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FORMULATION OF MAINTENANCE STRATEGIES

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ABSTRACT

In industry, there is a constant demand for increased productivity in order to stay competitive. Still, Swedish industry has an average utilization of about 60% in its production systems. One important factor for increasing the equipment utilization is effective maintenance of production assets.

Within process industry, a strategic view of maintenance activities is common, and most companies regard maintenance as a profit center. Meanwhile, the discrete units manufacturing industry still in many cases views maintenance as a cost driver. However, with the spread of Toyota-inspired production concepts, the manufacturing industry is beginning to view maintenance as a strategic asset. Still, though, many companies have no formulated maintenance strategy.

The main purpose of the research, presented in this thesis, has been to develop a work-process for the formulation of effective maintenance strategies for enterprises in the manufacturing industry.

Through one descriptive and two prescriptive case studies, a work-process for the formulation of maintenance strategies has been developed. The descriptive study revealed some of the differences between companies with and without maintenance strategies. It also showed how some companies view the strategic contributions of maintenance. The first prescriptive study showed how stakeholder involvement may contribute to the identification of relevant performance measures for the maintenance activities. Stakeholder involvement also contributes to the organizational acceptance of the maintenance strategy. Finally, the second prescriptive case study led to the development of a work-process for the formulation of maintenance strategies. The work-process was tested and verified in three companies, handling different challenges for their maintenance activities. All three companies intend to use the formulated maintenance strategy as a road map for the development of their production maintenance.

SAMMANFATTNING

Det finns ett stort tryck på industrin att höja sin produktivitet idag. Trots detta är den genomsnittliga utnyttjandegraden av svenska produktionssystem cirka 60%. En av de viktigare faktorerna för att höja utnyttjandegraden är effektivt underhåll av produktionsutrustning.

Inom processindustrin är det vanligt att betrakta underhåll som en strategisk aktivitet och en vinstdrivande faktor. Traditionell stycketillverkande tillverkningsindustri däremot, betraktar fortfarande allt för ofta underhållet som en ren kostnadsdrivare. Med framväxten av nya Toyota-inspirerade produktionssätt håller dock tillverkningsindustrin på att ändra synen på underhåll till en mer strategisk tillgång. Trots detta har ändock en stor andel tillverkningsföretag inte någon formulerad underhållsstrategi.

Syftet med forskningen, presenterad i denna licentiatuppsats, har varit att utveckla en arbetsprocess för formulering av effektiva underhållsstrategier i tillverkningsindustrin.

Genom en deskriptiv och två preskriptiva fallstudier har en arbetsprocess utvecklats. Den deskriptiva studien påvisade några skillnader mellan företag med, respektive utan underhållsstrategier. Vidare beskrevs hur några olika tillverkningsföretag såg på underhållets bidrag till företagens strategiska målsättningar. Den första preskriptiva studien visade hur företag genom samverkan mellan underhållsverksamhetens intressenter kan identifiera bra strategiska nyckeltal för uppföljning av underhållet. Denna samverkan skapar dessutom högre acceptans för den formulerade underhållsstrategin. Den andra preskriptiva studien utgjordes av utvecklingen av arbetsprocessen för formulering av underhållsstrategier. Processen tar sin början i företagets överordnade strategier och beaktar produktionens strategiska målsättningar. Vidare beaktar den ett antal identifierat viktiga faktorer och dess inverkan på företagets underhållsverksamheter. Den utvecklade processen har testats och verifierats i tre företag med olika förutsättningar och utmaningar. Alla tre företagen kommer att använda den framtagna underhållsstrategin som bas för utvecklingen av produktionsunderhållet.

ACKNOWLEDGEMENTS

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Lastly, I send all of my love to my family and friends for their love, friendship, and support.

PUBLICATIONS

LIST OF INCLUDED PUBLICATIONS

Paper I Salonen, A., *Maintenance Strategy – An Enabler for Improved Competitiveness*, in the proceedings of 18th International Conference of Flexible Automation & Intelligent Manufacturing – FAIM 2008, Skövde, Sweden.

