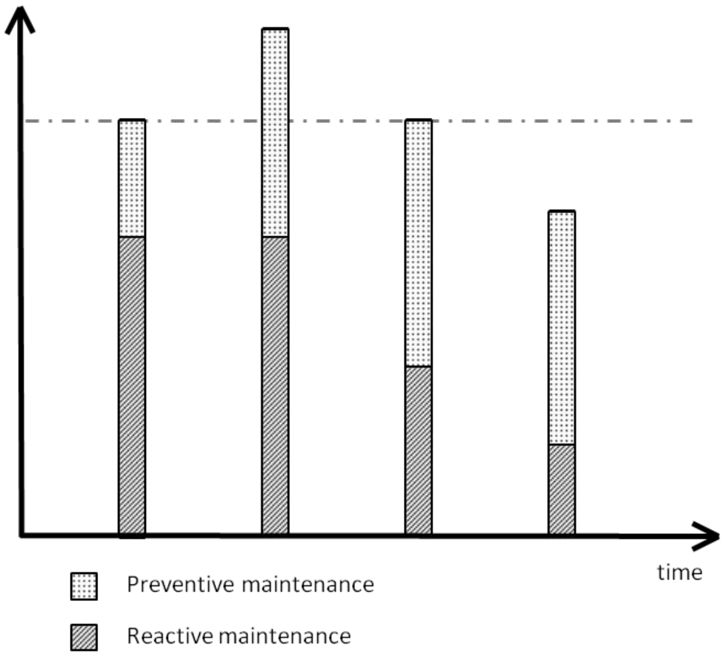

Invisible driving factors counteracting maintenance operations

Master of Science Thesis [Production Engineering, PPUX05]

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CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden, 2013

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Cover:
[Hypothetical development of the ratio between preventive and corrective maintenance operations]

[Chalmers reproservice]
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Abstract

Maintenance in industry has been increasingly important as demands on productivity and reliability are focus areas of manufacturing businesses. Maintenance operations are technically advanced and successful efforts result in non-occurring failures, which leave an organization with few points to evaluate their work and success on. This master thesis is investigating why GKN Aerospace Engine Systems in Trollhättan is not achieving their goal of reaching 70% preventive maintenance and 30% corrective maintenance. The study is delimited from service personnel's performance and equipment that is not connected to the surveillance system.

Four other companies were visited in order to see what prerequisites, techniques and tools are common in Swedish industry to handle maintenance. Experts in maintenance were interviewed to map challenges and what benefits a manufacturing business can have from an efficient and well working maintenance organization. To extend to internal empirical research, analyses of statistical data were made to investigate production data as well as to validate results from interviews and to strengthen arguments for the findings.

The purpose of the study is to surface the factors that are hindering the maintenance organization to reach their goals, the investigation takes a holistic system approach in order to give suggestions to reduce sub optimizations and decrease the overall production costs. The findings include organizational mindsets, demands, philosophical views of industrial engineering, and some key performance indicators that are not applied correctly. The findings are 12 factors standing in the way of the development of the maintenance organization, where: why they are barriers, how they were found, what consequences they have on GKN and how they could manage the issue, is presented. The suggestions include some hands on tools, some more long term advice that need adaptation and development to fit the application.

Some of the factors are more significant findings, for example insufficient demands on production stability which needs to be emphasized in order to surface points of improvement and identify where maintenance should be directed. Other significant factors are that there are gaps in the perception of what constitutes a sustainable production system, how maintenance is a relevant part of the production apparatus and to realize the connection between reliability and profitability.

The research leaves recommendations of how to manage each factor individually, and further recommendations of how certain factors could be emphasized in long term and short term perspective is presented in the *General discussion*.

KEY WORDS: Maintenance, Invisible driving factors, Benefits of maintenance, Productivity, Engineering, System thinking and demand, Stability, Reliability, Technical availability.

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Anton Andrén and Anders Brusing

Gothenburg, April 2013

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Terminology

AOM – Autonomous Operator Maintenance

CM – Corrective Maintenance

ERP – Enterprise Resource Planning

FMEA – Failure Mode and Effect Analysis

GKN – When GKN is used in the text it refers to GKN Aerospace Engine Systems in Trollhättan.

KPI – Key Performance Indicators

LTA – Logic Tree Analysis

MTBF – Mean time between failure

MTTR – Mean time to repair

OEE – Overall equipment efficiency

PF – Productivity factor

PM – Preventive Maintenance

RCFA – Root Cause Failure Analysis

RCM – Reliability Centered Maintenance

ROI – Return on investment

SMGC – Sustainability and Maintenance Global Center, community for maintenance.

SMM – Swedish Manufacturing Management, equipment surveillance system at GKN

TA – Technical availability

TPM – Total Productive Maintenance

WIP – Work in Progress

1 Introduction

The introduction will present why and with what prerequisites the thesis is made, the background for the project is presented and a description of the studied system and its complexity is given to provide context. Purpose and objectives explain what the thesis was expected to give and finally the scope and delimitations describes the prerequisites.

As industries today strive to be more competitive and effective in their organizations, demand for more effective maintenance increases, yet maintenance is often regarded mainly as a cost centre and an expense (Tsang, 1998). Traditionally, maintenance is not recognized as a contributing part of a well functioning production system and so the development of maintenance has fallen behind the rest of the production system in many industries. Researches investigating the costs related to maintenance show that (Chan, et al., 2003):

> *"Maintenance costs account for 15–30% of today's manufacturing costs."*
>
> *"Up to 33% of maintenance cost is wasted."*
>
> *"Emergency repairs are often three times more expensive than the same job done pre-planned (and may take 10 times longer). "*

Despite this, the interest in developing maintenance is low and might be due the unclear connection between maintenance operations and profitability (Jonsson, 1997). In Sweden the cost of maintenance is estimated to approximately 6.2 percent of the industries turnover, which is nearly 200 billion SEK per year (Ahlmann, 2002).

The Swedish organization Sustainability Maintenance Global Center (SMGC) is a continuously evolving network and forum with the purpose to emphasize the importance of maintenance and general sustainability. To promote sustainability and learn across industries and universities, SMGC provides seminars and study visits to and with active members. GKN Aerospace Engine Systems (previously Volvo Aero) is actively participating in this work as a member of the SMGC, and have during past years had a vision aiming to practice more preventive maintenance and less corrective maintenance, 70 % and 30 % respectively (work hours, number of cases). This has been a challenge and several attempts have been made to change the maintenance operations in this direction.

Despite these attempts to change, the history shows the maintenance activities is the same as during a period of ten years back i.e. 20 - 40 % preventive and 60 - 80 % corrective maintenance. Considering this it is assumed that there are invisible factors affecting the outcome of maintenance operations. Plausible reasons for failing in turning the numbers may be due to the outsourcing (2001 to 2010) of the maintenance at GKN, as well as efforts were solely concentrated to the maintenance department. As outsourced, the maintenance department may have accepted preventive maintenance work orders that did not focus on equipment reliability and thereby not lowering the amount of corrective maintenance enough to turn the numbers.

By succeeding to identify invisible factors affecting maintenance operations, and by showing how these factors connect maintenance to the production system i.e. how maintenance operations is connected to profitability, will provide a valuable contribution in line with the work of SMGC and emphasizing the importance of maintenance when developing competitive production systems.

1.1 Purpose

The effect of reaching the vision stated in the maintenance strategy might lead to a decrease of the total amount of maintenance, as can be seen in the hypothetical future state in figure 1.1. This is also intended to lead to decreased duration of stoppages since fewer is handled with unplanned corrective actions and more of the stoppages handled with well planned preventive maintenance operations.

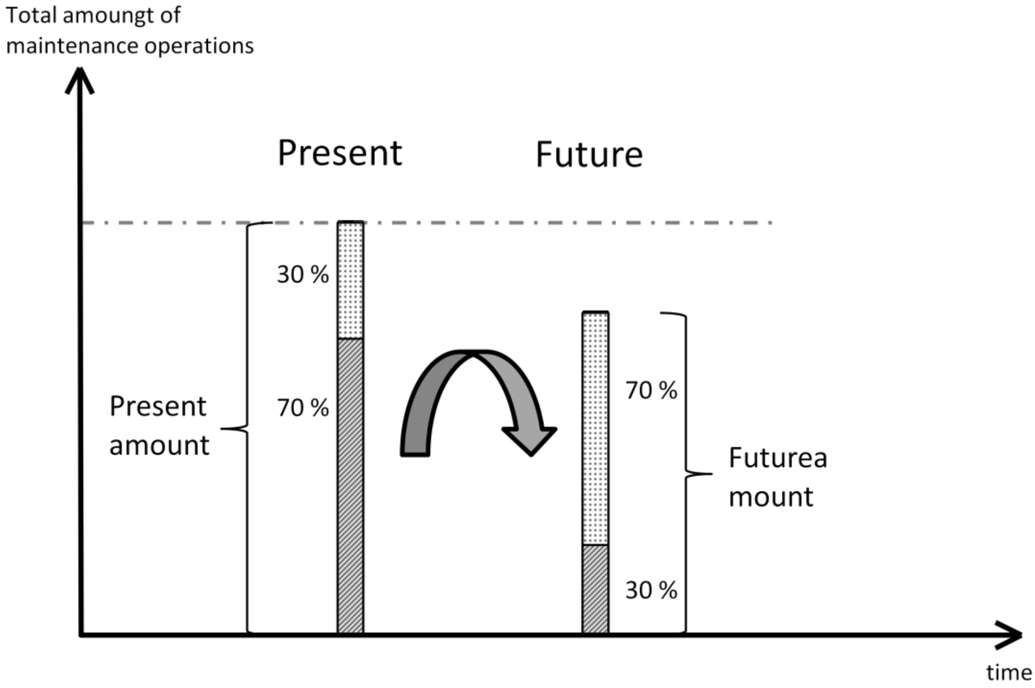

Figure 1.1 Ratio between preventive and corrective maintenance in present and hypothetical future state.

The overall purpose of the thesis is:

Empower fulfillment of maintenance vision, improve reliability and reduce overall production costs by surfacing invisible, counteracting factors.

1.2 Objective

The maintenance strategy at GKN, developed 2012, has the objective and future goal of changing the ratio between preventive and corrective maintenance. The vision is set to reach70 % preventive maintenance operations and 30 % corrective maintenance operations of all performed maintenance activities.

The objectives are formulated to find valuable deliverables and will serve to fulfill the purpose of the master thesis. The objectives are sought of GKN and will produce customized input for the company, input that can be used as means to reach the stated vision.

The objectives for the master thesis in prioritized order are:

- Identify invisible factors, bring these to the surface and make them visible.
- Analyze the most significant driving factors.
- Suggest how to manage the identified driving factors.
- Evaluate if the actions taken is contributing to fulfill maintenance vision.

1.2.1 Project research questions

The research questions are formulated to be answered with the results of the project. The research questions provide a clear focus for the aim of the investigation.

What demands on stability and reliability is present in the organization?

What factors affect preventive maintenance operations?

How is maintenance challenges handled at other companies?

The first question serves to investigate what need there really is for effective maintenance in the organization as well as what is perceived to be needed. The first question will also investigate how maintenance affects production disturbances and related succeeding effects.

The second question will give answers about and if there is factors outside the maintenance department counteracting development of preventive maintenance, how maintenance operations is perceived in the organization and what challenges there are. The second question will also give answers of where in the organization these challenges are present and active.

To answer the third question, prerequisites, techniques and tools will be investigated at other companies connected to SMGC to give knowledge of how maintenance is commonly managed in industries.

The purpose of the questions is to look further into the matter of which factors that affects maintenance operations with a clear focus on how maintenance is regarded in the organization.

1.3 Studied system and its complexity

At GKN there are three main workshops, A, C and X which all manufactures different components. There are also shared resources, meaning that components do not follow a designated flow through one workshop but needs to travel between workshops. A special case is when a component has defects, then the product enters a repair loop for correction and control. This structure creates:

- Lost visibility over product flow whenever a component changes workshop which contributes to an incomplete holistic view and covers problems that occurs outside one self’s field of sight.
- Delays in operations further ahead if a variance occurs.
- Demand on output makes the production prioritize machining time ahead of preventive maintenance operations.

The product mix at GKN contains different and very complex products, with high demands on quality from processes, incoming material and after treatments. Product volume is generally low, the product with the largest volume is approximately 500 pieces a year. Products undergo heat treatments, quality inspections and surface treatment in shared processes which brings even more complexity to the production system.

The maintenance organization at GKN is defined as a supporting process to the production organization. Equipment and machine maintenance is triggered by the need of operations availability and occurs mostly as reactive maintenance operations. The maintenance organization at GKN operates internally and with production department who is customer to the maintenance department.

The maintenance is divided into preventive and corrective operations. The corrective process starts whenever a variance or error in equipment occurs. This creates a need of a reactive maintenance action in order to start the production as soon as possible. The corrective maintenance operation takes place when there is a mechanic with sufficient tools and competence available. During the latter part of production hours as well as in weekends the maintenance personnel is only available on call, and it is possible that a particular failure need expert knowledge meaning that the work and stop time is further delayed.

Repair personnel are located nearby two of the main workshops, C and X. The structure is visualized in figure 1.2.

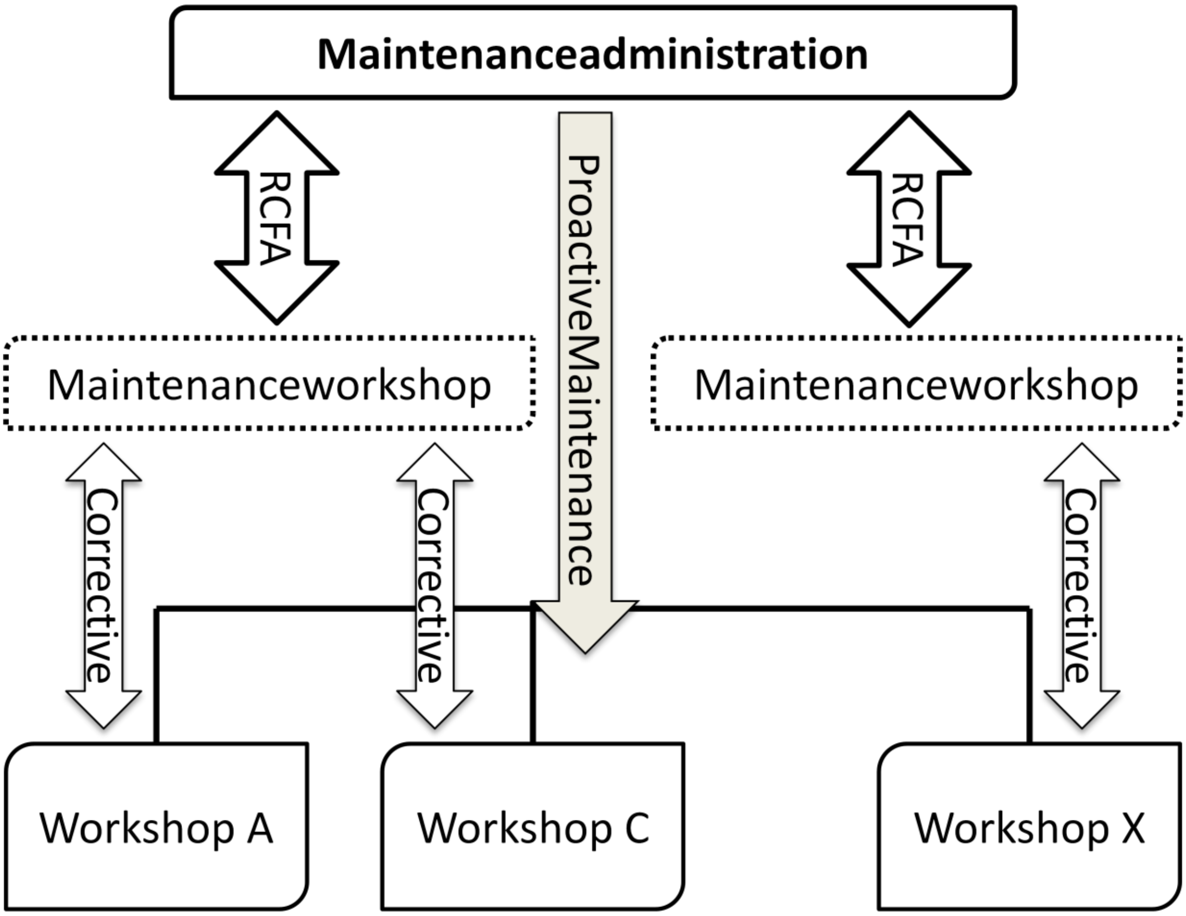

Figure 1.2 Schematic picture over studied system.

Preventive maintenance operations are planned by maintenance department and communicated to production. Planned maintenance consists of recommendations from equipment manufacturer and regular service. An attempt is started to collect root causes from unplanned stops (Root Cause Failure Analysis), actions to prevent these is at times carried out during planned maintenance operations. The operations are carried out during pre-set time windows which sometimes are too short for the actual need of preventive maintenance. Errors and variance are logged in the production equipment surveillance IT system, SMM (Swedish Manufacturing Management), but not visualized to present an overview.

Machines at GKN are classified according to a number of parameters affecting the criticality. Some of these are, utilization, available backup, spare part availability, effects on production flow, bottleneck etc. The most critical machines is assigned A-class and the least critical, D-class.

1.4 Scope

The master thesis will be conducted at GKN Aerospace Engine Systems in Trollhättan (Sweden) with focus on maintenance strategy and applied tools, organizations view on reliability and prerequisites for development, in order to find the invisible driving factors affecting maintenance. The scope will therefore have focus on the maintenance organization interfaces but it will also become important to include how economic incentives, production strategy and organizational control affect the maintenance organization.

To evaluate the prerequisites for development, other companies connected to SMGC will be visited to map tools used to drive their maintenance. Companies with assembly and manufacturing similar to GKN, will be investigated in order to compare the usage of maintenance tools with GKN.

More detailed what will be included at GKN is:

- Triggers for preventive and corrective maintenance operations[1].
- Maintenance service personnel working flow.
- Stakeholders for cost/budget of production and maintenance.
- KPI's and goals, what is supposed to be achieved, and how are these interpreted by stakeholders.

Machines at GKN are classified according to criticality, A, B, C and D. The study will not be limited to one specific classification of machines as important attributes could be missed.

Outside GKN
Find relevant prerequisites and techniques to manage maintenance to a 70% preventive maintenance and 30% corrective maintenance output.

1.5 Delimitations

To limit the analysis of the thesis and stay in line with the objectives some limitations are stated.

The whole plant will not be regarded in detail. For analysis of statistical data, machines connected to the production equipment surveillance IT system, SMM, will be used. To review a value flow in manners of sensitivity to production disturbances, the product V2500 is chosen due to its significantly high volume.

For the analysis of the thesis to keep a consistent level and to present a relevant overview of the identified factors, all topics should be investigated at a reasonable level regardless of significance.

Individual performance of maintenance service personnel is not a subject for the study. Companies used for the external research will be interviewed in two rounds. Further iterations of observations and interviews are possible at GKN. Suggestions of improvements will not be considering technical aspects of machinery.

---

[1] The terminology of the maintenance concepts is more detailed described in the Theoretical framework.

2 Methodology

The methodology chapter describes what methods and techniques that were used to conduct the thesis. The methodology of the project is briefly described in the flowchart below, figure 2.1.

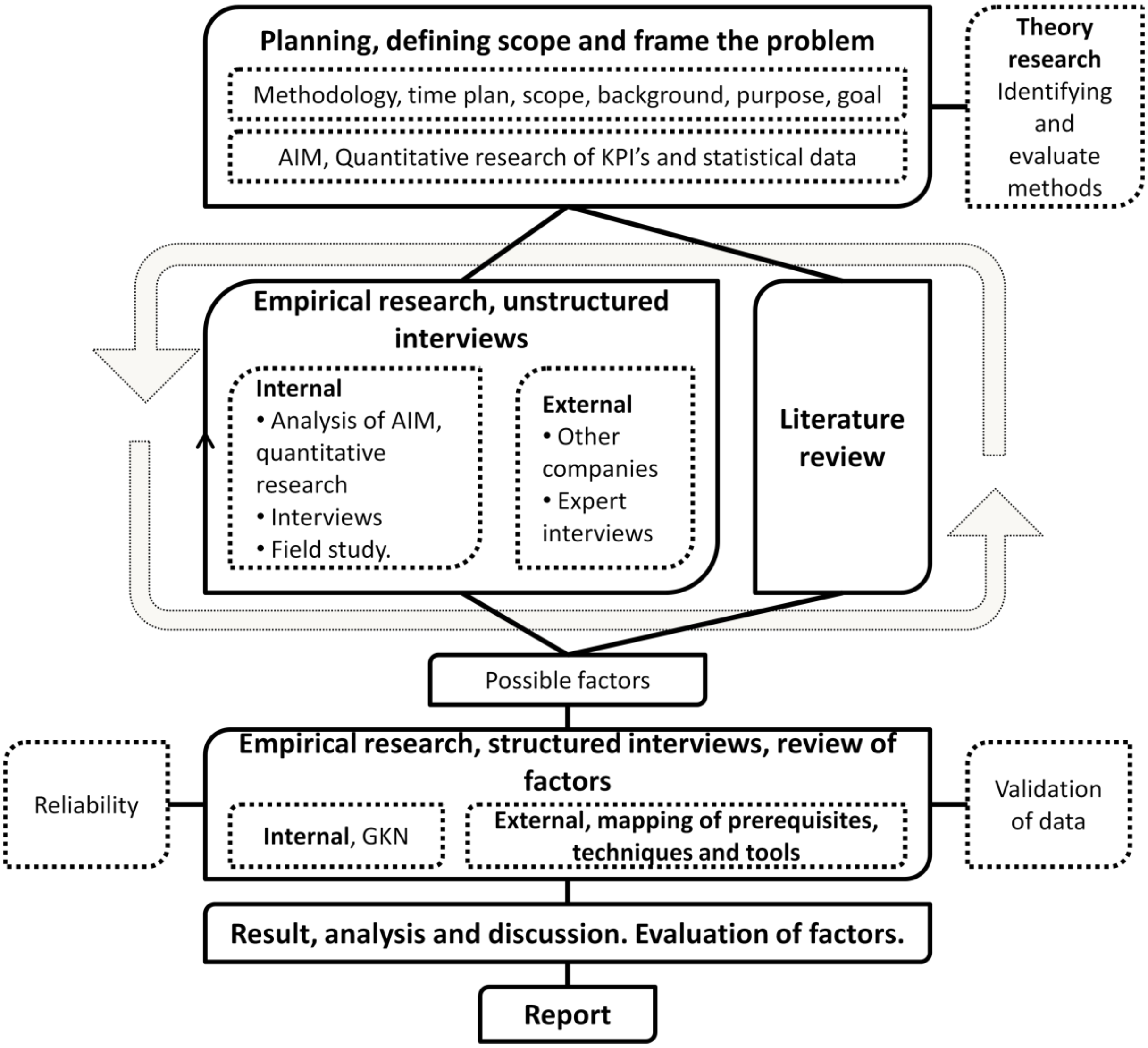

Figure 2.1 Methodology of project with the mid-section visualizing the iterative process of interviews and literature research.

