Goal setting there are three recommendations:

- Create incentives for improvement
- Set maintenance goals *together* with production
- Develop and visualize means for the technicians to reach the goals

Within Resource planning the following recommendations are given:

- Plan staffing according to resource utilization
- Use functional maintenance to support the central maintenance unit
- Change shift on site at ongoing reparations

Within Communication the recommendations are to:

- Inform operators in advance of the technicians arrival
- Develop the existing escalation model about communication
- Incorporate maintenance in the production steering meetings

# 8 Discussion and Conclusion

*This chapter contains a discussion about how the thesis was conducted and the results that came out. Further, the applicability in other situations and future fields of studies are also dealt with.*

## 8.1 Thesis discussion

The layout of the thesis made it possible to base the study on previous findings presented in literature. The Corrective maintenance model became the result from literature study in the field of corrective maintenance and thereby answering RQ1. The model was first and foremost created to support further analysis of the maintenance at SKF Gothenburg. However, it is believed to be a strong tool for usage in other organizations as well. The model became very helpful to structure the findings of how SKF worked with corrective maintenance. The observations and interviews that were conducted gave a fairly complex picture of how the corrective as well as the preventive maintenance were done. The complexity originated from the low rate of standardization where almost each production channel had a different view of how maintenance should be used. There were also varying needs of maintenance in the channels; the reason for this was not fully investigated from neither SKF or from the authors. This was something that could have been investigated further. However, it was outside the scope of the thesis and would be more useful if combined with a study in preventive maintenance. RQ2 was answered in chapter 5 Empirical findings and was structured to fit the Corrective maintenance model in order to give a clear picture of what was of importance in the aspect of improvement potential. The answer to RQ2 was however not a small and simple answer which perhaps makes it slightly difficult to get an overview of how SKF worked with the whole corrective maintenance. At the same time RQ2 was developed to support finding improvement areas, and not to be used as a benchmark to compare with other organizations. This could have been done if the purpose was to create a point of reference of the maintenance service level at SKF. This was not done due to the fact that SKF used the internal maintenance service in first hand and other actors secondly but only if the situation required it.

The next two research questions were to find areas for development and to create suggestions for how to improve. RQ3, which is answered in chapter 6 Analysis, was reached through finding inconsistencies in how SKF worked with corrective maintenance and by collecting and putting together opinions and ideas with maintenance system data. This method gave the authors a rigid set of improvements areas. These areas were further investigated in RQ4 and chapter 7 Recommendations to SKF Gothenburg. The areas were refined by giving each of them three specific points of improvement that were all connected to the organization through the Corrective maintenance model. By answering RQ4, all the research questions had been answered and the purpose of the thesis had been fulfilled.

## 8.2 Applicability in other situations

This thesis was conducted as a case study with a deductive base. This raises the question regarding how the findings could be used in other situations. It is believed that some of the conclusions are applicable in other cases. The final results presented as recommendations are specific to SKF but the importance of them are general. For other organizations these final findings can be used to see whether they are excelling within the areas or not. However, for a more extensive evaluation and improvement process it is recommended to start with using the Corrective maintenance model and thereafter use the research questions 2, 3 and 4 to find areas of improvement specific for the organization. Thereby the major contribution this thesis gives to the field of corrective maintenance is the Corrective maintenance model. Any equivalent model specified on corrective maintenance has not been found in the literature.

## 8.3 Future fields of study

This thesis has identified some areas for improvement for the central maintenance unit at SKF Gothenburg and presents some general ideas for how to create a more efficient corrective maintenance. There are however areas that the thesis, due to the focus, has not handled that could be of great interest for SKF to study further. The first of these areas are the spare part handling within the company that the authors believe can be improved. Efficient spare part processes would not only create shorter repair time for the corrective maintenance unit, but also for the functional maintenance and everyone else that is in need of spare parts.

Regarding the production an interesting area for further analysing is the differences in the amount of corrective maintenance orders between the different shifts. More specifically why there are so much fewer orders put in during the night when all hours of the day are treated equally in the production planning.

Another area is the connection between the functional maintenance teams and the production where there in interviews has come forward a need for closer connections between these functions to create a more efficient production. There is a wide spectrum of how the production works with its functional maintenance teams both at factory and channel level but there seems to be a common awareness of the need for a collaborative spirit between the units. An interesting area to study further would be to find the reasons for this variety and to find a potential best practise with the goal to create higher machine utilization rates.

During the thesis the authors have discovered a lack of academic literature in the area of corrective maintenance. The focus on preventive maintenance is understandable in some respects, but the literature seems unanimous in the fact that only having preventive maintenance is extremely expensive. This would indicate that there is an interest in how to handle the last percentage of maintenance that still has to be corrective in different environment.

## 8.4 Final conclusion

The value of the thesis depends on who the reader is, for SKF it is likely the recommendations given for improving the maintenance organization and for others it is probably the Corrective maintenance model in conjunction with the focused improvement areas. For SKF the goal with the thesis was to investigate whether any improvements of the corrective maintenance could be found. The authors claim to have found such improvements and believe that the three areas will improve the overall performance of the unit. The three areas are equally important and will give different benefits if improved. There is no prioritizing between them since they influence the work differently and has to be handled in different ways. If developing Goal setting, Resource planning and Communication as suggested, the central maintenance unit at SKF Gothenburg will become more efficient, create more value for the customer and improve the corrective maintenance service.

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## Appendix A Production interviews

### The interviewees

| Factory/channel | Position | Name |
|---|---|---|
| D/K1 | Production manager | Göran Larsson |
| R | Manufacturing manager | Lars Fält |
| R | Production manger | Rikard Milner |
| R | Production manger | Dennis Wiberg |
| E/Lt3 | Production manger | Ann-Catrin Andersson |
| E/K30 | Production manger | Ulrika Jonasson |

### Interview template

1. Five short questions about the connection to maintenance
    a. How high is your involvement in the functional maintenance unit work in your channel/factory?
    b. Does it happen that the need for production capacity is so high that the planned maintenance stops are postponed?
    c. Do you feel that you can influence the maintenance work done in your channel/factory even if it is another department performing it?
    d. How much do you work with operator maintenance?
    e. Do you do any calculations on how much the maintenance saves or costs you?
2. Do you feel that the repair time or the response time is to long today?
    a. Except from increasing the workforce in corrective maintenance, do you see any other possibilities to decrease the response or repair time?
3. The last years the external personnel taken in to do corrective maintenance have increased, what are your reflections to that?
4. Do you want to be able to prioritize the orders from your factory/channel? Is prioritizing a problem today?
5. How do you communicate with the corrective maintenance staff?
6. Is there any difference between the factories when it comes to corrective maintenance?
7. Are you generally satisfied with the corrective maintenance?
    a. What do you think is the most important possible improvement area in corrective maintenance?

## Appendix B Group interview

### The interviewees

| Position | Name |
|---|---|
| Head of Maintenance | Christain Moldén |
| Maintenance engineer, Central maintenance | Yngve Svensson |
| Maintenance manager, D-area | Göran Larsson |
| Maintenance manager, R-area | Jonas Vallström |
| Maintenance engineer, R-area | Isak Bäckström |

### Discussion areas

1. Goal setting
   a. What are the goals today?
   b. Is everyone aware of them?
   c. How are they connected to the customer?
2. Resource planning
   a. Why does resource utilisation differ between shifts and functions?
   b. How can a 5-shift system work?
   c. Is escalation models needed?
3. Communication strategies
   a. Can production know when a technician is on the way?
   b. What information does production want and what do they get?