Paper II Salonen, A., *Strategic Factors for Maintenance in Manufacturing Industry*, in the proceedings of 21st International Congress and Exhibition COMADEM – 2008: Prague, The Czech Republic.

Paper III Salonen, A. and Bengtsson, M., *Identification of Maintenance Performance Indicators through Stakeholder Involvement*, in the proceedings of Swedish Production Symposium SPS 2008, Stockholm, Sweden.

Paper IV Salonen, A., *A Work-process for the Formulation of Maintenance Strategies*, Submitted to Journal of Quality in Maintenance Engineering.

ADDITIONAL PUBLICATIONS

Salonen, A., *The Importance of Maintenance Strategies when Making Correct Sourcing Decisions*, in the 20th International Congress and Exhibition COMADEM – 2007, Faro, Portugal.

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CHAPTER 1

INTRODUCTION AND POSITIONING

This chapter is intended to give the reader an understanding of why this thesis has been written, why this research is relevant, both to industry and academia. Also the chapter presents the objectives and expected results of the conducted research.

Background

With the competitive market of today, industry is forced to continuously increase its production efficiency. One important aspect of this is to optimize the maintenance of production equipment. Kelly expresses optimum maintenance as the ability: "*...to achieve the agreed plant operating pattern, availability and product quality within the accepted plant condition (for longevity) and safety standards, and at minimum resource cost.*" (Kelly, 2006, p.26). However, optimum maintenance comes at a price. Bevilacqua and Braglia (2000) state that the maintenance department costs can represent from 15% to as much as 70% of the total production cost.

According to Ahlmann (2002), the total cost of maintenance in Sweden constitutes 6.2% of the industry's turnover, which is close to 200 billion SEK per year. However, Wireman (1990) means that as much as one third of the maintenance cost is unnecessarily spent due to bad planning, overtime costs, bad use of preventive maintenance, and so on. Ahlmann (2002) showed in a study that the mean overall operational effectiveness in Swedish industry is about 60%. Another study showed an average Overall Equipment Effectiveness (OEE) level of 66%, although the results showed a rather high variation between the studied companies (Kinnander & Almström, 2006). Ljungberg (1998) presents a study of 23 machinery systems that have an average OEE of 55%. A similar study of 10 companies is presented by Ericsson (1997), indicating that only 59% of the production time was actually used for production. Of the remaining unproductive time, 39% was used for maintenance-related activities. Failures in production systems may cause high losses, e.g. lost production time or volume, negative impact on the environment, lost customers, warranty payments, etc. (Todinov, 2006). This clearly

shows how important well-structured production maintenance is for a manufacturing company.

Still, within manufacturing industry, maintenance is often regarded as a cost driving necessity rather than a competitive resource. According to a survey performed by Alsyouf (2004), 70% of the respondents considered maintenance a cost centre. Jonsson (1997) suggests that one reason for the lack of interest for maintenance among management might be that visible connections between maintenance activities and profitability are quite seldom put forward. The lack of visual connections may be true in the manufacturing organizations, but recent research has showed that the connections exist. For example, through the use of a survey, Swanson (2001) has shown a strong relationship between proactive and aggressive maintenance strategies and performance.

Jonsson (1997) points out the importance of goals and strategies in developing a maintenance management framework. These goals and strategies should support the corporate strategy and business drivers considered as critical success factors by the company. Maintenance strategies are coordinating and integrating when related to corporate and production strategies and maintenance knowledge. Further, management and personnel should support them. The fact that many companies have no clear goals for their maintenance activities is serious, since goals and strategies are the driving forces for increasing the maintenance effectiveness (Jonsson, 1997). As an example, Backlund and Akersten (2003) found the lack of an overarching maintenance management strategy to be one of the obstacles for the introduction of RCM in a Swedish hydropower organization. Walker states that: "*it is necessary to consider maintenance as a company issue and not a maintenance issue because maintenance should not be something to consider in isolation.*" (Walker, 2005, p.52). Furthermore, Walker argues that when maintenance is taken seriously at Board room level and seen as a key business driver, the profitability of the company will improve (Walker, 2005).