In a project of this character (Master thesis), the working process is independently defined by the project group (the authors of the thesis) to provide a strategy for the separate phases of the working process. The method is established in the initial phase of the project[2]. The main phases of the project are divided into a time plan, providing sufficient time for each phase and clarifying the time horizon.

The project will be started with the phase of defining the scope and framing the problem, which will be done through initial observations of maintenance strategy, some quantitative research of internal company data and workshops according to the Affinity Interrelationship Method (Alänge, 2009). The

[2] The project started with establishing method, time plan, scope and focus for the project which resulted in a planning report.

purpose of this is to build up a perception of the prerequisites and possible parameters to investigate. The methods for this part are further described in the section of *Empirical research* below.

When the projects method is set up and the problem is defined, an empirical research will be started to investigate matters of relevance brought up in the initial phase. This will be done both internally at GKN and externally at other SMGC connected companies and through expert interviews. These methods and their purposes are more detailed described in sections *Empirical research - internal* and *Empirical research - external below.* Parallel to the empirical research, literature review, described in section *Literature review*, will be conducted to expand the theoretical framework with topics relevant to the analysis of the investigation. This phase will be conducted iteratively to permit the project group to expand and bring further findings to the investigation.

Next in the working process, a number of possible factors will be defined and validated through further interviews both internal and external. The possible factors will be reviewed with the project supervisor at GKN to ensure reliability.

The found factors will be analyzed of impact and discussed how to manage in the *Analysis and individual factor discussion,* chapter 5.

Time plan
The time horizon for the Master Thesis is 20 weeks of 40 hours and in total 800 hours. The project work will consist of five main phases which is problem framing on site, planning report, literature review and external empirical research, internal empirical research and finally analysis and documentation by report writing. The time for each phase and other activities is further specified in a Gantt chart(Kumar, 2005) to visualize the overlaps together with the time distribution of each activity (attached in Appendix I). Except the five phases, the project will contain mandatory elements such as opposition and attendance of other master thesis presentations.

2.1 Empirical research - internal
The question at issue for the thesis is open and provides no defined approach of where to start the investigation. To build up a perception of the prerequisites and possible parameters for investigation, the first steps of the project will be aimed at building a base of information, which will be used to form qualitative interview questions for the latter part of the empirical research. With conditions and qualitative questions established for the investigation, the research of parameters influencing maintenance operations will continue.

There are several useful tools that can be used early to analyze complicated and complex problems according to stakeholder's views. The maintenance at GKN is influenced by several departments and internal organizations, all bringing different driving factors into game.

Ethnographic method
In the line of framing the problem and understanding the processes involved, internal field studies will be performed. Ethnographic studies are used when it is necessary to familiarize oneself with a real situation which may be difficult to grasp by reading a description or when the description is insufficient. The method contain observations, listening, reading work related documents and notes etc. all to grasp the situation and being able to describe it (Gillham, 2008). The field studies was used to identify what decisions are made and why i.e. influenced by what factors.

Ethnographic methods is mainly used to study cultures and community types rather than organizations, the method could however be applied since several of the components such as observation and participation fits well into the investigation of a complex and open problem. The concept of the included components in the method is related to the concept of standing in the circle, as referred to by Liker (Liker, 2003). Standing in the circle is part of the Toyota philosophy of genchi genbutsu, which emphasizes going to the actual place to observe, listen in order to understand (Liker, 2003).

Data collection

Observations and discussions will be conducted through conversations process review with project supervisors, managers and operator at GKN. Perceptions of factors and prerequisites relevant to the project questions will be sought while doing this. Information gathered from observations and general conversations will be noted if relevant to the project.

Data analysis

Relevant information and topics of interest that is found during observations and conversations will be validated with an independent source and further researched as questions for interviews and quantitative research.

Affinity Interrelationship Method (AIM)

There are several useful methods that primarily aim to find the root cause of a stated problem e.g. Ishikawa fishbone diagram, Affinity diagram and the Affinity Interrelationship Method among others. In the processes several reasons and factors are discussed and brought up in brainstorming workshops. With a strategically formulated question, participants in any of these methods should be able to consider the important aspects of their departments to provide a more complete picture of possible causes.

Possible reasons for driving factors can be identified by observations, unstructured interviews and simply by studying the maintenance organization. These will however be interpretations of the interviewers or observers. To further extend the collection of possible factors, people’s own perception at GKN is important and will be gathered in an AIM workshop (Alänge, 2009).

The AIM is specially designed to bring up all participants views to the surface, regarding a pre-stated question, in order to reach consensus in a concluding sentence. The method is suitable for cross functional groups investigating complex problems and will also show the relations between different inputs. In the starting phase the reasons of the problems are individually stated in silence, which allows every participant to think without influence of others (Alänge, 2009).

The workshop is guided and observed by the project members while participants write their causes of the statement on post-it notes. Grouping and topics are made by the participants and a conclusion is stated as a response to the voting of the strongest causes.

Data collection

The data from the AIM workshop is collected both by observations and the post-it notes that participants produce during the sessions.

Data Analysis

Analysis, integrated in the workshop procedure will be brief, in manners of asking why, how and where problems might be confirmed. Problems causes that arise in the workshop will make path for questions in further stages of the investigation. Further analysis will be done through a loop of five why that will be asked by the project group for each cause to deeper analyze the perceived cause.

Interviews

Unstructured interviews is often used as a first step of a research to open up the area of interest and deepen the knowledge for questions which needs to be further investigated in a more structured manner later in the investigation. The unstructured interviews allow the interviewee to share experience based opinions, unaffected by the fragmentation of a structured questioning (Gillham, 2008).

Semi-structured interviews provide more structure but the questions are still open and allow space for follow up questions and elaboration of thoughts. The interviewer can make use of keywords to find specific information which can be compared among participants (Gillham, 2008).

Structured interview follows a more strict order and the answers are limited to the design of the questing form. Answers found in this way will be comparable and useful to verify earlier findings. Results of structured interviews provide quantitative data that is preferably analyzed. For relevant results the interviewees needs to have adequate knowledge about the topic and the interview questions carefully prepared considering purpose and formulation (Bohgard, et al., 2009).

Since the first part of the investigation aims at finding unknown factors the interviews will be unstructured to allow the interviewee to share the interests affecting the concerned department. In the next iteration of finding critical driving factors, semi-structured and structured interviews will be used to find comparable data, in order to evaluate driving factors between GKN and other companies.

At GKN, persons working in functions managing the factors found in the earlier study will be conducted with interviews with the aim of confirming if factors are of importance and how their department influences on the maintenance operations.

The unstructured interviews will examine the following topics among different functions within GKN. The interviews will have focus on one main question, covering the topic. Supporting questions are prepared to steer the interview in right direction if necessary (Gillham, 2008). A complete list of topic and questions is attached in Appendix II.

Main question:

- How is the function of maintenance regarded in your work?

Supporting questions:

- Triggers for maintenance operations.
- Interpretation of maintenance strategy.
- Challenges for maintenance.
- Planning of maintenance.
- Interpretation of KPI's and target evaluation.

The semi-structured and structured interviews will be formed after the first part of the empirical research.

Data collection

To collect the data from the interviews notes will be taken during the conversations and later compared with regard to correlations and contradictions. The results will be compiled to provide an overview.

Data analysis

Occurrence of brought up matters will be compared with literature of the given subject as well as quantitative production data. The matters and parameters found in the interviews will be more thoroughly investigated and regarded as strong matters, especially if clear recurrence is found in interview samples and/or correlations with literature and expert research is found.

Quantitative research

To extend the investigation and validate information from interviews and workshop, systematically quantitative research of internal data will be made. The data for this part of the research will be collected from objective sources as internal IT systems. With large enough data samples, results can be somewhat generalized if relevant conclusions is found (Bohgard, et al., 2009). For the research, Key Performance Indicators and statistical data will be used.

Questions to analyze from production and maintenance data:

- Distribution of preventive and corrective maintenance in different work centers according to total cost and time.
- Stop times and the production pace impact, delays, variations.
- Available capacity in relation to stop time and cost.

The empirical research will in the first stage be conducted as unstructured to semi-structured interviews at GKN. The unstructured interviews will open up the field and bring more factors that influence decisions regarding maintenance. To perform a test as indestructible as possible the interviews will begin with the subject of disturbances in production and tools they use to manage it. What the drivers are for their department, and what their goals are.

Data collection

Data will be withdrawn from the production equipment surveillance system, SMM, as well as alternate sources like internal investigations considering production disturbances. Maintenance costs and work orders for individual equipments will be collected from the ERP system SAP.

Data analysis

Data will be compiled from the different platforms in order to overview the utilization and technical availability along with costs. Production stability and overall process robustness will be investigated to find connections with maintenance actions. Data gathered will be set in relations with different parameters to investigate possible connections. Further, data will be analyzed with basic statistics to investigate deviation and mean where applicable data is found.

2.2 Empirical research - external

At external companies, maintenance managers will be confronted with a structured interview regarding the aspects considered most important when managing and implementing a strategy for preventive maintenance. Several other comparisons can be made, such as statistical data and internal numbers, but since all the participating companies have very different products, equipment and methods for measuring, a comparison of the mindset and strategic choices is more suitable for the investigation.

Information from SMGC connected companies will be collected and compared with the prerequisites, techniques and tools found at GKN.

As the research of external companies will be done briefly and during shorter sessions, an attempt to map prerequisites, techniques and tools that favors the maintenance work will be the main focus of the external research. The findings will be handled equally even if their organization impact may differ. Some findings of the external research are expected to be more detailed and some more philosophical and abstract. The limited time for the external research and the scope of the project will not allow deeper investigation of how to realize the more abstract techniques. The external research will neither, due to the time limit and project scope, investigate how each technique is affecting related subjects as motivation, individual behavior etc.

Data collection

The first meeting with the external companies will be in a form of an interview and study visit in order to map which techniques and prerequisites are used. In the second round that will be more structured, the usage of the total found techniques and prerequisites are asked for, in order to see how spread a certain technique or prerequisite are among visited companies.

Data analysis

The techniques and prerequisites will then be compiled in a matrix where they are sorted in presence in order to see the most common ones, as well as compare to the prerequisites, techniques and tools GKN possess.

Expert interviews
The purpose of conducting expert interviews is to extend the perspective of underlying factors affecting the outcome of maintenance operations. The answers from the experts will give further input on the research questions and help to develop the foundation for structured interview questions.

Questions:

1 What are the biggest challenges when implementing strategies and practices for preventive maintenance?
2 What are the heaviest arguments for preventive maintenance on corporate level and how well is this in line with daily tasks in production?
3 What motivates or counteracts companies to develop an organization for preventive maintenance?
4 What motivates or counteracts recurrent maintenance operations on operator level i.e. autonomous maintenance?

Data collection

Participants are identified according to their area of expertise (maintenance) and chosen in cooperation with project supervisors and contacts within SMGC. Experts participating will have connection to Swedish Universities, companies and ongoing research within the area of maintenance.

The experts will be interviewed according to the Delphi method (Rowe & Wright, 1999). A number of questions will be sent to the experts to answer. The answers will be compiled anonymously and re-sent to the participants, who are then able to rethink and possibly extend or develop their answers. The interview process can continue in two or more rounds.

Data analysis

Answers will be sorted and compiled in order to confirm and triangulate (Woodside & Wilson, 2003) information from interviews and literature. Where correlations are found, answers will be used arguments for the analysis.

2.3 Literature review

Maintenance in heavy industry is a part of the production system and by that affected by the degree of challenge on the particular system. The purpose of a literature review is to provide a relevant theoretical framework. This will be used to give an overview of the context of the research and to introduce relevant terminology and theories to support argumentation, analysis and discussion of the result (Ridley, 2012).

Data collection

To gain knowledge, arguments and to understand maintenance operations and organizations, literature review in the area of maintenance will be initiated early in the project and supplemented throughout the thesis.

Since the nature of the problem contains several different aspects of maintenance and organizational management the articles are chosen from different fields of advance to cover a large perspective for the thesis. The focus of the literature review is possible to expand depending of the outcome of interviews and AIM as well as new areas will be necessary to research as new information comes to surface.

The articles and topics for review will be gathered from a number of scientific databases available through Chalmers library:

- Scopus (scopus.com).
- Emerald library (emeraldinsight.com).
- Google scholar (http://scholar.google.se/).

Key words, to find relevant topics, reviewing maintenance as a contributing part of production systems, maintenance connected to profit and productivity and known drivers of reliability will be used and are listed below. The key words will be used in combination with each other.

- Maintenance
- Reliability
- Production
- System
- Productivity
- Economy
- Profitability/profit
- Planning
- Performance
- Cost of
- Benefits
- Quality
- Improvement
- Motivation
- Variation
- Lead time

Data analysis

The literature review will provide a theoretical framework where information will be used to discuss results and be a base for triangulation for data gathered in interviews. Literature regarding maintenance connected with further aspects of a production system, such as productivity, economy, management philosophies will be regarded as relevant to connect the matter of how stability, reliability and profitability is affected.

Theory and articles regarding more detailed parameters affecting the outcome of maintenance operations and what affects sensitivity in a production system will also be treated most relevant to answer the project questions.

3 Theoretical framework

The theoretical framework will provide the reader with necessary theories and terminology to understand the context of the thesis and its findings.

3.1 Maintenance

To stay competitive and to reach high level of business performance more and more companies has started to overlook their activities in the maintenance function as part of the effort to advance. Effective and correctly performed maintenance contributes to maintaining proper equipment functionality, technical availability and improving equipment life, while poor maintenance might contribute to the opposite and even scrap as a result of misaligned equipment (Swanson, 2001). An overview of maintenance as described in the European and Swedish standard (Swedish Standars Institute, 2001) is shown in figure 3.1.

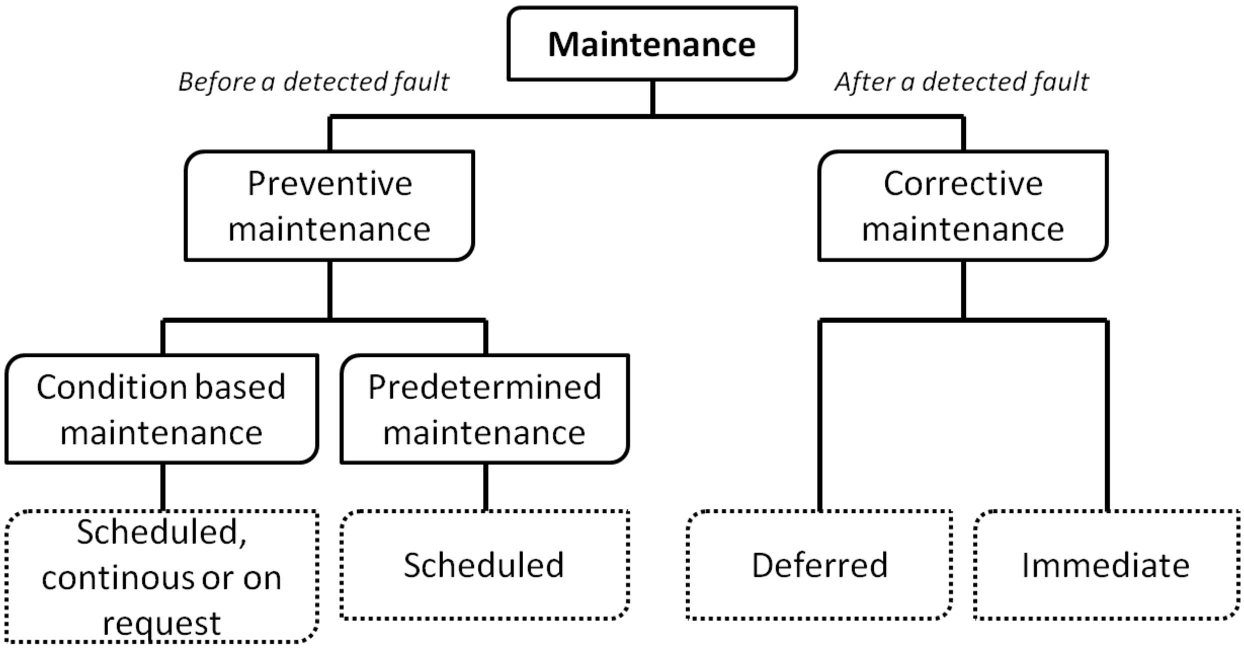

Figure 3.1 Overview of maintenance as described in Swedish Standard (Swedish Standars Institute, 2001).

The term *maintenance*, *preventive maintenance* and *corrective maintenance* is described in the standard (Swedish Standars Institute, 2001) as:

> Maintenance - *"Combination of all technical, administrative and managerial actions during the life cycle of an item intended to retain it in, or preserve it to, a state in which it can perform the required function."*
>
> Preventive maintenance - *"Maintenance carried out at predetermined intervals or according to prescribed criteria and intended to reduce the probability of failure or the degradation of the functioning of an item."*
>
> Corrective maintenance - *"Maintenance carried out after fault recognition and intended to put an item into state in which it can perform a required function."*

There are several other activities that may be allocated to the maintenance organization, activities with the aim of improving or altering prerequisites of maintenance and could be used to develop preventive and corrective maintenance operations. Among these are improvement and modification which is described in the standard (Swedish Standars Institute, 2001) as:

> Improvement - *"Combination of all technical, administrative and managerial actions, intended to ameliorate the dependability of an item, without changing its required function."*
>
> Modification - *"Combination of all technical, administrative and managerial actions intended to change the function of an item. NOTE 1: Modification does not mean replacement by equivalent item. NOTE 2: Modification is not a maintenance action but has to do with changing the required function of an item to a new required function. The changes may have an influence on the dependability or on the performance of an item, or both."*

Reliability is a concept in close relation to maintenance activities and is also the purpose of preventive maintenance. Reliability is defined in the standard (Swedish Standars Institute, 2001) as the:

"Ability of an item to perform a required function under given conditions for a given time interval."

Reliability may also be used in performance metrics or to evaluate the probability of failure.

3.1.1 Preventive Maintenance

To obtain stability and reliable in processes and to start the journey towards a sophisticated maintenance organization, an effective preventive strategy is needed. Preventive maintenance contributes to technical availability, safety and reliability.

Preventive maintenance operations can help reduce unplanned stop time to a minimum, but of sometimes rather high cost. For predictive maintenance operations to be justified the expected loss from an unplanned stop needs to be larger than the cost for planned preventive actions.

According to Hagberg and Henriksson (2010) an organization can apply different degree of preventive maintenance based on the risk classification of the equipment. Hagberg and Henriksson (2010) propose that equipment could be divided in three risk classes, namely A, B and C. For equipment classed A, the focus should be to avoid failure with help of effective use of condition based maintenance, RCFA, continuous improvements of maintenance operations and by keeping spare parts available etc. Equipment belonging to class B should have a degree on preventive maintenance that is most profitable and for equipment in class C, one should apply minimum amount of preventive maintenance (Hagberg & Henriksson, 2010, p. 321).

In figure 3.2below, different degrees of maintenance are schematically described.

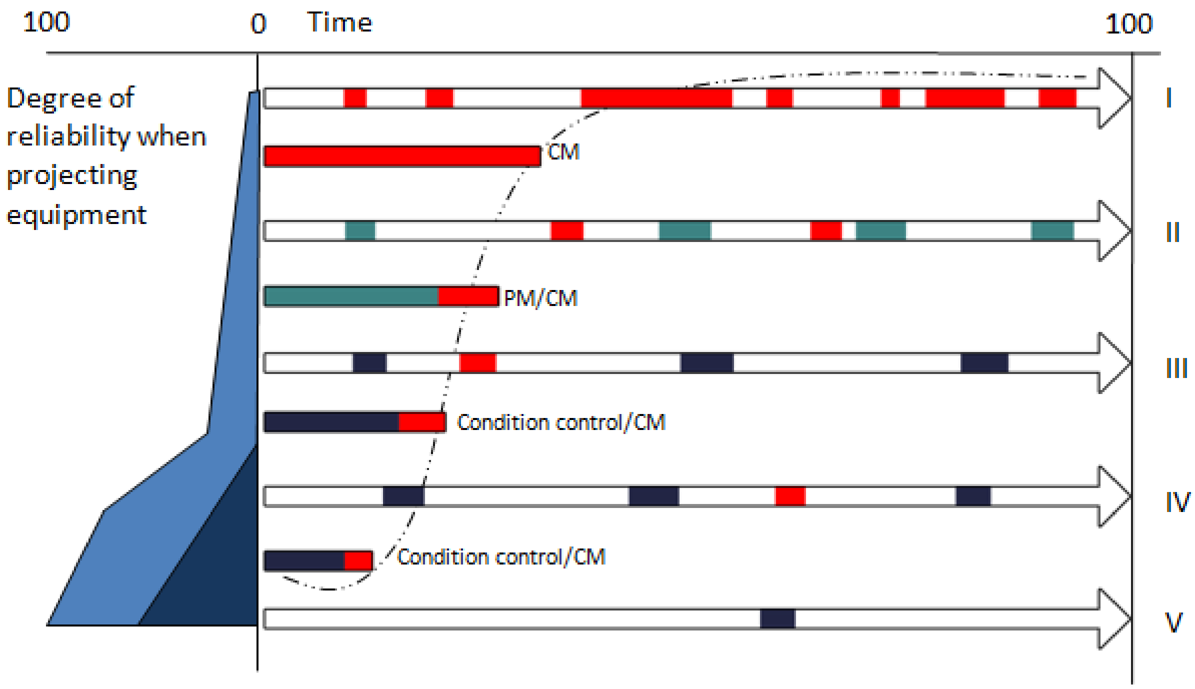

Figure 3.2 Degree of maintenance as described by Hagberg and Henriksson (2010).

Figure3.2 is describing the hypothetical conditions for maintenance. The first condition (I) is where only corrective maintenance occurs, and almost no degree of reliability was considered when equipment was projected, and where (V) is totally procured with reliability and sustainability focus, with the result of non occurring corrective maintenance (Hagberg & Henriksson, 2010). Without equipment procured and designed for reliability it is only possible to reach (III) according to this hypothetical model.

Condition based maintenance

To apply maintenance operations according to the condition of the equipment is to realize that most failures do not occur instantaneously. If potential failures can be identified before the functional failure occurs, effective maintenance can be performed and the equipment functionality is preserved (Smith & Hawkins, 2004).

Several applications can be used to monitor the condition of equipment. Examples of applications used in industries are, vibration monitoring, monitoring of power use, monitoring of temperature and monitoring of particles in cutting fluids.

One way to apply condition based maintenance is by predictive planning. A planned predictive maintenance operation can prevent failure with costly outage and repair as result. Even if this is not always the case the predictive operation can provide enough warning to be prepared for an upcoming failure and reduce the duration and consequences of the outage (Daley, 2008, p. 200).

Identified predictive operations can also lead to improvements where risk is high and consequences severe. If it is known that a component will need to be changed within a period of time, actions for gradually replacement can be added to the autonomous maintenance task carried out by the operator and by this the risk of breakdown or outage is completely gone (Daley, 2008, p. 200).

Predetermined maintenance
Predetermined maintenance operations are such that takes place according to established intervals or after a certain usage. Predetermined maintenance operations are usually carried out without previously investigation of the equipment condition (Swedish Standars Institute, 2001).

3.1.2 Drivers of reliability

The article regarding the business performance and maintenance (Narayan, 2012)investigates how reliability, performance and maintenance is related. The relations depend in some cases on single aspects concerning individual decisions, perquisites and behavior. Asset reliability is brought up as one important matter to reach business objectives. The drivers affecting the outcome of asset reliability is shown in figure 3.3. The three aspects, human, process and equipment reliability affects asset reliability. These three elements is further depending of the outcome several more profound aspects.

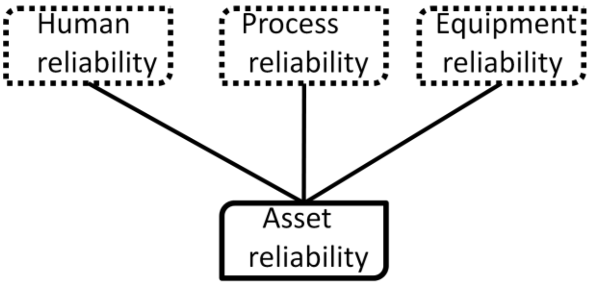

Figure 3.3 Aspects affecting asset reliability (Narayan, 2012).

The aspects affecting human reliability is shown in figure 3.4. Human reliability is affected by competence and quality aspects such as knowledge and skills which also can be influenced by proper methods for training but is also depending on personal experience. The outcome of human reliability is also strongly depending on personal behavior which in turn is influenced on the personal situation and motivation of work.

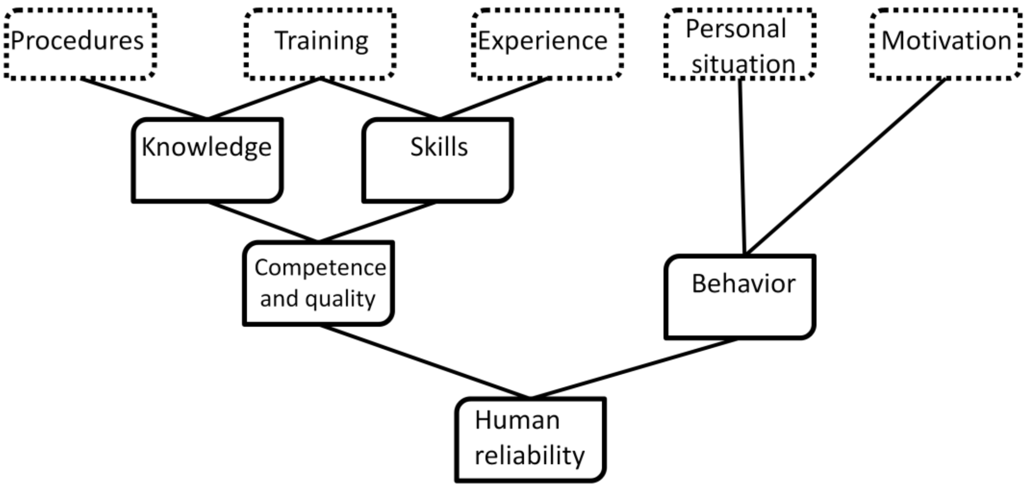

Figure 3.4 Aspects affecting Human reliability (Narayan, 2012).

Process reliability is depending on routines for keeping the operations in good shape but also on the communication between operations and maintenance department shown in figure 3.5. Operations is further influenced by keeping a predictable level and keeping control over deviations as well as clear ownership and taken responsibility for processes. Three elements are mapped as influencing ownership namely, care of equipment, minor maintenance and housekeeping.

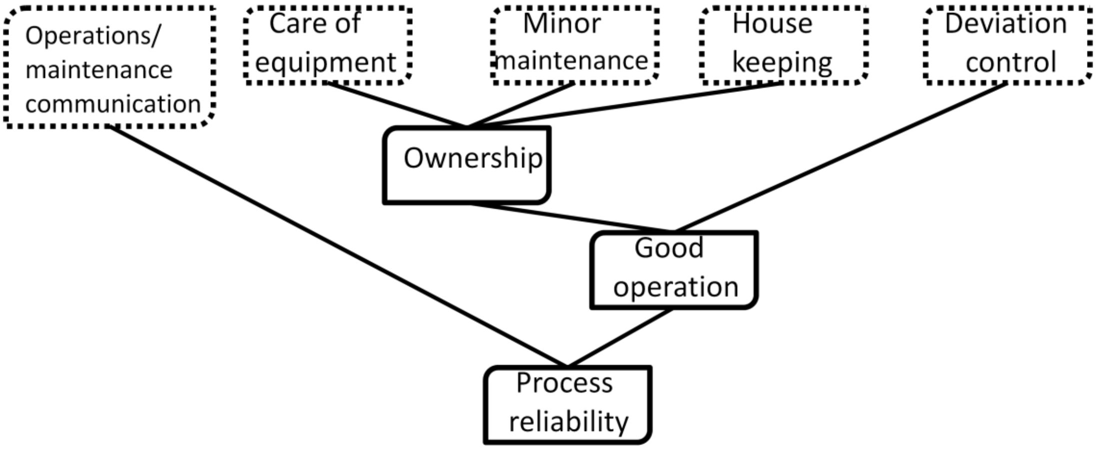

Figure 3.5 Aspects affecting Process reliability (Narayan, 2012).

The combined outcome of all presented aspects (including equipment reliability, which is not presented here) is affecting the outcome of asset reliability as shown in figure 3.3, and needs to be individually considered as contributing elements.

3.1.3 Benefits of well performed maintenance and cost of poor maintenance

To justify maintenance operations by proving the benefits of them can initially be difficult. It can be difficult for any organization but especially where processes are carried out and accepted in a manner shaped over time i.e. operations in production takes place, breakdowns occurs, maintenance operations takes place and things go on, without concern of the effects of the breakdown or of what could have worked out smoother.

To prove the benefit of a certain maintenance operation, the maintenance department needs to track the statistics of machine breakdowns and conclude the effects of improved prerequisites. In order to do this the improvement must first be approved invested in. This can present difficulties since maintenance is often regarded as having mainly a tactical role for existing assets and is commonly viewed at as an expense in organizations, meaning the resources spent is kept at a minimum (Salonen & Deleryd, 2011). Research has shown great economic potential in performing effective maintenance, a case study concerning losses due to insufficient maintenance in a paper mill concludes that 7.8 million SEK could be gained (Alsyouf, 2007). However the savings or economical benefits of well performed maintenance might be hard to communicate in several organizations.

As with the concept of quality it can be easier to present the benefits of maintenance by outlining the drawbacks of poor maintenance. Antti Salonen *Ph.D.* published an article (Salonen & Deleryd, 2011) with a proposal for the concept of cost of poor maintenance (CoPM). The applications for the model are lent from the CoPQ model (Cost of Poor Quality) and are:

1. To increase the awareness of implications of maintenance improvements among the managers and employees.

2. To identify and prioritize among different problem areas.

3. To follow up and evaluate the outcome of the maintenance improvement actions.

The purpose of the model is to be able to derive all related maintenance costs to either cost of conformance or cost of non-conformance. Costs for preventive and corrective maintenance are set up in a simple matrix, figure 3.6(Salonen & Deleryd, 2011). For a precise calculation and justified incentive, the indirect cost such as cost of recovering for lost production, insufficient quality and non-realized revenue needs to be included in cost of non-conformance (Salonen & Deleryd, 2011).

	CorrectiveMaintenance	Preventive Maintenance
Cost of Conformance	Indispensablecorrectivemaintenance: Correctivemaintenancedue to: •Failures with random distribution and no measurabledeterioration. •Failureswhich are not financiallyjustified to prevent.	Valid preventive maintenance: Preventive Maintenancenecessary to upholdnecessarydependabilityimprovementsintended to increase the reliabilityof equipment.
Cost of Non-conformance	Non-acceptedcorrectivemaintenance: Correctivemaintenancedue to: •Lack of preventive maintenance. •Poorlyperformed preventive maintenance. •Poorequipmentreliability.	Poor preventive maintenance: UnecessaryPreventive Maintenance. Poorlyperformed Preventive maintenance.

Figure 3.6 Costs of maintenance as described by Salonen & Delaryd (2011).

The costs related to maintenance have been described by several authors. To concretize these, a classification of direct and indirect costs is listed below (Hagberg & Henriksson, 2010).

Direct costs are defined as all costs to maintain or restore functionality of equipment, for example:

- Work hours.
- Material and spare parts.
- Bought services.
- Administrative costs.

There are two more severe traps in accounting routines for maintenance. The first is if a maintenance operation performed by operators is not included, the second is minor investments not directly related to maintenance, which is not to be regarded as maintenance costs. If maintenance is not carefully accounted for in an accurate manner, the costs for maintenance risks being higher or lower than the true amount.

Indirect maintenance costs are those costs that could be affected by maintenance operations but occur somewhere else in the company, usually in production (Hagberg & Henriksson, 2010). The most important of these are(Hagberg & Henriksson, 2010):

- Scrap and defects, which leads to lost contribution margin, material and work hours.
- Cost of tied up, physical capital. For example, WIP to secure material supply in case of production disturbances, fixed capital in form of redundancies which could be necessary but should be compared to corresponding maintenance operations. Maintenance operations could also increase the lifetime of equipment and shift the need for new acquisitions.
- Use of resources. Correctly performed maintenance could secure avoidance of e.g. oil leakage.
- Safety, correctly performed maintenance could keep risk of safety issues at a minimum and costs for injuries or damage is avoided.
- Overtime, extra working shifts and administrative planning costs.

In an article regarding business performance in relation to maintenance, various drivers that has effect on the end result of maintenance is presented (Narayan, 2012):

> *"High uptime generates an opportunity to raise revenues. Low downtime and maintenance costs means the overall costs fall. Both effects contribute to profitability."*

Costs in this matter is regarded as consequences of actions which in turn is depending of which decisions that are made.

3.1.4 Accountability

For any work process to be effective and carried out in a consistent manner all work task needs to be assigned accountability. Any number of persons working in a team can be responsible for the work but it is crucial that only one person is accountable for the execution. The person accountable for the performance of a task will be the final person to answer for any deviations. If the accountability is divided among several persons there is always a possibility to blame the other persons for the inadequate result (Daley, 2008, p. 32).

3.1.5 Sustainability of maintenance

Efficiently carried out maintenance can extend the lifetime of equipment and prevent expensive breakdowns of assets which may result in economic losses and effects on social sustainability as well as environmental sustainability. An approach to form maintenance strategies in line with sustainability aspects is therefore necessary (Yildirim & Nezami, 2013), such a maintenance strategy with carefully chosen components may:

> *"...significantly influence the personnel, energy, material and the overall costs in a company."*

The three aspects of sustainability, economical, environmental and social are further discussed from a maintenance perspective below.

Economical sustainability

Poorly planned maintenance may be a source of extensive failures in an organization. Such larger failures may among other include high costs for rare spare parts, hired repair competence, scrap, delays and lost production. These drawbacks may affect growth, market share and profit for the organization and could be especially serious in failures occur during a critical phase of a products life cycle (Yildirim & Nezami, 2013):

> *"The cost of lost production and return on investment are indicators of a maintenance strategy's economic impact on a production system."*

Environmental sustainability

By reducing unplanned breakdowns with effectively planned maintenance operations, the risk of producing scrap can be lowered, right amount of spare parts can be applied, less energy consumed if the equipment runs in good condition throughout technical lifetime and hazardous wastes can be handled in a planned manner (Yildirim & Nezami, 2013).

Social sustainability

A common definition of social sustainability according to the Western Australia Council of Social Services (WACOSS) is:

> *"Social sustainability occurs when the formal and informal processes; systems; structures; and relationships actively support the capacity of current and future generations to create healthy and livable communities. Socially sustainable communities are equitable, diverse, connected and democratic and provide a good quality of life."*

When forming a sustainable strategy for maintenance, aspects of social sustainability may influence the choices of components in the strategy. The included components can be fitted to create prerequisites for the implementation with regards to aspects of social sustainability (Yildirim & Nezami, 2013).

3.2 Maintenance philosophies

There are several concepts of maintenance philosophies, among which there are several different approaches. Some of these are briefly described in this section of the theoretical framework and the elements most relevant for the project is brought up for review.

3.2.1 Total Productive Maintenance – TPM

Total Productive Maintenance (TPM) is a mindset and a method aimed to minimize stoppages and disturbances in production. The goal of TPM is to continuously improve operational conditions within the production system. To reach this goal, empowerment and involvement of employees to increase awareness is central within the concept (Kumar Sharma, et al., 2006).

How to measure the effectiveness is crucial to show in which direction the organization is headed. Key Performance Indicators (KPI) needs to be developed individually for each company and should be measures of critical processes. The KPI's should be leading indicators i.e. formed so that they measure the problems before they arises (Smith & Hawkins, 2004).

Overall Equipment Efficiency - OEE

OEE, Overall Equipment Efficiency is a metrics to measure and evaluate the performance of a manufacturing process. The purpose of measuring and calculating OEE is to create a comparable and holistic index to compare equipments as well as finding potential improvements. OEE contains the elements availability, performance and quality rate (Dal, et al., 2000).

The OEE metrics was developed by Seiichi Nakajima (1989) and is presented in its original form below.

$$\boldsymbol{OEE = Availability \cdot Performance\ efficiency \cdot Quality\, rate}$$

$$\boldsymbol{Availability} = \frac{Loading\ time - Downtime}{Loading\ time}$$

$$Loading\ time = Total\ available\ time - Planned\ downtime$$

$$Planned\ downtime = Planned\ maintenane + Management\ activities$$

$$Downtime = setup + adjustments + stoppages + exchange\ of\ dies$$

$$\boldsymbol{Performance\ efficiency} = Net\ operating\ rate\ \cdot\ Operating\ speed\ rate$$
$$= \frac{Theoretical\ cycle\ time \cdot Processed\ amount}{Operating\ time}$$

$$Operating\ time = loading\ time - downtime$$

$$\boldsymbol{Rate\ of\ Quality} = \frac{Processed\ amount - defect\ amount}{Processed\ amount}$$

By calculating OEE in this manner all six big equipment losses, used in the publication (Nakajima, 1989) are accounted for. These six big equipment losses are:

- Equipment failure
- Setup and adjustments
- Idling and minor stoppages
- Reduced speed
- Defects in processes
- Reduced yield

There are several ways of calculating the OEE and there have been proposals of more modern ways of establishing the metrics. An alternative way is described in an article by Dal, et al. (2000) and presented below with following examples.

$$\boldsymbol{OEE = Availability \cdot Performance\ efficiency \cdot Quality\, rate}$$

$$\boldsymbol{Availability} = \frac{Actual\ operating\ time}{Planned\ operating\ time}$$

$$Planned\ operating\ time = Total\ shift\ time - Planned\ maintenance$$

$$Actual\ operating\ time = Planned\ operating\ time - Unplanned\ maintenance - Minor\ stoppages - Setup\ \&\ changeover$$

$$\boldsymbol{Performance\ efficiency} = Net\ operating\ rate\ \cdot\ Operating\ speed\ rate$$

$$Net\ operating\ rate = No: produced \cdot \frac{Actual\ cycle\ time}{Operation\ time}$$

$$Operating\ speed\ rate = \frac{Theoretical\ cycle\ time}{Actual\ cycle\ time}$$

$$\boldsymbol{Quality\ rate}\ = \frac{Total\ no: produced\ -\ No: scrapped}{Total\ no: produced}$$

In this way of calculating the OEE metrics, planned maintenance is also considered as a loss, even though it is necessary, an example can show the impact on availability of one hour of PM on a eight hour shift where setup times and minor stoppages makes up one hour:

No maintenance: $\frac{8-0,5-0,5}{8} = 87,5\%$

One hour corrective maintenance: $\frac{8-1-0,5-0,5}{8} = 75\%$

One hour of planned preventive maintenance: $\frac{8-1-0,5-0,5}{8-1} = 85,7\%$

By calculating OEE in this manner (Dal, et al., 2000) the impact of a corrective maintenance or breakdown is larger to the availability than a stoppage for planned preventive maintenance, as the later is subtracted from the planned time, even though it has impact on the OEE. There are several ways to calculate OEE, and the impact of a preventive operation could be as large as for a corrective operation if the planned activity is not subtracted from the *Planned operating time*.

One hour of planned preventive maintenance: $\frac{8-1-0,5-0,5}{8} = 75\%$

By this composition, the method is not considered, which means that if the cycle time is improved, and the number of units produced is the same, the OEE will point in the "wrong" direction. Therefore it is important to note that OEE shows the potential for productivity, as if the method is improved, there is more available time for production. As well as several ways to calculate OEE there is further proposals of what should be considered a loss. Five more losses except the six original is presented by Smith and Hawkins (2004) making up to a total of eleven major losses which are shown in figure 3.7, divided into four categories.

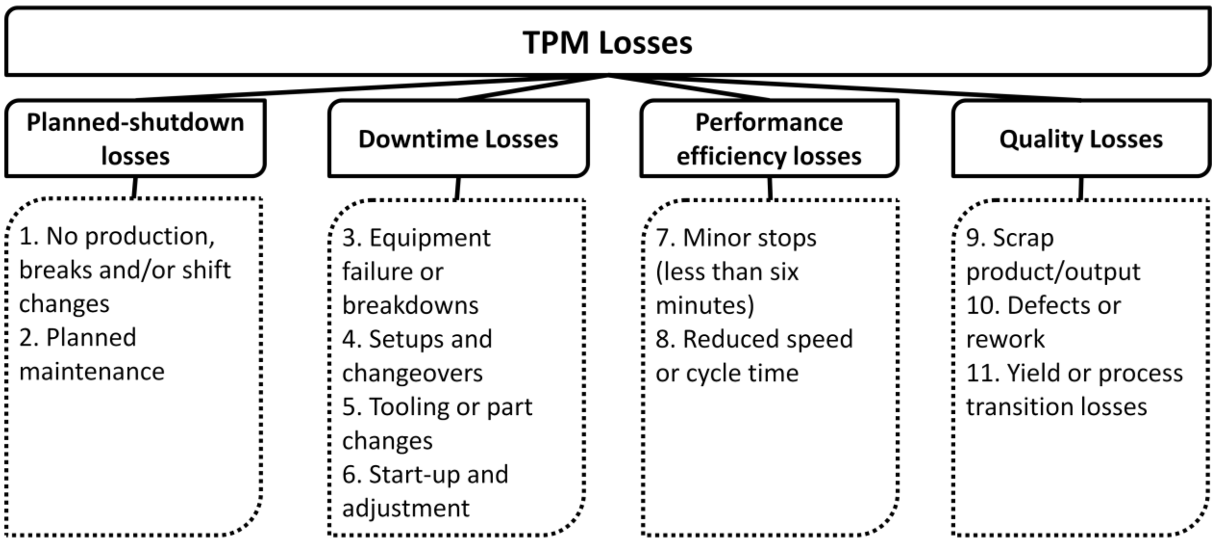

Figure 3.7 The eleven major losses.