Still, quite few manufacturing companies consider maintenance to be a strategic asset. Alsyouf (2004) presents a survey in which 28% of the respondents had no maintenance strategy at all. Another survey among 284 Swedish manufacturing firms showed that only 48% of the respondents had a written maintenance strategy. Twenty-three had no maintenance strategy at all (Jonsson, 1997). Also, Johnson notes that many of the respondents considered ISO 9001 a maintenance strategy, which indicates that the true proportion of companies with full maintenance strategies is less than 48% (Jonsson, 1997). Furthermore, it is not evident that maintenance strategies among those firms that do have a strategy are clearly linked to business strategies.

Problem Statement

Maintenance strategies are not widely used in manufacturing industry today. Moreover, there does not seem to be any clear picture of what areas of focus/content a maintenance strategy could or should have. This means that in many companies, there is no obvious connection between the maintenance activities and the fulfilment of the companies' strategic goals. With this in mind, the research presented in this licentiate thesis is focused on how to formulate maintenance strategies in manufacturing organizations characterized by serial production of discrete-items.

Objective

The main objective of this licentiate thesis is to develop a work-process for the formulation of effective maintenance strategies for enterprises in the manufacturing industry.

Research Questions

In order to develop a work-process for the formulation of effective maintenance strategies, the following research questions have been formulated.

> RQ1 – What components should a maintenance strategy include?

Within current literature there is a wide variety of descriptions of what components a maintenance strategy should include. There is probably no general definition that suits every company; rather, various sets of strategic components that suits different kinds of enterprises.

> RQ2 – How should a maintenance strategy that supports the company's over-all business strategy be developed?

Many authors conclude that a maintenance strategy must support the business strategy. For example, Javidan (1998) means that the aim of functional strategies is to ensure the implementation of business strategies. Jonsson (1997) claims that if the maintenance strategy is related to corporate and production strategies, it will act as a coordinating and integrating mechanism.

> RQ3 – How may acceptance for a maintenance strategy among its stakeholders be gained?

For a maintenance strategy to be successful, it has to be accepted by all stakeholders within the organization. Management must allow the appropriate funds to be spent on

realizing the intended strategy. Also, maintenance personnel must accept the strategy in order to change their work methods in a desired way. Therefore, it is interesting to ascertain how acceptance and support for the maintenance strategy can be achieved among all stakeholders.

Delimitations

The research presented in this thesis was performed in manufacturing organizations, with serial production of discrete items, either by various types of machining and/or through assembly operations. The focus is to study strategies for the maintenance of equipment within the production system of these manufacturing organizations.

Expected Results

The research presented in this thesis intends to generate two kinds of results: scientific and industrial.

The expected scientific results mainly concern how a work-process for formulation of maintenance strategies should be structured in order to generate maintenance strategies that contribute to the overall goals of the company.

There are two expected industrial results: a structure for maintenance strategies that contributes to the competitiveness of the company and a feasible work-process for the formulation of maintenance strategies The results are intended to be useful for manufacturing companies with serial production of discrete items.

Outline of the Thesis

Chapter 2 presents the research methodology employed in the research presented in this thesis. Thereafter, the theoretical frame of references is presented in Chapter 3. Chapter 4 provides an overview of the conducted case studies. In Chapter 5, a proposed process for the formulation of maintenance strategies is then presented. Finally, the conclusions from the conducted research are presented in chapter 6.

CHAPTER 2

RESEARCH METHODOLOGY

This chapter intends to present the scientific view of the author. Further, it presents the research methodology used in the research work presented in this thesis.

The research, presented in this thesis is intended to generate results that are valid not only for academia, but also for industry. As described by Fagerström (2004), the starting point for a research process is influenced by various theoretical foundations as well as real world problems (see Figure 1). As shown in Figure 1, the researcher moves continuously between theoretical aspects and the real world during the research process. This movement is essential in order to produce results that are valid both in industry and in the scientific community.