The OEE is a fundamental performance indicator in TPM where the primary focus is the equipment efficiency as it is where the largest gains can be realized in shortest time (Smith & Hawkins, 2004, p. 56).

Autonomous operator maintenance

Within all work teams in production there should be an operator assigned and responsible for autonomous operator maintenance (AOM). The production and maintenance manager will need to define a policy containing where in production AOM is needed, at what level and type and how the work process will flow. The operator responsible should receive proper training to perform AOM. The training should contain a significant amount of theoretical elements to ensure that the purpose is understood. Favorable ways of training is to let operator rotate in a customized maintenance apprenticeship program or matching operators with maintenance personnel for a period of time to learn the practical skills for the work (Smith & Hawkins, 2004).

To emphasize the operations included, visual cues and labels should be used ease the reading of recommended levels at meters and gauges, amount of lubricant at lubrication points, adjustments of frequency etc, inspections of recommended conditions and so on. In larger manufacturing organizations an AOM Coordinator should supervise the AOM operations and provide planning, resource data, adjustments, criticality data etc (Smith & Hawkins, 2004).

Suggestion systems

Suggestion systems are a source of continuous improvement and have also been used to increase commitment to the company of workers (Rapp & Eklund, 2007). Suggestions are driven by monetary rewards as well as self fulfilling of the actual implementation result. According to (Rapp & Eklund, 2007) the number of suggestions coming in is dependent on both economical reward and the number of rejections that the submitting employee is perceiving. The article mentions that employees do not submit new suggestions more frequently if the reward is higher.

Teams in TPM

Within TPM, team work is highly emphasized to breed a healthy culture of autonomy and responsibility of processes. With closely working teams, having defined areas of responsibility, understanding of processes and motivation, ongoing improvements of processes and operations is possible as lessons learned is reviewed and valued. The teams will build a base for a learning organization as they will continue to discover and develop processes (Smith & Hawkins, 2004).

3.2.2 Reliability Centered Maintenance – RCM

RCM is risk based methodology with the purpose to optimize maintenance operations according to function, cost and safety. The results of a correctly done analysis are a cost effective plan derived from the systems maintainability and critical functions with a balance between corrective and preventive maintenance. The analysis demands resources, time and knowledge and is recommended for costly and complex systems.

The seven questions according to the SAE standard JA1011 is the minimal requirements for a procedure to be called RCM methodology (Smith & Hinchcliffe, 2003).

1. What is the item supposed to do and its associated performance standards?
2. In what ways can it fail to provide the required functions?
3. What are the events that cause each failure?
4. What happens when each failure occurs?
5. In what way does each failure matter?
6. What systematic task can be performed proactively to prevent, or to diminish to a satisfactory degree, the consequences of the failure?
7. What must be done if a suitable preventive task cannot be found?

A systematic way to implement the basics features of RCM can be translated into 7 steps is described in the book RCM - Gateway to World Class Maintenance (Smith & Hinchcliffe, 2003).

Step 1: System selection and information collection.
Step 2: System boundary definition.
Step 3: System description and functional block diagram.
Step 4: System functions and functional failures--Preserve functions.
Step 5: Failure mode and effects analysis (FMEA)--Identify failure modes that can defeat the functions.
Step 6: Logic (decision) tree analysis (LTA)--Prioritize function need via the failure modes.
Step 7: Task selection--Select only applicable and effective PM tasks.

The phase of system selection is related to the total cost and it is consistently found that an approach where a whole plant is treated will not come out cost effective (Smith & Hinchcliffe, 2003, p. 76). To be effective in the system selection phase RCM advises to use the 80/20-rule to determine which systems that should be analyzed, parameters to include in the analysis could be (Smith & Hinchcliffe, 2003):

1. Cost of corrective maintenance actions over a recent two-year period.
2. Number of corrective maintenance actions over a recent two-year period.
3. Number of hours attributed to plant outages over a recent two-year period.

To get the greatest ROI, the focus should be to improve the stability of the functions in the equipment that are in the top of a pareto chart with these parameters according to RCM. System boundary definition is important in manners of not overlap as well as systems may be subjected at different times and by different analysts, but most importantly to define in/out interfaces of the system. To complete the system description interfaces, component list and equipment history is compiled together with the functional block diagram of the system. The next stage of the analysis is to focus on the loss of function and define margins for a function to be considered to have a functional failure. Failure mode and effects analysis is what connects the function to the components, what can break down to cause a failure and what the effect will be. The failure modes is then tested in a logic tree to classify if the fail is noticeable for the operator, causes safety problem or have effect on the outage. To translate the analysis this far into PM actions, the applicable and effective test should be performed (Smith & Hinchcliffe, 2003):

- Applicable, the task will prevent or mitigate failure, detect onset of failure, or discover a hidden failure.
- Effective, the task is the most cost-effective option among the competing candidates.

The option if there is no applicable task is to run to failure, as well as if the cost of the preventive action exceeds the cost associated with failure. This rule should only be excepted if the fail is causing a safety risk, design modification should under these circumstances be considered. The task selection road map in the (Smith & Hinchcliffe, 2003, p. 114) is a tool to structure and record the process.

In the studied RCM literature, according to Smith and Hinchcliffe (2003), preventive and corrective maintenance is viewed as:

> *"Preventive maintenance is the performance of inspection and/or servicing tasks that have been preplanned (i.e. scheduled) for accomplishment at specific points in time to retain the functional capabilities of operating equipment or systems. "*

Preplanning is the essence in their view, the main element in developing a sophisticated preventive maintenance system and culture. The PM tasks have four categories according to RCM methodology, time directed, condition directed, failure finding, and run to failure. Were run to failure is premeditated chosen due to that others are not applicable or economically favorable. By clearly describing PM, it is possible to derive the actions that should be classified as corrective maintenance:

> *"Corrective maintenance is the performance of unplanned (i.e. unexpected) maintenance tasks to restore the functional capabilities of failed or malfunctioning equipment or systems."*

The book emphasizes problems that companies have with their own definitions, where a PM task is performed and an unexpected deterioration is revealed, the right thing according to the literature is to consider the action as PM as it was found during the PM task. To go around the confusion about logging data, all PM tasks should include an analysis to find hidden failures.

To perform system analysis and planning, the RCM methodology clearly implies that teams for these tasks should be put together by the people within the organization that has the most relevant knowledge. Teams, should generally consist of 4 -5 persons plus a facilitator and should include an operator, a mechanical technician, an electrical technician and a maintenance or systems engineer with sufficient process knowledge.

RCM methodology is using failure curves which indicate the fail intensity according to component life cycle. The curves indicate that most of the investigated equipment does not benefit from PM and excessive overhauls can introduce "infant mortality" i.e. increase the rate of CM (Smith & Hinchcliffe, 2003, p. 59).

A case study (Smith & Hinchcliffe, 2003, p. 306) describes a RCM project on a pressurized wind tunnel that really realized benefits from RCM, corrective maintenance tasks were reduced with 40-60%. Throughout the project *items of interests* was found and improved, these findings alone yielded economic returns that exceeded the whole RCM project. Among others unpainted drive wheels were found, painted to avoid corrosion as well as dust covers were installed on clutch inspection ports, all saved future time consuming and expensive maintenance actions, as the stop time cost for the wind tunnel was estimated to be $4000 per hour. Other benefits are that involved team members truly learns the equipment, which in the long run pioneers for improvements.

3.3 *Concepts and attributes of industrial engineering*

Industrial engineering is a generic name of the combination of several engineering fields together with principles of scientific management, where engineering methods applies to production and service enterprises. Understanding of the system as well as the workers needs is emphasized in order to improve and challenge the organization (Badiru, 2005).

3.3.1 Technical Availability

Technical availability (TA) is an indicator of how much of total time a particular machine is available to perform its designated operation.

In order to compare different work centers or companies, a standardized way of calculating technical availability will be necessary (Hagberg & Henriksson, 2010, p. 47). Variables included in the calculation are the number of hours available and stop times that reduce the available time, which may vary throughout a workshop. The stop times that reduce the technical availability can be unplanned stoppages, setup times, adjustments and exchange of tools. Planned maintenance is not included since preventive maintenance should be regarded as a better choice and should not be compromised (Ljungberg, 2000). The time period should be selected carefully to be representative for the processes and indicate points for improvements. A too long time span can easy hide a longer and critical stops, as well as small number of shorter stops can have a large impact on productivity.

Example 1.

$$Available\ time = 365 \cdot 24 = 8760h$$

$$Stop\ time\ losses = 500h$$

$$TA = \frac{8760 - 500}{8760} = 94{,}3\%$$

Example 2.

$$Available\ time = 220 \cdot 18 = 3960h$$

$$Stop\ time\ losses = 500h$$

$$TA = \frac{3960 - 500}{3960} = 87{,}4\%$$

Example 1, all hours in one year minus the time of losses which causes a production stop.An alternative (Example 2) can be to use the number of manned hours i.e. the planned production hours. There is a clear difference in the two examples which is due to how available time is selected.

Functions in series, in a tight process oriented flow where machine 1, 2, 3 and 4 has to function simultaneously, puts high demands of technical availability on each individual to reach 90% in total.

$$TA = TA_1 \cdot TA_2 \cdot\ TA_3 \cdot\ TA_4 = 0{,}98 \cdot 0{,}95 \cdot 0{,}99 \cdot 0{,}98 = 0{,}903 \approx 90\%$$

3.3.2 Lead time

Lead time in production is the time between demand and delivery, LT can be viewed in smaller or extended scales from internal linked processes or from raw material to end customer. Reducing lead time has positive impact on inventory level (tied up capital) and is one of the fundamentals in Lean philosophies. Variances in lead time are more critical to inventories and supply chain performance than a high mean lead time (James He, et al., 2011).

3.3.3 Leveled production and variations

The foundation of a reliable and efficient production system is standardized and stable processes and a smooth, leveled production flow (Liker, 2003, p. 81).

If a machine breaks down in a company using leveled production, where minimum amount of WIP and buffers between work centers is possible, the problem will immediately be visible and the need of reparations will be crucial since not only the affected machine Is stopped but also further production steps ahead. This means that the effect and importance of maintenance and preventive maintenance will be notified and justified, especially preventive maintenance since it includes possibilities of fewer production stops in a long term perspective.

In a company using undefined buffers between work centers, operators working ahead when possible and lead time varies, the importance of effective pro-active maintenance will not be as clear. Whenever a machine breaks down it will eventually be fixed by the maintenance department and production can go on due to buffers (Liker, 2003, p. 88).

3.3.4 Inventory according to Toyota way

The Toyota way (Liker, 2003, p. 44) describes inventory as one of the eight wastes that should be minimized and preferably eliminated to achieve a true lean production system. All kinds of inventory, WIP, finished goods, raw material etc. serves to dampen the effects of an inflexibility and to compensate the systems weaknesses. The more inventory used the more variations is allowed in the system.

In a journey towards continuous flow, problems and causes of variations will be surfaced and must be dealt with if not high levels of inventory is kept to handle the variations (Liker, 2003, p. 81). In the Toyota philosophy there is also a paradox regarding inventory:

"Until all processes are capable, careful use of inventory may be advantageous" - (Liker, 2003, p. 44)

Which basically means that as long as stability is not achieved some sort of buffers or inventory is needed and it may be an advantage compared to not utilizing equipment, perhaps as a result of low buffers. These strategic inventories should however be moved as far back in the value stream as possible, to have as little impact as possible.

3.3.5 Motivation through the design of Work

Oldham and Hackman (1976) presents a model of job characteristics that affects the motivation potential of a work task. The model is based on that work tasks include different attributes that contribute positively or negatively to the critical psychological states which are *experienced meaningfulness of the work, experienced responsibility* and *knowledge of the results.* These states are broken down to changeable properties i.e. the core job characteristics. *Skill variety, task identity* and *task significance* contributes to meaningfulness. *Autonomy* relates to *experienced responsibility* and *Feedback* affects the *knowledge of result*.

If these conditions are considered in design and planning of the work task, it has potential to be motivating for the worker to perform well and feel pride in doing so. If not, the performance of the specific task might suffer since to workers motivation is low and the design of the work only adds unhappy feelings. These core characteristics might sometimes be necessary properties for the worker to be able to perform the task but in many cases the core characteristics must be defined by the process to enable the worker in performing well. In other words, work processes needs to provide sufficient characteristics and means to enable fulfillment of tasks e.g. autonomous operator maintenance.

3.3.6 Organizational Ignorance

An organization needs to manage their knowledge in a efficient manner. Knowledge management aims to find, gather, describe, allocate and take advantages of what the organization know, but more important is what is to manage what the organization do not know or ignore. If an organization acts upon the assumption that they know enough and that there are restrictions of what is possible to know or control, it will only lead to a competitive disadvantage (Zack, 1999).

The article *Managing Organizational Ignorance* (Zack, 1999) presents four *Knowledge Problems:*

1. Uncertainty: not having enough information;
2. Complexity: having to process more information than you can manage or understand;
3. Ambiguity: not having a conceptual framework for interpreting information;
4. Equivocality: having several competing or contradictory conceptual frameworks.

These problems contribute to organizational ignorance and needs to be managed in order to fully be aware of all details for inspection or improvement within the organization. Successfully handling these problems can bring an competitive advantage and responsiveness, and create a healthy approach towards continuous improvements.

3.3.7 Standardized work and problem-solving continuum

For an improvement to truly be better than the previous, a reference needs to be in place. These references are commonly referred to as standards and needs to be in place in order to improve any process. Standardization is a prerequisite and tool to build up a consistent process, and without it predictable processes and stability will not happen (Liker, 2003, p. 113).

The Toyota way field book (Liker, 2003, p. 331) emphasizes the importance of regarding any problem in a larger context. Often it is not the perceived problem that is the root cause and neither will show the true effects, therefore any problem always needs to be regarded in a larger context to find the true problem and its effects and the underlying root cause. This is referred to as the problem-solving continuum (Liker, 2003, p. 331) and is a process that consistently should be ongoing to refine processes and deal with new problems.

3.4 Total Quality Management - TQM

The concept of Total Quality Management has been widely discussed to its meaning but is generally perceived as a management philosophy or a management system. This mindset is based on a number of principles or core values which slightly differs depending on where the definition is found. In most descriptions of TQM however the following core values are found: “focus on customers”, “management commitment”, “everybody’s committed”, “and focus on processes”, “continuous improvements and fact-based decisions” (Hellsten & Klefsjö, 2000).

Bergman and Klefsjö (Bergman & Klefsjö, 2010) presents the core values of TQM as the “Cornerstones of Total Quality Management”, in a perspective emphasizing all business functions and employees, and to be used as a management theory acting to reach organizations goals. The cornerstones of quality management are shown in figure 3.8.

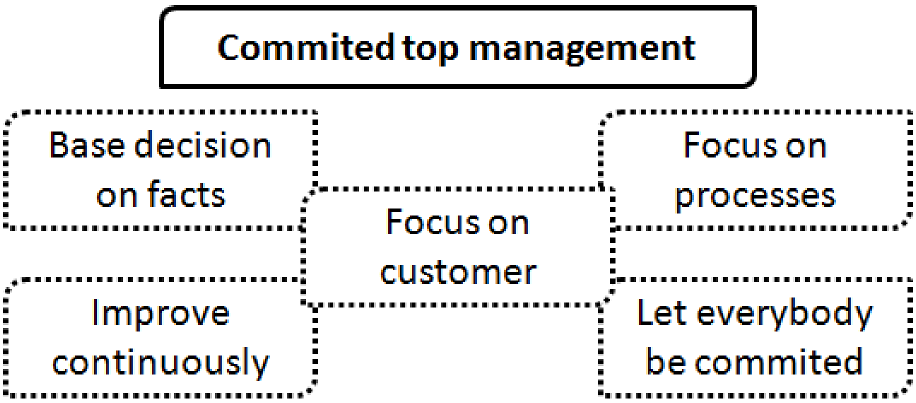

Figure 3.8Cornerstoness of TQM as described by Bergman, Klefsjö (2010).

The cornerstones are the basic components for TQM and the aim is to increase external and internal customer satisfaction and reduce the amount of resources. To complete to management system and to reach the goal of customer satisfaction, components of techniques and tools are also needed (Hellsten & Klefsjö, 2000).

3.4.1 Customer perspective

In a manufacturing plant the operating department is customer to maintenance, and the maintenance department should fulfill the needs of the operating department. But many times the maintenance department delivers only what they assumes operations need since operations is not expressing a clear expectation or don’t know what they need (Daley, 2008). This can be related to the customer satisfaction model presented by Kano (Kano, et al., 1987) which states that products have a certain level of spoken must-be quality which preferably should be exceeded with attractive quality attributes, which usually is unknown and therefore unspoken by the customer. If however, the must-be quality also is unknown or hard to specify it will be troublesome for the service provider to ensure that the sufficient quality is reached.

In a customer - supplier relationship there must be specified requirements and a mutually conditions to get demanded service. If requirements are lacking or merely specified the service will be as well, forcing maintenance department to be reactive and supplying reactive service. This reactiveness will lead back up the chain through production and the company approach (Daley, 2008, p. 92).

4 Results

Individual results of empirical study at GKN, company visits, expert interviews and reviews of internal data are presented in this section. The results are presented as answers to the research questions.

4.1 *Perception of challenges regarding maintenance operations in the organization*

Two workshops with the Affinity Interrelationship method was conducted in the beginning of the project, one with participants from the maintenance department and one with participants partly from production but also financial controller. The workshops was held with two slightly different questions regarding the maintenance situation and resulted in two conclusions formed by the participants, which is presented below.

AIM 1 - Maintenance department:

Question: *What is the problem when trying to increase the amount of preventive maintenance operations?*

Conclusion: *"Maintenance is not planned in to the production schedule which means that it is regarded as a disturbance, this affects the view of maintenance in a negative aspect and counteracts cooperation for optimization."*

AIM 2 - Production and financial:

Question: *What is problematic with maintenance as a tool to counteract production disturbances?*

Conclusion: *"Planning for a too high utilization when the organization suffers from too many unnecessary stops as a consequence of the difficulty to clarify the economic benefits of maintaining the production equipment is not a sustainable strategy."*

Except the participants agreed conclusions, the AIM workshops led to a number of possible factors with relevance to the project.

One topic that was widely discussed during the workshops was the utilization of equipment, which is perceived to be very high and possibly too demanding for the equipment. It was also brought to discussion that the production is planned for more capacity than historically proven. The technical availability is high and participants seem to experience insufficient capacity.

Both workshops resulted in further questions with relevance for the investigation, some of them were followed and used in the unstructured interviews to examine how the organization work with reliability and deliverability. Challenges regarding maintenance operations found in the workshops are listed below.

- Deficiencies in operator maintenance, differs among equipment.
- Insufficient consideration of equipment risk analysis.
- Hard to control variations in deliveries of raw material.
- Lacking understanding and communication of the financial benefits of maintenance and in the extension system stability.
- Barriers for implementing improvements, insufficient financial means to justify need. Changes are made when demanded from customer or if implied by a safety risk.

4.2 Demands on stability and reliability

Unstructured interviews were conducted with persons at different functions in the organization. First and second line managers in production and also operators and planners were asked regarding the topics stated in the method section for unstructured interviews. The result was a general view of the maintenance as a function at GKN and what challenges that are present.

"No, there is no such connection" – "Yes, the connection is crystal clear"

Among the interviewees, most of them did not recognize the connection between production reliability and delivery performance, and variations in lead time due to product and process complexity was not seen as focus area. While some answers indicated that maintenance is an important factor for reaching production goals, but in these cases to perform repairs and minimize breakdown duration. Delays in production were not mainly blamed on insufficient maintenance but rather on deliveries of raw material and high system complexity, which is generally accepted. This indicates that the maintenance operations in general work well and that mostly the corrective operations are notified. Demand for preventive maintenance is varying as production managers experience capacity shortage and do not inquire for preventive operations with uncertain effect. An incentive to reduce stop time (such as a representative stop time cost) was not commonly perceived as desired.

"Late incoming goods and defects is the biggest sources of disturbances"

Several interviews with production planner gave an overview of how production is planned. This seems rather undefined and apparently not according to existing operation lists. The planning is made in several steps by different planners for different time horizons, based on numbers from marketing department. Plans made in the first step might therefore deviate from the actual outcome. On top of this there are many other reasons for changes of the final plan, such as late deliveries of material, occupied shared resources, repair loops due to defects and corrective maintenance of equipment. If capacity according to assigned equipment is not enough, other available equipment is used to reach production demands. When production is planned it is not done in collaboration with maintenance department and not considering necessary preventive operations.

"Challenges? No good tool to predict the need of maintenance"

The unstructured interviews also confirmed other topics discussed in the AIM-workshops. Several of the interviewees experienced that capacity and production planning is an issue. The execution of autonomous operator maintenance can be hard to audit and control, the methods for autonomous operator maintenance contains gaps and the benefits of well performed maintenance is not clear and operator maintenance is not regarded as core part of work tasks.

The interviews led to an understanding of how production and maintenance operations are regarded among employees. Some new topics were discovered but the main result from the unstructured interviews was the unclear demand of stability throughout the organization.

- Unused potential in operator maintenance.
- Personal drive for improvement is overall low.
- Utilization of equipment is perceived too high to plan PM effectively.
- Hard to control variations in deliveries of raw material.
- Lacking understanding of system stability, deliveries are the main KPI.
- Benefits of maintenance are not provided.

Observations during department meeting at different levels showed that the production goals is high and at several occasions not reached, leaving the production often behind the production plan.

Customer Need Analysis (CNA) performed by SKF in February 2012
In an analysis to map the current state as a part of SMGC work with maintenance strategies a CNA was performed by SKF at GKN (then Volvo Aero). In this analysis a number parameters was evaluated in relation to best practice. Among these parameters, technical availability which at the time of the analysis was 97,5 percent at GKN.

Stop time cost
At GKN the stop time cost is low and does not represent indirect cost from the succeeding effects of a production stoppage. The stop time cost that is used at GKN is the average of the overall direct production cost for a total workshop, which seems to be too low to justify investments for stability.

Budgeting
Internal budgets shows the maintenance cost is consistently decreased by 10 percent, compared to the cost proposition made by the Maintenance department. This has been recurring for the last years.

Suggestion of improvements
Reviewing the development of suggestions made over the last 5 years, shows that the number has decreased. In interviews, the reward for suggestions was commented as too insignificant and the effort not justified.

4.3 *Production disturbances and succeeding effects of stops*

The investigation has led the master thesis work into several topics outside the maintenance department, topics highly concerning driving factors for preventive maintenance operations. These topics have mainly been examined with internal reports based on collected statistics at GKN.

4.3.1 Capacity utilization

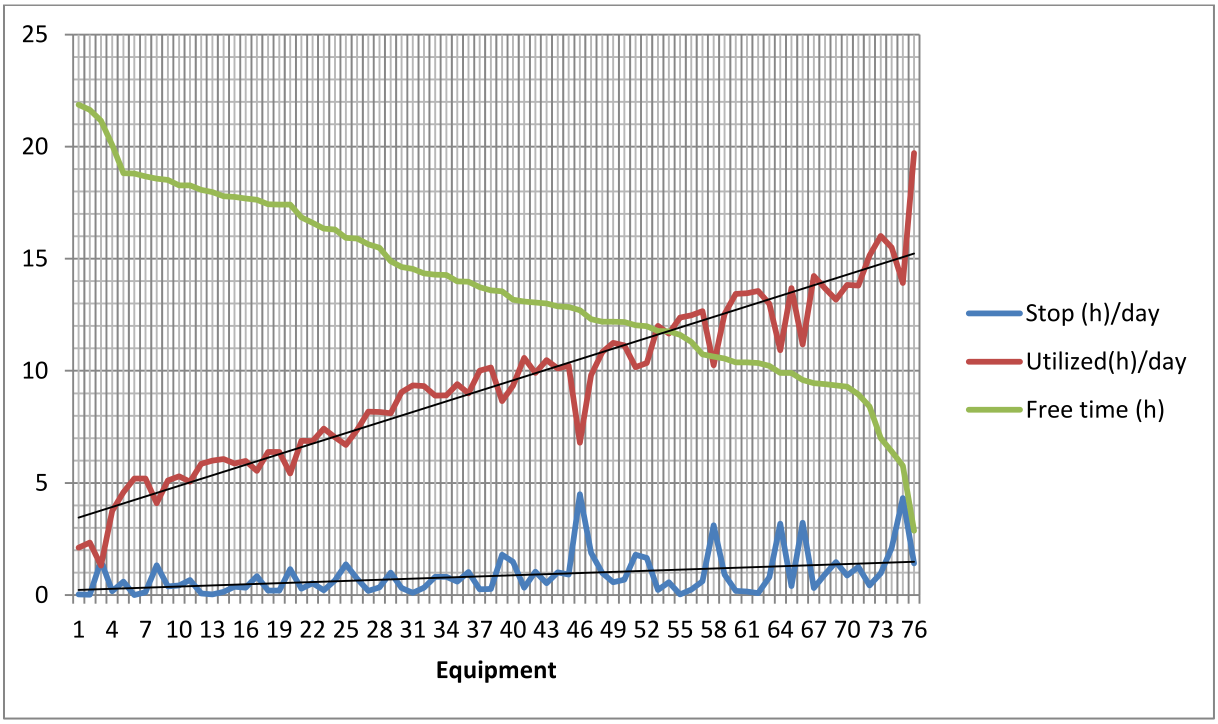

Figure 4.1 capacity in relation to available time and stoppages per day.

Figure 4.1 shows daily utilization$(\mathrm{PF} \cdot 24)$, daily stop time $\big(24 \cdot (1 - \mathrm{TA})\big)$and available time $(24 - (\mathrm{PF} \cdot 24 + 24 \cdot (1 - \mathrm{TA}))$ translated into 24 hours for 76 machines, one point on the X-axle is one unit. The production is not as challenged as described by production managers in AIM2, 80% of the equipment have more than 10hours available capacity each day. The failure time seems to have impact on the productivity factor as the peaks in failure time are responded by lower productivity for several equipments, even if the available time is indicating on room for production disturbances. Productivity factor derives intervention time in NC-machining equipment by the logging system SMM.

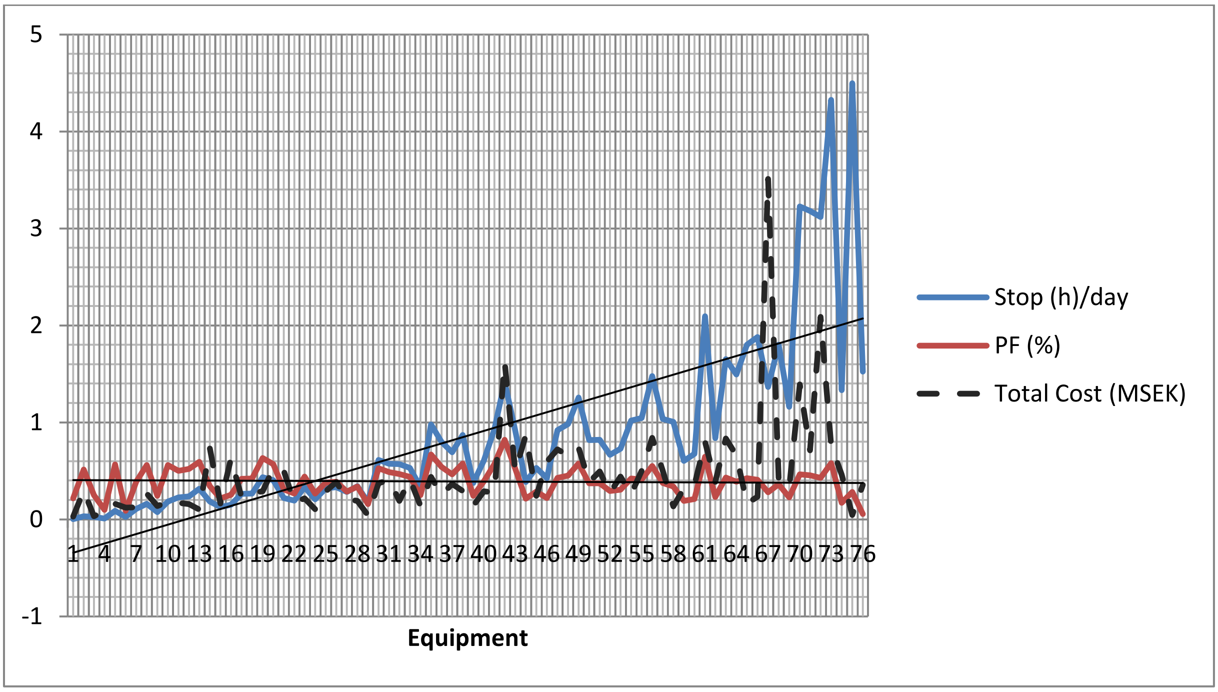

Figure 4.2 Productivity factor in relation to total costs and stoppages per day.

Figure 4.2.show daily stop time$(24 \cdot (1 - TA))$ and productivity factor for each equipment installed with SMM. The PF and $Stop\ (h)/day$are with few deviations following each other. X-axle is representing individual equipments sorted by $((Utilized\ (h)/day)/(\ Stop\ (h)/day))$ where the best performing equipment is at position 1. The dotted line is the total cost in MSEK for maintenance during the time period for each equipment. Lower level of daily stop time seems to correlate with less maintenance costs.

4.3.2 Variance in lead time

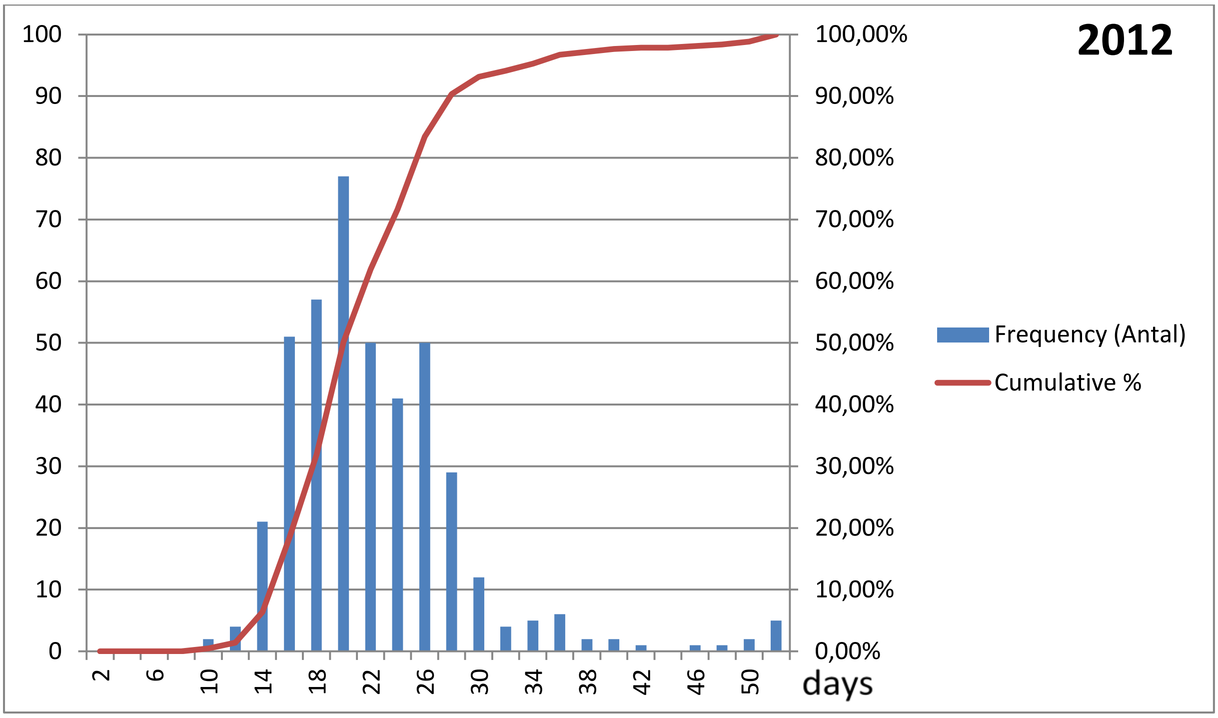

Figure 4.3 Variance in lead time.

Figure 4.3 show the spread of lead time in days during 2012, it shows that the spread is normally distributed, with a standard deviation of about 6 days.

A brief study investigating lead time for a certain product and work centers shows that the variance is high and the range for what is normal is very big, In the internal report reviewed in Appendix III it is shown that 80 % of all products in a certain flow have a lead time between 15– 28 days, a delay due to a breakdown of 7 days might not be a big deviation enough to be noticed. Variations in process times as well as in buffers are present throughout the V2500 value flow i.e. critical operation 400 have a planned time for 15 hours, which only managed to be met at 12 of 91 (13 %) occasions during the studied period.

Main findings from the data:

- 80% of the equipment has more than 10 h available capacities per day.
- 30% of the equipment is suffering of 1h (or more) breakdown a day.
- PF have little effect on cost.
- PF is affected by TA at some cases.
- Lead time is unpredictable.

4.3.3 Succeeding effects

An internal report (*IaF2 - Dimensionering av beredskap för stopp i utrustningar*, produced at the logistics development department) investigating the succeeding effects of different duration was made in 2012 for a new production area. The investigation was made to describe the succeeding effects of stoppages and to dimension preparedness for disturbances.

The results and reasoning of the report shows that the direct and indirect consequences of a stop have large effects on WIP and lead time and are long lasting in the concerned process. For any product with a long operation list, it is likely that a new disturbance will occur within the duration of the previous breakdown consequences. In this case the effects of the new disturbance will be added upon the previous. This will put the system in a downward spiral with increasing backlog which is hard to recover from.

The report suggests that all the sources of production disturbances should be coped with and prevented. Other sources of production disturbances are brought up as well, such as material shortage, absence etc. The results show that a stoppage of only 2 days gives significant effects.

4.4 Prerequisites, techniques and tools to handle maintenance challenges

The interviews at external companies were conducted to find prerequisites, techniques and tools considered important when managing and implementing a strategy for preventive maintenance. The investigation resulted in a compilation of techniques and applications commonly found in industries that is seen to be beneficial for the work at the maintenance department. The usage of these applications serves as a fair comparison of how companies handle their maintenance.

The result showed that there are several common prerequisites, techniques and tools to manage the maintenance operations, in the unstructured interviews these were collected among the companies, some more reappearing and some less frequent. The findings were compiled into a question form in order to map the use of these among the visited companies.

The criteria to confirm usage or presence was a definite yes, and filled with a cross (X). If the usage or presence varied or was not consistent the form was filled out with a dash (-).

Table 1 presents the results of the question form where the prerequisites, techniques and tools are sorted according to appearance and can be compared among the companies. The result was compared to the maintenance organization at GKN in order to show potential for improvement and fields of development.

Table 1 Presence of prerequisites, techniques and tools.

P,Te& To*		**1**	**2**	**3**	**4**	**GKN**	P1**	P2***
Te	Individual monitoring of (important) equipment	X	X	X	X	X	100%	100%
To	Condition monitoring	X	X	X	X	X	100%	100%
Te	Compiled operational overview	X	X	X	X	-	100%	80%
To	Calculated stop time cost	X	X	X	X	-	100%	80%
P	Takt flow in production	X	X	X	X	-	100%	80%
Te	Integrated planning of PM with production	X	X	X	X	-	100%	80%
Te	PM together with operator and service personnel	X	X	X	-	X	75%	80%
Te	AOM developed by equipment need	X	X	-	X	X	75%	80%
Te	Cross functional teams, PM preparation	X	X	X	-	-	75%	60%
Te	Evaluate every maintenance effort	X	X	-	X	-	75%	60%
Te	Preparatory meeting in advance of every PM	X	-	X	X	-	75%	60%
Te	Follows up on equipment improvements	-	X	X	-	X	50%	60%
Te	Seeks and eliminates frequent failures	-	X	X	-	X	50%	60%
To	RCA on every CM	X	-	-	X	X	50%	60%
P	Dedicated maintenance engineers	-	-	X	X	X	50%	60%
Te	Measure demand and result every day	-	X	X	-	-	50%	40%
P	Backup solutions always available	X	-	X	-	-	50%	40%
Te	Improves maintainability	X	X	-	-	-	50%	40%
Te	Updates AOP continuously	X	X	-	-	-	50%	40%
		79%	**79%**	**74%**	**58%**	**42%**		

**Prerequisites, Techniques and Tools*

***Presence in companies except GKN*

****Presence Overall*

In the fifth column is GKN only using 2 out of 6 of the most common tools, which shows the potential for improvements. The collected prerequisites, techniques and tools are not evaluated according the performance of the visited companies maintenance, and merely indicates the usage and presence of found parameters without telling level of success. The list is sorted by presence and not ranked according to importance.

4.5 Expert interviews

Participating experts, all active within ongoing research in the field of maintenance and Swedish Universities, provided answers of the prepared questions in two rounds. The interviews resulted in rather similar answers to the questions, some different perspectives but no contradictions. The answers to the questions formulated in section 2.3 are presented in a summary below. This summary is based on the answers given by the participating experts and compiled to include all different aspects gathered.

Answers to question 1, the biggest challenges when implementing strategies and practices for preventive maintenance are:

- Understanding and convincingly communicating the benefits and gains of preventive maintenance. To see the connection between reliability and a cost effective organization.
- To have a long term plan and focus on *right* resources and tools, not implementing too many at once and consider risks.
- To have durable committed management and develop competence throughout concerned positions in the organization.
- Breakdown possibilities and failure modes scattered among machine users.

Answers to question 2, the heaviest arguments for preventive maintenance on corporate level and how well this is in line with daily tasks in production are:

- It will contribute to safe (reliable) and effective operations as well as technical availability and long term cost.
- Preventive maintenance is profitable in a long term perspective and will help to communicate the benefit of a long term plan.
- A breakdown should never occur unforeseen on critical equipment. If so, it will affect the company’s production, deliverability, customer commitments and market position.

Answers to question 3, what motivates or counteracts companies to develop an organization for preventive maintenance:

Motivates:

- Measurable results of improved safety, reliability and decreased costs.
- Knowledge and understanding of the connection between reliability and deliverability.
- Robust and secure processes, more balanced production flow.
- Increased engagement, improved working environment.

Counteracts:

- Overall short term perspective of costs and also incompetence, both in maintenance department but foremost in other departments.
- Maintenance operations regarded as low status jobs will counteract the development of maintenance.
- Too wide and large efforts at once.
- Preventive maintenance not prioritized, easy to fall back into old habits of corrective measures.

Answer to question 4, what motivates or counteracts autonomous operator maintenance is:

Motivates:

- Production department should be responsible for equipment and develop routines in collaboration with maintenance department.
- Understanding for the impact of autonomous operator maintenance on all levels and all involved with production.
- Focused leadership and demand of result.
- Increased engagement, responsibility, status of work, working environment, variation in work tasks and chance of development.
- Personal engagement at operators.

Counteracts:

- Lack of understanding and competence among response positions and insufficient holistic perspective.
- Conservative and short term perspective, all maintenance operations regarded as non-core operations and not prioritized by production.
- Competitiveness between work flows and among operators.
- Unwillingness for extended work tasks without compensation.
- Lacking patience for results.

5 Analysis and individual factor discussion

In this chapter the results of the research is analyzed and individual factors stated. Each factor is further discussed regarding how they should be managed. In the end of this chapter the factors are mapped in relation to each other to show how they are connected.

The analysis of the results led to a number of invisible driving factors which counteracts preventive maintenance operations. The factors will be presented in three categories depending on where in the organization they are present and have effect, however all factors have consequences that will affect preventive maintenance operations.

Some of the factors are subfields of previous factors and will therefore have results and suitable actions that seem to overlap since the discovery of some factors arose from previously found factors. The factors could have been compiled and presented to avoid overlap of managerial actions, but there is also a value in presenting each of the factors to point out a specific area or function where the factor is active and could be managed individually without risk of losing connection to its related area. For overview the factors are compiled in figure 5.1 below.

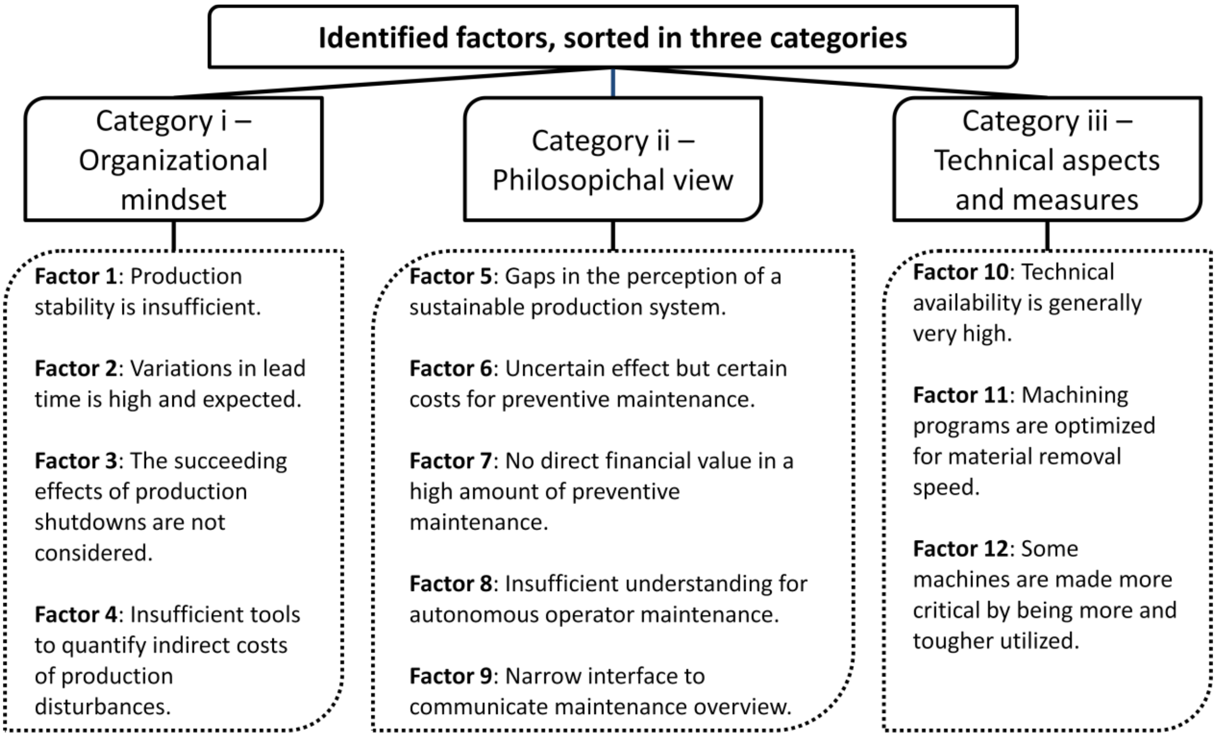

Figure 5.1 Overview of identified factors.