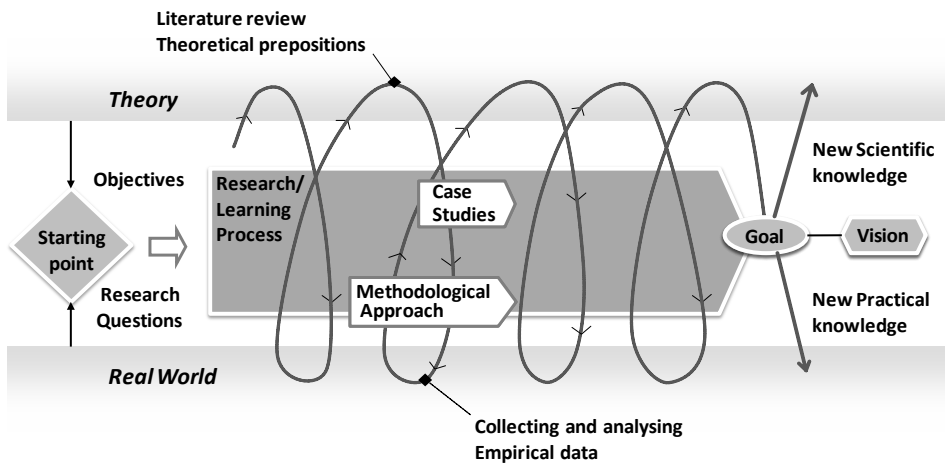

Figure 1. Schematic view of the research process, adapted from Fagerström (2004).

Research approach

Research can be conducted using various methodological approaches. The method to use depends largely on the researcher's views regarding knowledge and the nature of the research questions at hand. Lantz (1993) gives a brief overview of the differences between the positivistic and the hermeneutic view.

The positivistic view is usually associated with natural science. It aims for the universally applicable explanations. The ontological view of reality is objective. This leads the positivists to have an epistemological view that true knowledge is achievable.

In the hermeneutical view, more related to social science, explanations depend on time, culture, and individuals. Therefore, the ontological view of reality is subjective. The epistemological view among hermeneutics is that there is no true knowledge.

The performed research deals with companies in different contexts regarding culture, size, competition, and the like. Since these contexts differ from each other and vary over time, the author tends to apply a more hermeneutic view rather than a positivistic view.

Arbnor and Bjerke (1994) distinguish between three different methodological approaches:

- The analytical approach presumes that reality is objective. The aim to explain causal relations on isolated phenomena.
- The systems approach presumes that the reality is objectively achievable. The aim to find final relations in complex systems in which a component can not be treated as isolated.
- The actors' approach regards reality as a social construction. The aim is to understand the relations between different actors' interpretations of the studied phenomenon.

The research performed focuses on a complex, context-dependent system in which not all relations are causal. The system is dependent on various driving forces, internal and external. Therefore, a systems approach has been applied for the research.

Arbnor and Bjerke (1994) define two methods for developing knowledge. Induction is a method where the researcher forms common laws from isolated cases. Deduction, on the other hand, aims to predict an isolated event based on common laws. The systems approach is mostly associated with induction since it is not as dependent on theories as the analytical approach. A combination of induction and deduction has been used in the research performed.

Research strategies

There are different research strategies described in literature. Yin (1994) gives the following examples: Case studies, Experiments, Surveys, Histories, and Archival analysis. According to Yin (1994), each strategy has its advantages and disadvantages, which depend on: (a) the type of research question, (b) the investigator's control over actual behavioural events, and (c) the focus on contemporary as opposed to historical phenomena. As a guideline, Yin (1994) proposes the following approach:

- Experiments are best suited for "how" and "why" questions, focusing on contemporary events in controlled environments.
- Surveys are adequate for "who", "what", "where", "how many", and "how much" questions focusing on contemporary events.
- Archival analysis is suitable for "who", "what", "where", "how many", and "how much" questions for both contemporary and historic events.
- History is best suited for "how" and "why" questions, focusing on historic events.
- Case studies are suitable for "how" and "why" questions, focusing on contemporary events.

However, Yin (1994) points out that "what" questions of exploratory nature may be studied with any of the mentioned strategies. Also, Yin (1994) means that case studies have a distinct advantage when attempting to answer "how" or "why" questions about contemporary events, over which the investigator has little or no control. These descriptions fit the research questions of this thesis very well; therefore, case studies have been the chosen strategy.