The effects of all the factors combined are leading to current state where maintenance is slowly evolving and the numbers remain the same over years.

5.1 Category i - Organizational mindset

From the empirical research the matter of stop time cost was brought to surface, which if used in a right manner is a powerful tool to emphasize the importance of up-time and stability. Stop time cost is also a common tool used in industries as seen in the external research at other companies. At GKN the stop time cost is low and does not represent indirect cost from the succeeding effects of a production stoppage. To investigate succeeding effects of breakdowns, variations in lead time was looked into during the quantitative research and showed that variances are not only present after breakdowns but more or less constantly in production.

It was also discovered in the empirical research that raw material deliveries to the company is a source of variations. Unpredictable incoming deliveries create fluctuations and production disturbances and leads to further obstacles in production and maintenance plans.

The factors in *Category I* are effecting the entire organization and are results of the organizational view of reliability.

5.1.1 Factor 1: Production stability is insufficient

Why is this factor concerning preventive maintenance operations?

By not demanding and evaluating the company on stability, the production is not challenged in a way that creates long term results. Production stability is not challenged and neither are maintenance operations to secure stability. This factor is present in the entire organization but should be the responsibility of and be initiated by, top management.

How was this factor discovered?

With consideration to the many sources of variation discussed in the comprehensive analysis of C*ategory i*, it is clear that the demand of stability in the organizations is insufficient. The demand should be initiated from top management and transferred with relevant focus throughout the organization, a phenomenon to study, but later realized as not present.

Result and consequences of this factor.

Different departments have different functions and needs, and have customer relation with one or more supporting functions. When the demand for stability is not pushed down from top management it will not continue to maintenance. The demand for reliable, predictable equipment is insufficient.

When the systems stability is not questioned or challenged, effects of longer shutdowns may remain in the process without causing urgency, by fitting in the normal range of variations as shown in figure 4.3. The lack of directives will not drive the maintenance department into being more proactive but rather being reactive. Maintenance acts when there is direct demands from external customers to be more stable or if employee safety is at risk. The insufficient demands on stability will cause production and the entire company to be reactive and maintenance to only fulfill basic needs (section 3.4.1).

How to manage this factor.

For GKN to reach a higher stability, they will need to challenge their production processes. With higher demands on process stability, more sophisticated preventive maintenance operations will be necessary. Resources in both man hours and competence are important for the long term, when problems are surfacing, the workload may be exigent. This is pointed out in the expert interviews as well as the importance to emphasize the connection between reliability and a cost effective organizations.

Demands and directions should be present and defined for all levels of management in order to develop the tools for evaluation and control of stability. Deviations should be brought up to surface and be considered as a point for improvement. It is important to regard that the production process should be challenged at a level that requires stability so that the demand of preventive maintenance arises from the production apparatus, not only as spoken directives.

To challenge the production and value adding processes, all value streams for all products should be clearly defined, robust and balanced. The product flow (and plan) needs to be detailed enough to tell where a specific product is located, both in the value chain and physical location. The planned process should represent the reality and where buffers are needed; these should be strategic buffers with limited quantity and be positioned and displayed as described by Liker and Jeffrey (2003).

Production goals need to be set within realistic limits, with consideration to all possible production disturbances and reductions of available time. To provide a reliable foundation, the production volume should be leveled to get a predictable outcome of product mix and utilization (Liker, 2003).

One source for the problems with stability is explained to be raised from incoming deliveries, as suppliers have problems to deliver on time and in right quantity. To go around this problem, a safety stock for incoming material could be used, as the annual volume seems to be delivered. Safety stocks will tie up capital but will also create a prerequisite for stability and higher productivity, as production plan could be held.

5.1.2 Factor 2: Variations in lead time is high and expected

Why is this factor concerning preventive maintenance operations?

A delay in manufacturing of a couple of days does not create a deviation large enough to be noticed, which may lead to insufficient awareness and thereby an inadequate demand on maintenance. Allowing variations of this magnitude is not in line with a strategy for robust processes and may take away the incentive for a sophisticated preventive maintenance program.

How was this factor discovered?

Variations in lead times at GKN is commented in interviews as a non focus area and connections between less variations and more effective planning and higher output have a clear absence throughout the organization. The general perception of the interviewees is that it is more important to focus on utilization than problems arising from late incoming material and common resources such as surface and heat treatments.

The internal report that comments on variations in lead time (Appendix III) are mostly caused by quality deviations, which comes to surface in machining operations. By studying statistics of lead times through the V2500 production flow the range of what is normal (80% of the cases) is more than 10 days, as well as the queues are varying in amount. The operating time for the critical operation 400 have a planned time for 15 hours in process and 1 hour in setup time. During a studied period of 2 months and 96 produced units, the process time is varying between 15 and 20 hours.

The planning at GKN is made out of customer demand and if it exceeds available capacity, demanded volume is promised anyway. By analyzing the productivity factor, technical availability and operation list (Appendix III) of the set of equipment producing the V2500, it is possible to see that the demand is exceeding the available capacity. By comparing productivity factor with the weekly production volume it will show a great gap. When returning to planning function for further questions, exceptions are taken from the operation list and other equipments is utilized to partly fulfill needs.

Result and consequences of this factor.

As long as the system is not robust and stable the effects of a shutdown risks not being noticed. Established processes are not predictable or stable and based on the varying lead times and buffers, when a shutdown occur the effects is not noticed nor coped with. In the internal report that comments on variations in lead time (Appendix III), it is shown that lead time varies between 15 – 28 days for 80 % of all products, meaning that a shutdown of for example 7 days might be unnoticed. This creates an acceptance for variations and various shutdowns since the uncertainty in the process will handle it. If the production flow is aiming to be tighter with smaller buffers and shorter lead times the consequences will be severe and preventive maintenance actions most valuable to reduce stop time.

Variations in lead time have big impact on tied up capital and delivery performance, lead times should be stabilized and minimized (James He, et al., 2011).

How to manage this factor.

Processes should be planned according to an achievable process time, and statistics of lead time evaluated until a consistent process is established. To achieve the same amount of production every day, this is a step in right direction. With a consistent lead time, deviations will be more visible and actions should be taken in order to resolve the source of the problem.

Every single product released for manufacturing should have a clear designated path through the factory in order to track deviations and pick up potential improvements (Liker, 2003). A designated path will make the value flow visible and problems will be clearly presented as deviations from the plan arise.

To breed a culture of continuous improvement, engagement needs to be present at all levels. A lot of improvement potential is normally found close to the machines but might affect the company in a much larger context, which is why an urgency to create value needs to be present throughout the organization. Daily routines for equipment auditing at operator level should be emphasized in order to find weak spots for potential improvements, and to solve to true problem.

One major loss is identified as tooling and part changeover (section 3.2.1.). To improve this, the principles SMED or Single Minute Exchange of Dies pioneered by Shigeo Shingo could be applied.

5.1.3 Factor 3: The succeeding effects of production shutdowns are not considered

Why is this factor concerning preventive maintenance operations?

There are internal reports investigating the effects of production shutdowns. The criticality of the matter is not thoroughly communicated and considered when production processes are planned. Established processes runs with large variances in e.g. lead time and the effect of a shutdown is not noticed nor coped with since the variations in the process will hide the impact. If the effect of a shutdown is not noticed, the need of preventive actions will not be considered urgent.

How was this factor discovered?

In the project, the matter of stop time cost was early considered. To present a representative stop time cost, all related and succeeding effects of a single stop must be accounted for. The succeeding effects of a shutdown can also be described as the cost of poor maintenance as discussed Salonen and Deleryd (2011).

Result and consequences of this factor.

If the succeeding effects of shutdowns are not brought up to surface, the effects will not be noticed and evaluated. A solution will not be developed and implemented to prevent a possible recurrent cause of the problem. Preventive maintenance will not be asked for since the need is not defined.

The succeeding effects of production stops are delays, variations, non-realized revenue and tied up capital. These effects can be present in the process long after the stoppage is resolved, depending on the duration of the initial breakdown and are described as costs of non-conformance (Salonen & Deleryd, 2011).

How to manage this factor.

To create awareness of the succeeding effects from productions stoppages, possible effects could be investigated in a similar way as described in section 4.3.3, S*ucceeding effects*. Such an investigation should be extended with related representative costs and the associated risks. The department for logistics development is working on request where the internal client is later deciding on how the information is used. Logistics development could instead work to deploy applied knowledge and educate related departments in order to increase the demand for stability and supply production departments with production logistics tools.

To increase understanding of these costs and what a stoppage actually means, employees could be educated in the theory of capital cost. Show that capital tied up in unused equipment or inventory could be used more effective and benefit the business where it is needed. This may create urgency to develop a robust production system with strategic buffers and control systems, and in the extension an effective preventive maintenance program.

A stop time cost including the indirect costs listed in analysis section may be considered high and equipment uptime might be a significant focus area. If the equipment is evaluated on productivity only by looking on OEE and productivity factor the investment could be regarded as not profitable due to the better method or higher performance (that will lower the OEE and productivity factor, for the same output) compared to older machinery. This may lead to unwillingness to invest in new equipment if they cannot be utilized fully from day one, which is not the subject of the stop time cost.

5.1.4 Factor 4: Insufficient tools to quantify indirect costs of production disturbances

Why is this factor concerning preventive maintenance operations?

With an representative financial tool to prove the cost of breakdowns, lost capacity and other indirect costs, different improvements of asset reliability could be compared and financially evaluated and the implementation could be a justified investment.

How was this factor discovered?

Since the maintenance vision has strived to increase the amount of preventive maintenance for a long time, the question of how they evaluate optional improvements was raised and responded with answers not in line with the expectations. By investigating the tool to justify reliability improvements financially, a source of the insufficient progress within the area of preventive actions could be found. The answer came to be binary as no such tool is used at GKN to validate improvements in terms of lost production time and surrounding indirect costs.

The external research showed that a representative stop time cost is a common tool used to justify investments as well as a case study in the RCM literature where the downtime cost for the studied equipment is $4000 per hour.

Result and consequences of this factor.

Without a solid argumentation, extensive preventive maintenance operations or modifications might be hard to realize since the costs of a reliability problem can be hard to define. Maintenance will be seen as cost driver, instead of a competitive resource (Salonen & Deleryd, 2011) and investments in reliability increasing actions may not be realized.

The empirical research at GKN showed that for changes to happen at GKN, there need to be direct requirements from the external customer to improve stability or if employee safety is at risk.

It was the discovery of this factor that initiated further research on succeeding effects of production disturbances which in turn resulted in the investigation of lead times and led to the discovery of factors in Category i.

How to manage this factor

To create incentives for an effective preventive maintenance organization, a representative stop time cost should be used to justify investments and actions to improve production reliability.

To establish the stop time cost in a representative manner with indirect and direct costs included, the calculation model could consider:

- Products in queue, all affected ques.
- Hourly cost rate on machine (total procurement and installation cost in relation to economic life, start up times, etc.).
- Spare parts, extra delay caused by hard-to-get-spares.
- Internal rate for concerned tied up capital.

- Personnel without work due to production stop.
- Overtime due to production loss.

- Cost for additional planning and administration.
- Lost contribution margin due to production stop.

- If delays are reaching customer, eventual penalty should be considered and included.
- Express deliveries of delayed products.

And, stops and related cost in following machines in value flow, if affected.

By surfacing a more representative cost for stops in production, urgency to improve will rise and investments in reliability will be righteous. All of the visited companies in the external research is using a carefully calculated stop time cost in order to drive improvements and critically justify the sources of indirect costs.

5.2 Category ii - Philosophical view

Communicating the benefits of maintenance was discussed from the beginning of the project and has been brought up in AIM-workshops and used as an investigating question in unstructured interviews. Factors in this category is mainly concerning how to communicate the positive effects of proactive work so the perception is generally that preventive maintenance is a necessary part of a well performing organization.

5.2.1 Factor 5: Gaps in the perception of a sustainable production system

(Benefits of preventive maintenance not thoroughly communicated as an important part of a reliable production unit)

Why is this factor concerning preventive maintenance operations?

The trust in more developed preventive maintenance system as a contributing part of a reliable, stable and sustainable production system varies through the organization. Without a clear connection between reliability and deliverability, efforts and actions to obtain deliveries might have a short term perspective and neglect preventive maintenance as a method to succeed.

How was this factor discovered?

The matter of effectively communicating what actually affects reliability in processes was early raised during the AIM-workshops. This question was later used in interviews to further investigate how the connection between reliability and deliverability was generally perceived. It was also found in the external research, during literature research and commented by experts that this is a widely spread problem and a major factor in the field of maintenance.

Even though there might be a belief in preventive actions throughout the organization, there is just not enough proof communicated or clear connections of improved delivery performance provided.

Result and consequences of this factor.

By not recognizing what parts that contributes to a reliable, stable and sustainable organization the need for preventive actions may be forgotten in production. This may lead to slower development and implementation of the maintenance methodologies such as RCM, TPM and condition control systems. Maintenance risks being seen as cost driver, instead of a competitive resource (Salonen & Deleryd, 2011).

How to manage this factor.

To close the gap and effectively communicate what benefits efforts of preventive maintenance operations can bring, internal success stories could be emphasized and communicated within the organization. To present success stories, progress of conducted maintenance projects and improvements could be gathered and presented in an informative and attractive manner.

To create engagement, information regarding origin of idea, monetary values, goals, efforts and results should be included as well as other gains such as ergonomically or environmental. To increase participation it is important to show both how the individual can contribute to a sustainable development and how the individual can benefit from it, as emphasized in the by Hackman and Oldham (1976).

To learn more and get influences from others, participation in seminars and communities (like SMGC) striving to develop the concept of maintenance, can be useful. The learning's of these seminars should be compiled and communicated back to the organization.

5.2.2 Factor 6: Uncertain effect but certain costs for preventive maintenance

Why is this factor concerning preventive maintenance operations?

As the production system and process thinking will evolve to a more sophisticated and predictable production level, it will increase the demand and expectations of the maintenance organization. The maintenance operations needs to be better to be able to keep equipment as reliable as needed. To develop the maintenance in this direction and to realize the maintenance strategy and vision, a larger effort could initially be necessary. In figure 5.2a hypothesis of the expected development considering the total amount of maintenance operations and the ratio between preventive and corrective actions is shown. The decrease in total amount of maintenance operations is due to improvement potential of both preventive and corrective operations.

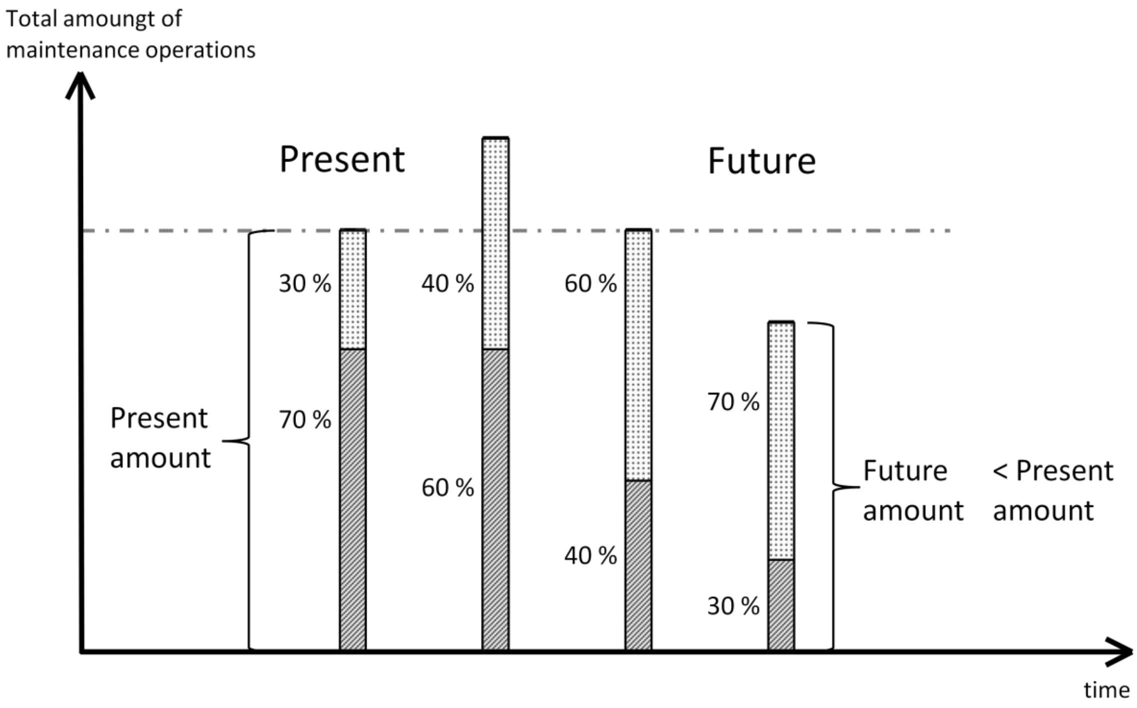

Figure 5.2 Hypothetical development regarding the ratio between preventive and corrective maintenance.

This factor is affected by decisions taken outside the maintenance department. Internal financial decisions show that production units are not even willing to spend the recommended (by maintenance department) amount on maintenance operations. A reason for this could be connected with the non-proven gains of preventive maintenance. The cost for preventive actions is always guaranteed but the effect might be uncertain and equipment can suffer from unplanned stops anyway, while the effects of corrective actions are more certain and the cost is not set or guaranteed in advance.

How was this factor discovered?

Reviewing internal budget propositions showed that the budget is systematically lowered with 10 percent of the suggested cost for maintenance. The questions of what preventive actions is right were also raised in the AIM-workshops and further investigated as a possible factor counteracting preventive maintenance.

Result and consequences of this factor.

When budgeting production, maintenance is viewed as non value adding activity and should be reduced. This short term view and unwillingness to invest in preventive maintenance can hold back the development of preventive measures. This might end up with more corrective maintenance and in the long run exceeding the maintenance budget together with lost production.

How to manage this factor.

The cost for reliability might be considered high, the risks should carefully be investigated with e.g. RCM methodology (section 3.2.2) and actively revised as critical production programs are set. Expert interviews tell that unplanned stops should never occur on critical equipment by any means, which at GKN are present more than 10 times each year on each machine that are called “A-work centers”.

Therefore, it is important that people with power over financial decisions also have technical competence and is able to evaluate the risks of cutting budget for maintenance.

To emphasize the importance of preventive maintenance operations and create awareness of the risks the production system needs to be challenged. This will place demand on a preventive maintenance program to be good enough to create stability, in order to tweak the utilization and lower overall production costs.

It is important to regard the entire organization as contributing parts to reaching production goals. Increasing the amount of preventive maintenance operations without having a need from production is not a solution itself. But with high demands on production stability a proactive organization for maintenance is fundamental and with a balanced level of strategic preventive maintenance, unplanned corrective maintenance is likely to decrease (see case example in section 3.2.2).

5.2.3 Factor 7: No direct financial value in a high amount of preventive maintenance

Why is this factor concerning preventive maintenance operations?

As a result of increased amount of preventive maintenance fewer unplanned stops is expected. If the increased production capacity from fewer unplanned stops is not needed or utilized, the increased amount of preventive maintenance may not be economically viable and not invested in.

How was this factor discovered?

During AIM-workshops, the participants communicated a perception that the production capacity is well utilized and seen as limiting to the output. Production data (figure 4.1) however, shows clearly that utilization of equipment is generally low and that there is available time.

During the unstructured interviews, indirect benefits of preventive maintenance were never brought to discussion by the interviewees. This indicates that the culture at GKN is to have a focus on direct costs, which they have insufficient tools to examine.

Result and consequences of this factor.

Until the large existing variations in manufacturing processes are reduced and the process is stabilized the production capacity cannot be fully utilized due to its unpredictability. The cost for a higher amount of preventive maintenance may not be financially justified by GKN if the level of productivity is not increased.

How to manage this factor-

To justify the effort and cost of developing the program for preventive maintenance might be hard, if the output of the plant does not need to increase. To emphasize on the indirect parts of stability such as easier planning, fewer moments of stress, better work environment, increased safety, demand on fewer temporary workers and easier overviews for top management a point of understanding beyond financial might be found. In the long run, less people in production might be needed as well as fewer on administrative tasks as the demand on re-planning and fire fighting might decrease (section 3.1.3).

5.2.4 Factor 8: Insufficient understanding for autonomous operator maintenance

Why is this factor concerning preventive maintenance operations?

If the vision of increasing the amount of preventive maintenance operations is to be realized, the preventive part of autonomous operator maintenance needs to be emphasized. Without a clear description of work tasks concerning what, why and by whom, several expected actions might be lost.

Until there is one specific person assigned accountability for each work task such as operator maintenance, there will be a risk of non fulfillment of the task. If it is not clear why or how a task needs to be performed there will be a risk of tasks being performed in insufficient manner or not at all.

How was this factor discovered?

The result from AIM-workshops and unstructured interviews points at the irregularities in the operator maintenance. The execution of operator maintenance is confirmed and signed by the operator, which leaves no guarantee for the tasks being carried out. Indications of the event of only being signed as well as performance are to differ between departments and equipments, have been shown in interviews. It was also found during interviews that there in some cases seems to be a perception that maintenance is not a core part of operators work description and therefore neglected.

The theoretical framework (sections 3.1.4 and 3.3.5) points at the importance of having clearly defined meaningfulness and accountability for work tasks. Absence of this is likely to lower engagement and quality of execution.

Result and consequences of this factor.

Routines for autonomous operator maintenance will not be followed and the expected preventive maintenance assigned to operator maintenance may not be performed, leaving a segment of the expected maintenance to uncertainty and possible risk of unplanned failure or breakdown.

The operator maintenance can also be a source of finding beginning failures, and should drive continuous improvement of equipment and routines. A culture of neglecting maintenance in operator work performance may prevent this and work against the development of maintenance. Over the past 5 years overall suggestions have been decreasing as can be seen in section 4.2, which might indicate on the beginning declining of commitment among employees.

How to manage this factor?

To increase the understanding of the benefits associated with operator maintenance, clear descriptions of why, what and by whom needs to be in place, custom designed according to individual equipment need. It is important that these instructions clearly communicate how the individual contribute to the holistic outcome of reliability and reaching the goals (Hackman & Oldham, 1976).

The execution and outcome of operator maintenance should be assigned with accountability to one single person (Daley, 2008). First line managers should truly understand the meaning and benefits of operator maintenance to be able to teach and educate, and when auditing, if a routine is not followed, it may be more likely to find an improvement than a failure. In TPM the use of improvement teams is emphasized and could if applied successfully overcome the decline in improvement suggestions.

5.2.5 Factor 9: Narrow interface to communicate maintenance overview

Why is this factor concerning preventive maintenance operations?

A clear overview of what actions is needed to secure equipment reliability is important to create a throughout understanding in the organization. If communication from maintenance administration to maintenance repair personnel and production is inadequate, overview of strategy, workload and demand might be lost and it is likely that this will inhibit the development of maintenance.

How was this factor discovered?

This tool was discovered during the external research of other companies who used long term overview to effectively visualize all maintenance activities using relevant KPI's and logging of progress. The presence of similar overview was examined at GKN, which showed that a lot of statistics is logged and processed but not presented in coherence over time.

Result and consequences of this factor.

Lacking communication of KPI's and future events might hold back the development of maintenance. Relevant statistics of maintenance performance needs to be communicated in a long term perspective to increase the degree of participation and understanding for the system.

If only parts of the maintenance activities is presented or notified due to different working hours, location and function, the big picture might be lost. Understanding and acceptance of planned activities is lowered as patterns and planning is not visible. Single maintenance activities might seem common to certain working hours while very unusual to others and not perceived as a problem at all.

How to manage this factor.

To get an equivalent perception of the maintenance progress and needs, all maintenance actions, planned and unplanned should be communicated clearly to show expected outcome, expenditure of time and trends. Between the maintenance administration and maintenance repair personnel, all past, present and upcoming activities over e.g. on year could be displayed with a sectioning for each work center, product flow or category of equipment, whichever is most suitable. With this tool a clear overview and foundation for analysis is given and no information regarding activities is lost due to shifting work hours. Techniques to accomplish this were found at other companies in the external research.

By presenting status and history of efforts on individual equipments relevant to the observer, GKN could possibly close the gap between operations and performance indicators. Educating involved employees of the higher goals of the maintenance strategy and not the goal of achieving a statistical number of events or budgets kept. Let maintenance service personnel be involved in analyzing how to reach higher goals, in order to collect points for improvements. Internal data showing a lot of these parameters is already available within the maintenance department of GKN and could to be used for these purposes.

There are good examples of how to display information and communicate purpose within the company[3] which could be used to develop an effective interface between maintenance and production. In the forum of SMGC, discussions of how to hands on communicate successful maintenance journeys should be a main topic, as great examples were found during the external research.

5.3 Category iii - Technical aspects and measures

The factors in the third category are generally derived from statistical numbers and internal data.

5.3.1 Factor 10: Technical availability is generally high

Why is this factor concerning preventive maintenance operations?

Equipment is evaluated on an average over machines and over long time leading to an inaccurate high number for technical availability and equipment seems to be well maintained in general. Utilization is not put in relation to technical availability, which mitigates the urgency for maintenance operations. Figure 4.2 shows the relationship between technical availability and utilization for a selection of equipment, based on internal data loggings.

How was this factor discovered?

In a Customer Need Analysis performed by SKF in February 2012, technical availability is brought up in one of the assessment question. This analysis was reviewed early in the project and the technical availability further examined. Internal data of technical availability was compared to the actual and planned utilization of equipment, leading to the results presented in section 4.3.

Result and consequences of this factor.

The high numbers communicate that equipment is working well and the need for more preventive maintenance operations seems low. However, there is no intrinsic value in high numbers for technical availability as long as the productivity factor is low i.e. the capacity is not utilized or perhaps even needed. Some of the equipment driving the high average is barely utilized at all.

As can be seen in figure 4.2 there is a connection between utilization and technical availability, and in general the more stable they perform the less maintenance cost they have.

The equipment in need of most preventive care might be missed as the productivity factor is not used in relation to the time of failure. The worst 20% of the equipment have a ratio of machining hour/failure hour between 51min and 6h and 36min, which mean that on an average they have a breakdown of more than one hour each shift. The technical availability is for these machines between 81,26% and 96,51%, showing that the technical availability is not a secure performance indicator for reliability.

[3] For example *Safety Corner* Initiative which clearly displays awareness and concern of safety issues. A safety corner is set up close to the canteen area at GKN in Trollhättan, for everyone to visit.

How to manage this factor?

To communicate relevant conclusions based on the technical availability, the relation to the productivity factor and breakdown intensity needs to be included. Time span should be chosen to be representative and indicate points for improvements. Not available time can be derived from technical availability should be used by planners in order to plan for capacity.

To get an overview of status and direction two intervals could be used, 12 months to see the status of the equipment and 1 month to see in which direction the status are leading to. By analyzing technical availability in an individual way, considering utilization of each equipment more directed actions could be performed. When equipment is in series and in tight value flows with limited buffers, the technical availability should be multiplied in order to get the technical availability for the set of work centers (Hagberg & Henriksson, 2010). By using OEE, productivity factor and quality outcome is included and gives a more comparable status to create incentives for improvement.

A suggested basic analysis of technical availability follows below.

Questions If high:

- Is it true? Is the calculation right?
- How is the equipment utilized?
- Is it different from similar equipment in preventive maintenance cost/scheduling?

Questions if low:

- MTTR and MTBF? Investigate source of stops.
- Is preventive maintenance schedule in line with utilization?
- Is the stops planned or unplanned?
- Is the equipment on its end of technical life?
- What technical availability is needed?

5.3.2 Factor 11: Machining programs are optimized for material removal speed

Why is this factor concerning preventive maintenance operations?

Production department specifies an operation request which can include high demands on speed to reduce the hourly cost. If machining programs are designed for speed they may not be optimized with concern to maintenance costs they may drive.

How was this factor discovered?

In the second AIM session, the utilization and range of machining toughness was brought to discussion. Participants agreed that the cutting processes were over or close to the limit of the specifications due to the demands on high machining volume speed. Interviews with numerical control department showed that stress on machinery is not considered when production programs are set.

Result and consequences of this factor.

Machine wear and total cost is not considered when cutting processes are programmed which might result in a cutting process close to machine manufacturer recommended maximum. This leaves production department with a possible higher need of maintenance than expected. If planned maintenance is according to manufacturer recommendations, it risks being too seldom.

How to manage this factor.

To get machining programs optimized according to technical life of equipment and tools, wear of machines should for critical equipment be considered when setting process program times. The Numerical control department should work in collaboration with Maintenance department to possibly be able to estimate maintenance need according to how machines are utilized. RCM methodologies (section 3.2.2) implies maintenance program designed with concern to the system and surrounding environment, where for example cutting forces and cycles could be included. If these are higher than necessary, it is possible that this will drive a higher maintenance need.

5.3.3 Factor 12: Some machines are made more critical by being more utilized

Why is this factor concerning preventive maintenance operations?

Machining equipment is chosen for certain operations by Production department as they consider most convenient when planning. This is although not necessarily done according to product need and machine function. Which may lead to some machines are favored and made critical in terms of availability and maintenance needs.

How was this factor discovered?

By examining the operation list of the high volume product, the V2500, it is clear that process times are differing from 6 to 15 hours. Comparing these numbers with productivity factors of machines with SMM installed, it shows that utilization of similar equipment is varying.

Result and consequences of this factor.

When certain machines are chosen by Production department, the utilization increases and more maintenance could be needed. If the same machine is chosen for an additional operation the system may be saturated due to single equipment being critical for the process flow even though there might be other machines available for the same operation. As total process time for a work piece is strived to be minimized, system losses could grow as takt time is neglected.

How to manage this factor.

Numerical control department have knowledge regarding machine and product combinations and should preferably be consulted when setting up a process flow, in order to find the best fitted machine for the certain process according to stability, performance and available capacity. To further take advantage of the competence regarding equipment and processes, cross functional teams (Smith & Hinchcliffe, 2003)together with RCM methodology could be used to develop routines for effective preventive maintenance at critical points at critical equipment.

5.4 Relations between identified factors

The identified factors have been mapped in figure 5.3 to show the relative relations. Factor 1 has been highlighted to emphasize the importance and challenges of this factor. The factors in the top row will have effects on factors in underlying rows and should therefore primarily be focused on. The factors in the second row are however parts of the factors in the top row and cannot be neglected.

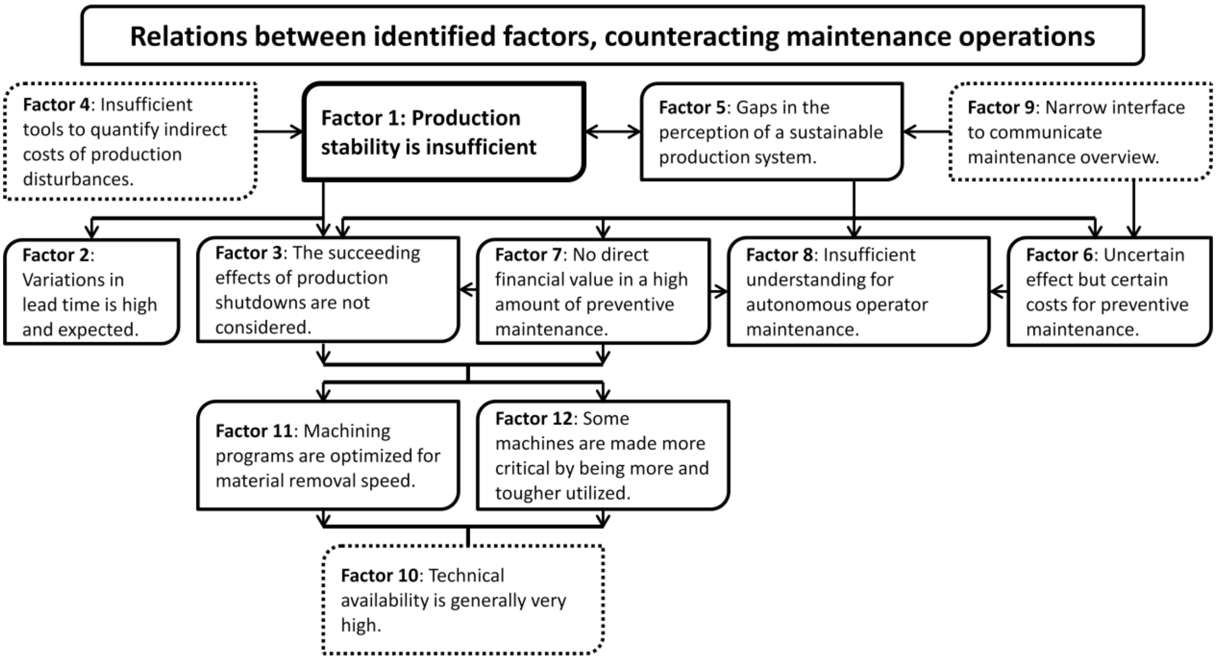

Figure 5.3 Overview of relations between identified factors.

Factors 4, 9 and 10 are boxed with a dash line. For these three factors there are more or less concrete suggestions of how they could be handled, which is presented in the *How to manage* section for each factor (sections 5.1.4, 5.2.5 and 5.3.1). The suggestions may be able to give instant effects and used as tools to reach the common goals of the organization.

6 General discussion

The development of maintenance operations at GKN has for a long time strived to reach a goal of more preventive maintenance and less corrective, the vision is 70 % and 30 % respectively. In spite of efforts made to improve, the number has not changed. It is believed that there are invisible driving factors in place that counteracts the development of maintenance operations.

The purpose of this research was to:

Empower fulfillment of maintenance vision, improve reliability and reduce overall production costs by surfacing invisible, counteracting factors.

When reading the master thesis proposal the first time, it was clear that there was an open problem. When interviewing the global production director Gunnar Brunius, he stated the quote below. The only part of the sentence that was clear in the beginning of the investigation was that the requested state was not the current.

"A problem, is the difference between the current and requested state" - Gunnar Brunius

The results led to a general perception of how maintenance is regarded in relation to reliability and productivity in the company, from which the stated factors could be analyzed. The factors presented in the analysis have been confirmed as invisible, valid and relevant by the project supervisor at GKN and is each provided with a suggestion of how to manage.

Since the thesis was proposed as a problem of what counteracts the development of maintenance, it was expected that demands from production and top management would be sufficient and that to develop maintenance would be a natural step in the organization's journey. Due to this, factors (counteracting maintenance operations) of a more technical nature and more focused on single maintenance operations were expected to be found. This was expected as the organization was believed be at a stage where more effective maintenance was needed to improve productivity. In several management philosophies such as e.g. Total Quality Management, it is highly emphasized that the organization should focus on their processes and regard internal as well as external customer relation (Hellsten & Klefsjö, 2000). These components are some of the cornerstones of TQM (Bergman & Klefsjö, 2010)as well as top management commitment, which implies that demands and development should be initiated and the responsibility of top management to drive the organization forward.

The identified prerequisites, techniques and tools are useful at different levels in an organization and at different degrees of maintenance maturity. Not all of them are applicable for all companies depending on the particular production system. For example, some are more useful when initiating a journey towards more developed maintenance and some more useful when trying to refine the maintenance system.

Unexpected results came up in form of an inhomogeneous view of common industrial system thinking. The long history of the facility, going from military products to civil products creates other demands on funding and deliveries which the organization may not yet been fully adapted to and production logistics development has slipped behind development of the products. The value flow at GKN is not visible mostly due to low volume, use of non visible buffers and shared resources but also since equipment is not always physically lined up according to value flow. If the production would have been leveled (Liker, 2003), takted and with strategic visible buffers, the value flow would have been clearly visible and all disturbances surfaced to bring up areas for potential improvement.

According to the Toyota Way Fieldbook (Liker, 2003) a smooth leveled flow is the foundation a reliable and efficient production system. The production department is clearly focused on delivery, which is mainly the door to exit the factory. Takt time (system losses) in the factory is not considered as a general problem and some equipment are made critical to the value flow, by long process times. The inhomogeneous view of system thinking in the production apparatus leaves the value flow with few points to demand and measure stability on. The significance of the matter of takted, balanced production flow has been found as a prerequisite at other companies to develop demands for maintenance and has also been brought up as a significant matter when developing maintenance in the expert interviews. Visualizing the value flow, lowering inventory (such as only using limited strategic buffers) and adopting a more leveled production will bring several problems to surface (Liker, 2003). These problems needs to be regarded as areas of potential improvement and standards should be defined and continuously improved. If the workload from surfaced problems seems too high and is not coped with, the organization risks falling back in to old habits and the demands on production and maintenance will not increase, inhibiting the development of the maintenance organization.

The cost for maintenance did not follow the utilization of the equipment, when comparing similar equipment the utilization and costs seemed to be random. Causes for this was not looked into further due to complexity and time planned for other activities.

Several of the factors are affected by the same or similar drivers described by Narayan (2012), section 3.1.2. The phenomenon of what drivers affects the outcome of reliability aspects is researched in literature, but for a single company striving the reach a vision like GKN, the means might be fairly unknown and taking on a philosophy like RCM might be too much work at once and could instead have a negative effect. An individual thorough investigation starting with the mapping of factors counteracting the maintenance development, followed by the tools to handle these and implement the changes is likely to have positive effect.

6.1 Discussion of possible flaws in the methodology

The methodology phase of empirical research and literature review was formed to be iterative. The purpose of this was to be able to expand the theoretical framework and bring new areas of relevance into the project as the investigation proceeded. The investigation could have been designed to complete a literature review prior to the empirical research, which likely would have inhibited this project due the nature of the problem.

An alternative approach to collect perceptions of the maintenance as a function and its challenges could have been to perform surveys with relevant employees. By doing this more opinions and data could have been collected but the reasoning behind the answers should have been lost. By performing the AIM workshops, data was automatically generated as well as the discussions were observed while the participants performed the workshop, which was of great interest and value for the project. The AIM workshop was conducted with two groups but the research could have included several more occasions to gather more data. The purpose of the AIM was to find areas for further investigation and as all the information from the workshops is thoughts and perceptions, facts was needed which more workshops could not provide.

Observations and applications of ethnographic methods could have been more extensively used. For example, specific work processes could have been studied more thoroughly by participation and valuable observations could have been made. This would however require far more resources of time and also time for reflection and documentation then available.

The expert interviews could have included more participants to possible gain a broader base of information, however the answer were as expected very consistent. The ratio of answered/contacted sheets was 0,66 where four experts answered. By including a larger group i.e. ten experts, six answers and reviews could have been presented in this report, but due to the consistency in the answers it would have little or no effect.

The production data gathered was given by request to the maintenance department. Data could not be retrieved by specifically designed questions to the database due to limitations in the interface and the presence of two different systems. By that the analysis was limited to what could be extracted manually from preset choices which generated lots of manual effort to combine and track data. With an open database and a sophisticated search tool, SQL questions (Structured Query Language) could have been programmed to track deviations or increases in costs, productivity factor or technical availability over history. To keep time plan and the level of abstraction of the different areas in the investigation, the analysis of data is restricted to one year, leaving statistics of eventual improvements (for the past ten years) unseen.

6.2 Recommendations

The stated factors represent problems in different areas and with different magnitude. To attack all of these will require a large collective effort which may very well be too much to handle at once. The recommendation is therefore to aim at a few significant factors that will bring effects on other factors, which then can be re-evaluated and handled in a later phase.

Factor 1 (production stability is insufficient) should be considered as a primary focus with a long term perspective and goal (years). The investigation has presented the effects of this factor for maintenance, but there are also effects in other areas e.g. high inventory and related cost of capital. Successfully dealing with factor 1, will bring effects on factors 2, 3 and 5.

For long term perspective factor 5 should also be regarded to recognize maintenance as a contributing part of the production system.

Over a more foreseeable period of time (months), factors 8 and 9 could be brought up in improvement projects. To handle these factors require some amount of effort to be initiated and some less to be maintained but the effects should be clear and also empowering which will fuel the higher purpose of a cost effective production system.

In a short term perspective, factor 4, 9 and 10 could be handled and the result used as a tool to justify further implementations.

Implementation of too many of the managerial suggestions at once might be costly and require extensive resources. The focus should therefore be kept to some factors at the time. The recommendations above will require development and adaptation of the managerial suggestions, time, participation, engagement and not least top management commitment. Without these components, any improvement implementation is likely to fail.

6.2.1 Effect on sustainability aspects

This research has led to 12 individual factors counteracting development of maintenance operations. The analysis of the factors is provided with suggestions of how to manage each factor and how this possibly would affect the organization. As all suggestions aims at improving the conditions for maintenance development, they also aim at securing the production system for future challenges by developing robust processes and value flows, all visible and manageable. To sustain market position as well as competence in the company, growing organic with right resources at right places are equal to a long term philosophy for improving sustainability.

For the individual at GKN the work situation may be improved by well performed maintenance in terms of:

- Stress of unexpected breakdowns in production.
- Planning reliability in production.
- Service personnel planning horizon.
- Stability in factory output creates stability in man hours.

A large aspect of sustainability is how actions today will affect the future. With a reliable production system based on a well performing and efficient maintenance organization the conditions for the future may be improved in terms of sustainable economic growth, care of environment and improved prerequisites for employees.

6.2.2 Implications on further research

The external research resulted in a number of applications commonly implemented around industries, applications to create positive prerequisites for maintenance development. An extended research of factors at the external companies would require more time and resources than available for this project but could be a subject for further research.

The unstructured interviews conducted at GKN were of a open character where the subject reliability and stability was introduced. At some occasions the interviewees was prepared for other questions like, the service level of performed maintenance or a specific maintenance effort. The subject was important for the study and have made path for the research to clarify the system thinking and reliability as the general mean to reach production goals. The purpose of introducing the terms reliability and stability was to make such an indestructible test as possible in order to extract their view on the system, this high level of abstraction could have left answers behind and also leaving the interviewee with questions of our presence.

Figure 6.1 below shows a hypothetical future state where the ratio between preventive and corrective maintenance operations is 90 % and 10 % respectively. For the future state, two scenarios is possible. In the first scenario the total amount of maintenance is greater in the future state than in the present, but justified by the savings of less CM (CM is three times more expensive according to

(Chan, et al., 2003)). In the second scenario the total amount of maintenance is greater in the future than in the present and not justified due to extremely high efforts in succeeding with preventive actions. I.e. keeping expensive spare parts in stock, availability of personnel and high degree of maintainability required (equipment may need to be designed and procured for maintainability).