Data collection

Yin (1994) presents six data sources for case studies: documents, archival records, interviews, direct observation, participant-observation, and physical artefacts. The empirical data collected in the case studies and presented in this thesis has been collected through documents, interviews, direct observations and participant observations. A "state of the art"-study has also been performed.

Documents

Yin (1994) finds that documents play an explicit role in any case study. When using documents in research, it is of importance to verify that the documents used are relevant to aspects of revisions, dates, and the like, and that they describe the reality of the intended phenomena. In the research performed, different documents such as maintenance strategies, OEE-charts, maintenance organisation charts, and others have been studied. Relevant documents provide reliable data on the formal structures and real outcomes of the system.

Interviews

According to Yin (1994), interviews are one of the most important data sources when conducting case studies. When studying a system that depends on human opinions and their resulting decisions, interviews of key people within the model is a valuable data base. Lantz (1993) finds that there are four major types of interviews: the structured; the semi-structured; the directed open; and the open interview. The first two forms are more suitable for collecting objective data (and are therefore associated with positivistic views). The latter two are more related to subjective data, and are therefore associated with the hermeneutic view. The performed interviews have mainly been directed open, but semi-structured questions do occur. For the most part, the respondents have been maintenance managers, productions managers, and maintenance technicians.

Direct observations

Observations may be conducted casual or formal (Yin, 1994). According to Merriam (1988), Kidder (1981) claims that for observations to be scientific, the following criteria have to be fulfilled: (a) fulfilling a scientific aim, (b) planned, (c) systematically registered, and (d) controlled with respect to validity and reliability. By observing the studied system, the researcher may verify or dismiss data obtained through other sources (for example, interviews and documents). The direct observations have mainly been performed by observing the status of the workshops at the studied companies. Also, when possible, observations of maintenance-related meetings have been observed regarding perceived culture within the maintenance staff and management. Notes have been taken during and after each visit to the case companies.

Participant observations

In the later stages of this research, participant observations have been performed by the author and researcher. A proposed method for the formulation of maintenance strategies has been tested in the participating companies. This test has been conducted with the researcher participating in a project group in each company. The project groups have formulated and evaluated a maintenance strategy based on the researcher's previous findings during the early case studies. By participating, the researcher has become a part of the studied system, which provides data otherwise hard to obtain (Yin, 1994).

Literature studies

In order to obtain a picture of the state of the art within the chosen research area, a literature study has been performed. The topics of the literature include maintenance management, maintenance strategies, and general management and strategy theories. The studied literature sources have been books and academic papers published in conference proceedings and journals.

Data analysis

In order to draw conclusions from the collected data, it has to be analyzed. There are many approaches for this described in literature. The following have been used in the research described in this thesis.

Pattern-matching logic is one of the better analysis methods for case studies (Yin, 1994). This technique is essentially about comparing empirically observed patterns with predicted ones.

To search for the probable, is another method for analysis (Merriam, 1994). This is an intuitive approach in which the researcher focuses on the conclusions that seem plausible and logical.

Clustering is a method in which the researcher groups similar data in specific categories (Merriam, 1994). An understanding of a phenomenon is developed, first by grouping and later by conceptualizing things that show similar patterns or characteristics.

All techniques mentioned for data analysis are to some extent dependent on the pre-understanding of the researcher. The author of this thesis has 12 years of experience working with production maintenance and maintenance development.

The Research Process

The research, presented in this thesis can be defined as design research. The aim of the research is to propose a work-process for the formulation of a maintenance strategy, which in this case may be regarded as the product. For design research, Blessing and Chakrabati (2007) propose a research methodology that aims at linking research questions and addressing them in a systematic way. It follows below, in Figure 2.

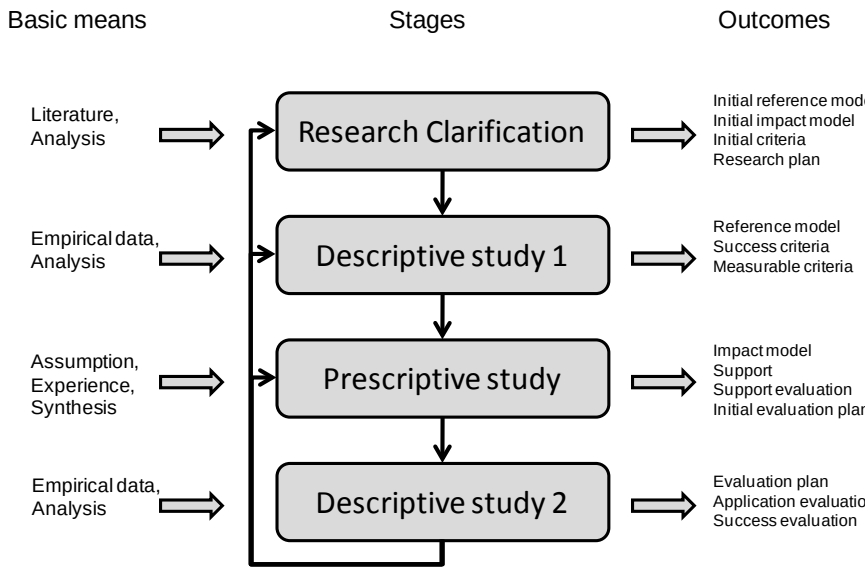

Figure 2: Design research methodology (DRM) framework: stages, basic means, and outcomes (Blessing & Chakrabati, 2007).

In relation to Blessing and Chakrabati's (2007) proposed model for the design research process, described in Figure 2, the performed case studies and research questions may be mapped as shown in Figure 3.

To clarify the scope of the performed research, a literature review has been performed. It establishes how different authors define maintenance strategy and what components such a strategy should contain.

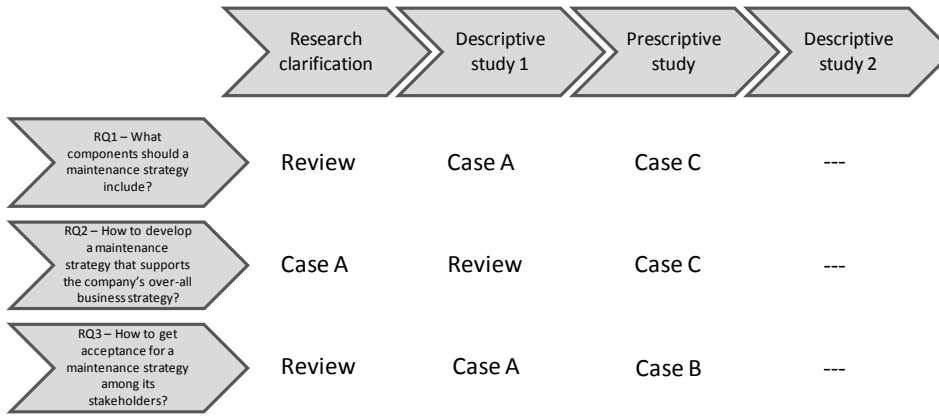

Figure 3: Design research methodology in relation to research questions and cases.

In an embedded single case study, Case A, data has been collected through structured open interviews, semi-structured interviews and observations. This was done in order to describe the current state and view of maintenance and maintenance strategy in various companies, selected to represent different sizes and status in industry. This is an inductive approach in which the collected data through analysis is used to form a view of the status of the maintenance in the reference and target companies.

A work-process for the maintenance strategy formulation has been prescribed and studied in a deductive approach by comparing and combining the findings from Case A and the literature review. The work-process has been tested and verified, partly in case study B and fully in case study C. In the latter, maintenance strategies were formulated in three different companies.

The Quality of the Research

A common approach to evaluating the quality of performed research is to regard validity and reliability. Arbnor and Bjerke (1994) discuss three different types of validity:

- Face validity means to evaluate the plausibility of the research results.
- Internal validity refers to the logical connections between a study and the existing theories within the field.
- External validity describes the extent to which the obtained results may be applied outside the research area.