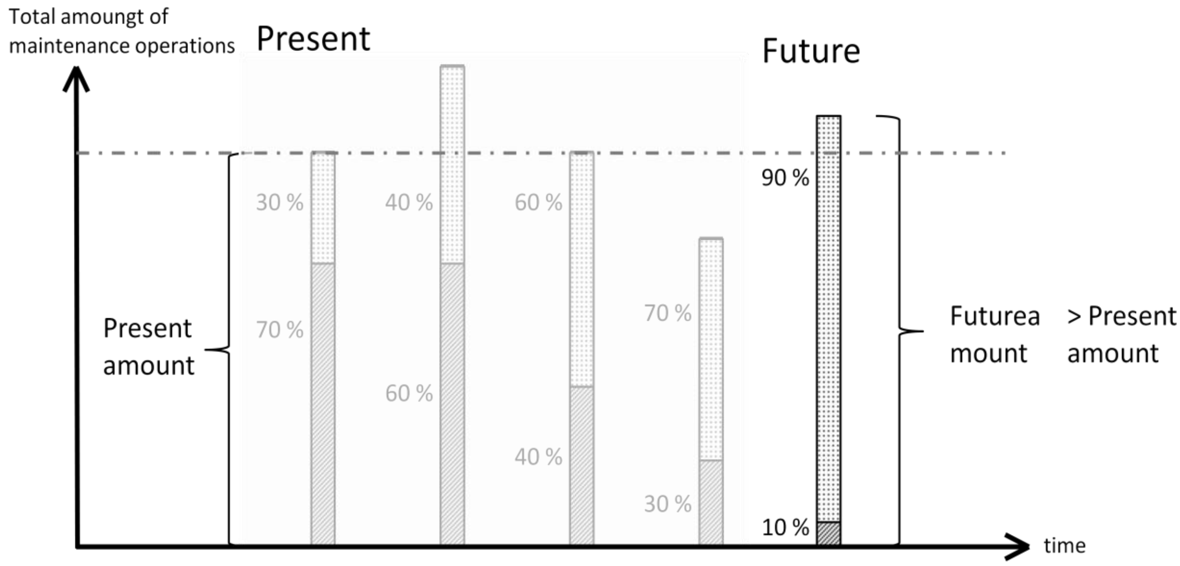

Figure 6.1 Hypothetical development of the ratio between preventive and corrective maintenance.

Which ratio of preventive and corrective maintenance that is most cost effective in a future state, and when preventive action may not be profitable is not investigated in this research but might interesting as a subject for further research.

7 Conclusion

This section will present the conclusions of the master thesis. The conclusions are mainly formulated as answers to the project questions.

Many activities already started in the maintenance department are in line with the vision and there is great potential to handle several of the identified factors. However, there is little value in developing a great maintenance organization unless the entire organization is trying to be more preventive. Several of the factors exist due to the limitations of system thinking, demand for stability and reliable processes. As the development of the production moves forward, the maintenance organization will need to evolve to meet the requirements of reliability as the organization grows as a company.

What demands on stability and reliability (effective maintenance) is present in the organization? (*How widely spread is the connection between maintenance operations and profitability?)*

The production at GKN is not challenged, nor developed enough to create a demand for preventive maintenance development. The demands on stability reach technical availability, deliveries on schedule as well as production starts. The investigation shows that the delivery goals in many cases are not reached and production is often behind. This were found when reviewing delivery KPI's of several months, which mostly presented late deliveries and also found when reviewing internal data of queues and late units in production, which can be seen in appendix III. Components are not produced according to predictable levels which create constant fluctuations and variations. The planning structure allows operations to take place in different equipments which further brings fluctuations and may choke the system if operations take place in shared resources.

The results from the interviews show that the connection between reliability in maintenance operations and profitability is not consistently perceived among production managers. These quotes where found and provides a split perception.

"No, there is no such connection" – "Yes, the connection is crystal clear"

The interview results also showed that the main focus is to reach the volume goal, not *how* to reach them. This leaves less room and thought to preventive maintenance operations and emphasizes corrective actions.

The production at GKN suffers from long lead times and high variances, there is a large administration that works with disturbances and quality issues. The value flows have slack and buffers to cope with system losses and other disturbances, the system is neither robust nor effective as the effects of the variances are hidden by choking the value flows with WIP.

The current need for effective maintenance operations is lost due to the sometimes choked system and absence of limited buffers.

What factors affects preventive maintenance operations?

The identified factors (Figure 7.1 below) presented in this research affect the outcome of maintenance operations and development. It is however likely that there exist more possible factors in the organization. For some factors where the reason of existence is an absence of some parameter, application or mindset, this missing component may directly be a solution.

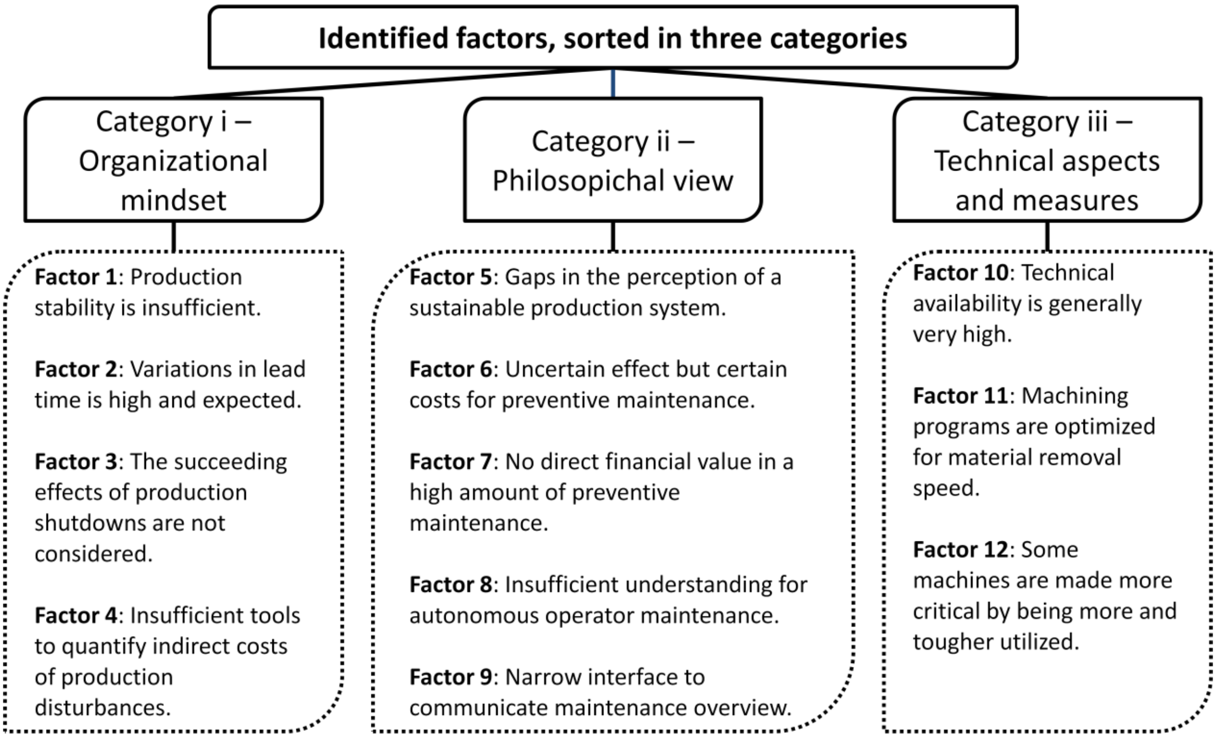

Figure 7.1 Overview of identified factors.

Maintenance is generally regarded positively, mainly due to corrective actions that will "fix the problem". This perception creates a great challenge in communicating how preventive maintenance operations will benefit the organization, a challenge that is present and needs to be emphasized in the entire organization. Benefits of maintenance are generally very difficult to communicate, partly due to the traditional view on maintenance as a cost driver and not a contributing part of the production system. This has been emphasized by experts, literature and confirmed in internal and external empirical research.

How is maintenance challenges handled at other companies?

From the visits at other companies connected to SMGC, prerequisites, techniques and tools were found and are presented in section 4.4. The most common production systems in the industry have a production takt, making the value flow the most important to serve at all times. By setting up limited buffers and production takt the demand increases on the maintenance organization, forcing them to develop and act to support the critical value flow where every single minute of lost production is affecting the bottom line.

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Appendix I – Time plan

Timeplan

Master Thesis GKN Aerospace

Project:	Maintenance GKN	Date: 2012-10-30	Reviewed: 2013-01-16
Customer:	GKN Aerospece	Version: 3	
		Author: Anders Brusing	

Activities — **Time plan 2012.10.29 - 2013.04.07**

	Week / Description	44	45	46	47	48	49	50	51	51-1	2	3	4	5	6	7	8	9	10	11	12	13	14	
1	Initiating Master Thesis work	5																						5
2	Draft Planning report	15																						15
3	Problem framing on site, quantitative data research	20	10	20	32	B	24			B														106
4	Planning report		20																					20
5	Plan project and methods		10	8		R				R														18
6	Literature research		8	8	3		16					24	16	24										99
7	External empirical					E		35	24	E	12					12	12	12						107
8	Expert interviews		2		4		4																	10
9	Attending presentation					A			1	A					1									2
10	Further investigation on site					K				K				6	33	24	24	24	24					135
11	Mid Evaluation												8											8
12	Report			4	5		5	5	15		28	16	8	5	5	5	5	5	16	35	35	35	38	270
13	Opposition												8	5	1									14
14	Presentation																			5	5	10		20
	Total number of hours	40	50	40	44	0	49	40	40		40	40	40	40	40	41	41	41	40	40	40	45	38	**829**

Appendix II – Topics and questions to examine during unstructured interviews.

Maintenance service personnel.

Main question – *How is the function of maintenance regarded in your work?*

Supporting topics.

- Triggers for corrective and preventive maintenance.
- Triggers for corrective maintenance.
- Differences of maintenance performance of different work centers.
- Distribution of FU/AU in different work centers.
- What are the biggest challenges when implementing strategies and practices for preventive maintenance?
- What targets are tracked? *(KPI's and goals, what is supposed to be achieved, and how are the interpreted?)*
    - How are these communicated?

Production Manager, Machinery, workshops.

Main question – *How is the function of maintenance regarded in your work?*

Supporting topics.

- Service personnel working flow.
- Differences of maintenance performance of different work centers.
- Distribution of FU/AU in different work centers.
- Stop times and the production pace impact, delays and overtime
- What are the biggest challenges when implementing strategies and practices for preventive maintenance?
- Is maintenance regarded when planning production?
- What targets are tracked? *(KPI's and goals, what is supposed to be achieved, and how are the interpreted?)*
    - How are these communicated?

Operators.

Main question – *How is the function of maintenance regarded in your work?*

Supporting topics.

- What motivates or counteracts recurrent maintenance operations on operator level?
- What targets are tracked? *(KPI's and goals, what is supposed to be achieved, and how are the interpreted?)*
    - How are these communicated?

Economy, production and maintenance.

Main question – *How is the function of maintenance regarded in your work?*

Supporting topics.

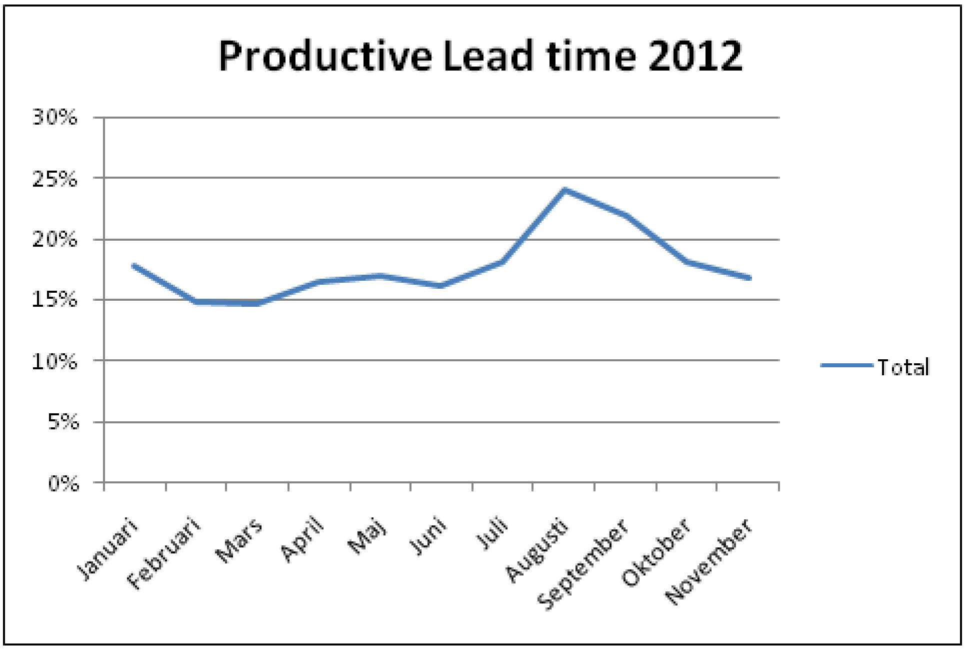
- Stakeholders for cost/budget of production and maintenance.
- What are the heaviest arguments for preventive maintenance on corporate level and how well is this in line with daily tasks in production?
- What targets are tracked? *(KPI's and goals, what is supposed to be achieved, and how are the interpreted?)*
    - How are these communicated?

Appendix III – V2500 Statistics

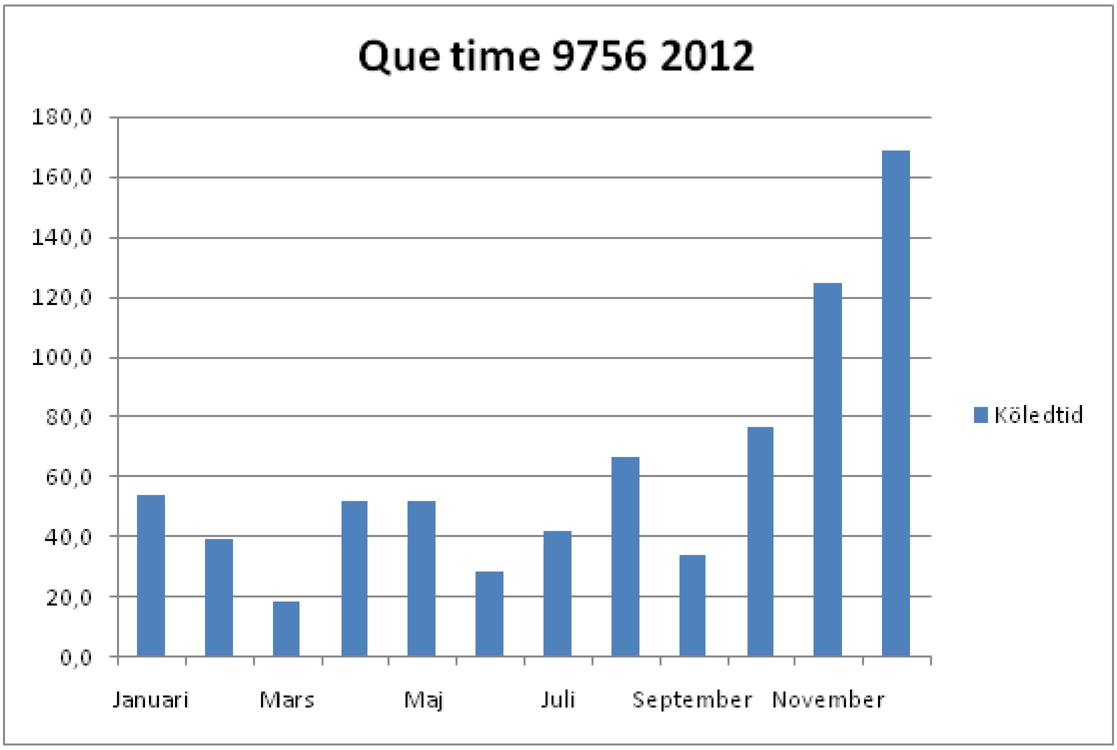
This appendix is a summary of production statistics collected during the study together with data from an internal report that presents production data from the V2500 of2012. Total operation list, machining operations and the particular equipments productivity factor and technical availability. The products that go through this set of equipment is regarded as a high volume product and of great importance to improve.

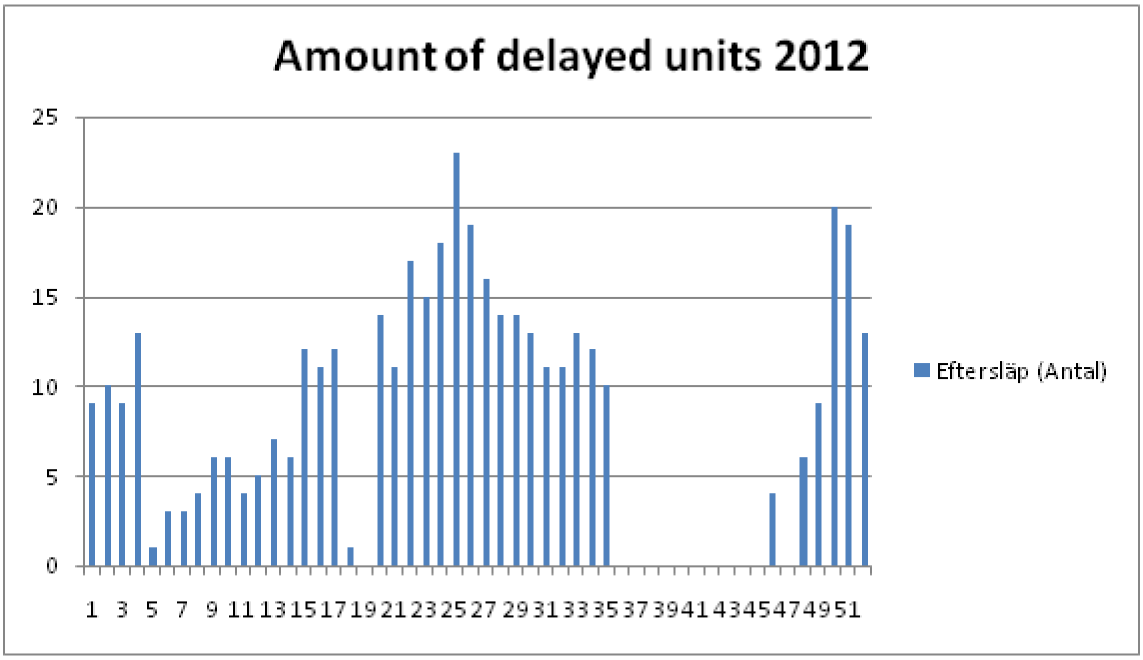
WC		Wait	Setup	Process
8773	11475-09 (WC 8773)	8	1	6
8771	11264-13 (WC 8771)	18	1	12
8770	11264-12 (WC 8770)	6	1	15
8784	15206-16 (WC 8784)	24	1	10
9756	16209-03 (WC 9756)	60	0	10,5

This table is containing the times that is used for capacity planning for process and setup time.

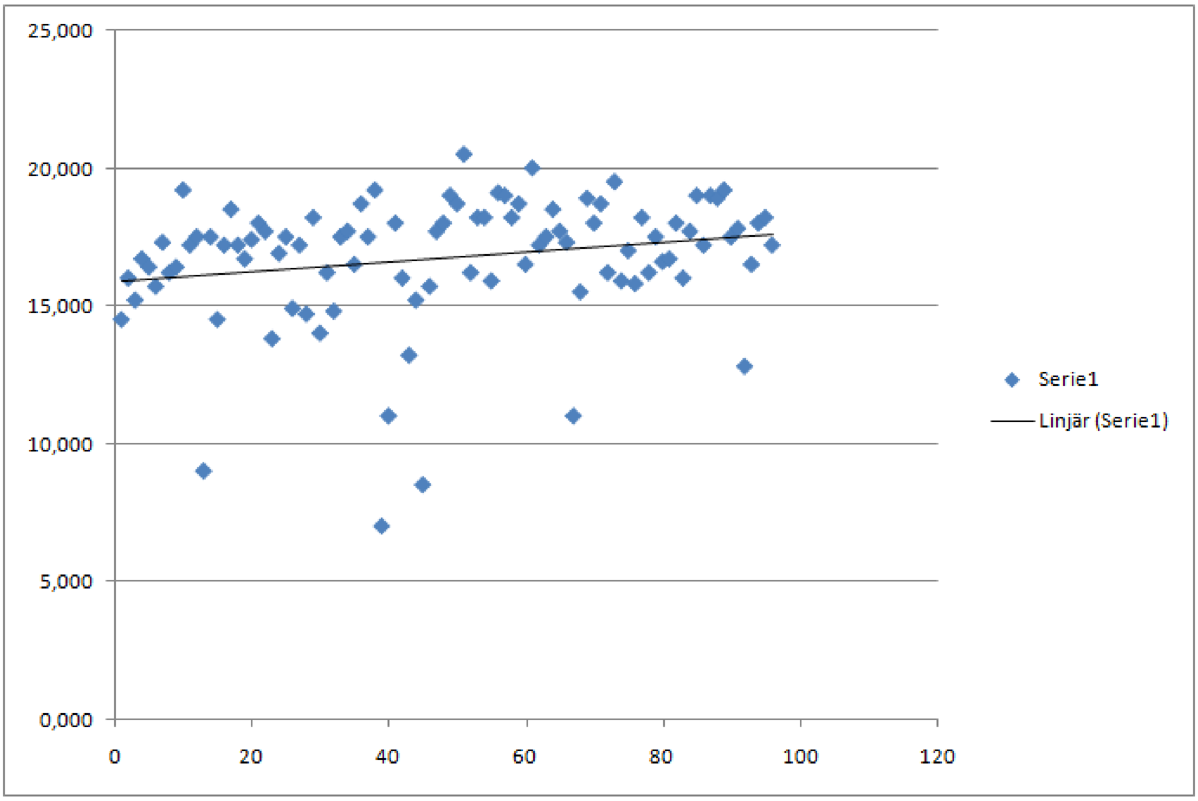


Value adding time during 2012





Amount of delayed units according to plan during 2012, weel 46-48 there was a stop in 9756 where the ques clearly builds up after being in pace from week 35 to 45.



Show that instability is present in critical operation 400, target is 15h but varying between 15-20h.