For the systems approach, Arbnor and Bjerke (1994) find that definitions do not have to concur with existing theories or be operational. It is more important that they are perceived as substantial and correct by the researcher as well as other participants in the real system.

To strengthen the validity of the research, observation notes were taken during visits to the production and maintenance departments of the companies. Also, documentation relating to maintenance strategies and maintenance sourcing was collected and used in the analysis. The use of various methods for data collection makes it possible to triangulate, thereby strengthening the internal validity of the research (Merriam, 1994). A pattern matching logic was used in order to analyze the collected data. Matching an empirically-based pattern with a predicted one may further strengthen the validity of the findings (Yin, 1994). Also, searching for the probable was used for analysis of the collected data. This approach is of course influenced by the experiences of the researcher; however this does not necessarily have to be of a negative nature. In case study A, clustering was used for analyzing the interviews. The combination of these methods further strengthens the validity of the performed research.

Reliability refers to the repeatability with which a study measures the intended phenomena. The systems approach is not very quantitatively oriented; hence, the measurements are not very precise (Arbnor and Bjerke, 1994). Therefore, reliability may be hard to estimate when applying a systems perspective. However, given that the same questionnaire was used with the same respondents, it is plausible that similar results would be achieved.

CHAPTER 3

FRAME OF REFERENCES

This chapter presents the theoretical frame of references on which this thesis rests. As a starting point for the research, a literature review was conducted. Mainly, maintenance-related literature was studied. Literature on strategy in general was also examined and theories relating to functional strategies and formulation of such strategies as well.

In addition to relevant books, scientific articles were also reviewed in the study. The articles were found through searches on the Internet, mainly by using the Mälardalen University library database collections. The search engine, primarily used for this study, was ELIN@mälardalen which simultaneously searches several databases[1]. Finally, some articles were found in proceedings from conferences attended by the author.

Maintenance

Swedish standard, SS-EN 13306, defines the term maintenance as a "*Combination of all technical, administrative and managerial actions during the life cycle of an item intended to retain it in, or restore it to, a state in which it can perform the required function*". Industrial maintenance supports the production process in which input, in form of material and manpower, for example, is transformed into output (i.e. finished products) (Gits, 1994). Maintenance is a secondary process that contributes to the achievement of production (see Figure 4).

[1] ABI/Inform, ACS, Blackwell Synergy, EBSCO, Emerald, IEEE Xplore, JSTOR, MUSE, Oxford University Press, Sage Premier, Science Direct, Springer LINK, Wiley Interscience

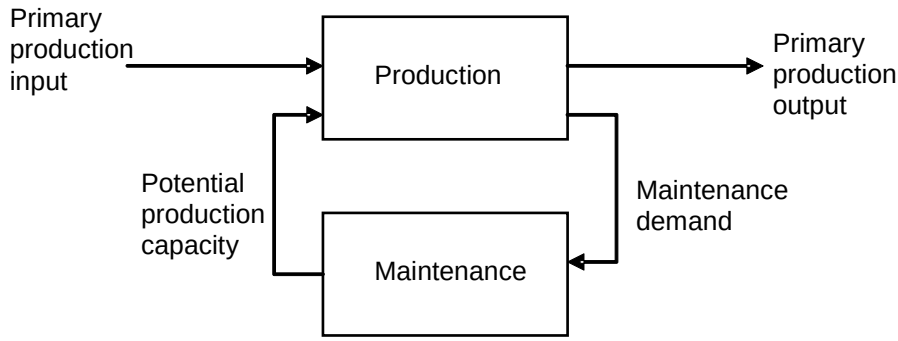

Figure 4: The relation between Production and Maintenance (Gits, 1994). Maintenance demand is a secondary output from the production equipment, while maintenance results in potential production capacity as a secondary input to the equipment.

Simeu-Abazi and Sassine state that "*The main purpose of maintenance engineering is to reduce the adverse effects of breakdown and to increase the availability at a lower cost, in order to increase performance and improve the dependability level*" (Simeu-Abazi and Sassine, 2001, p.268).

However, the demand for good maintenance performance has increased heavily. According to Tsang (2002), the reasons for this development are the following:

- *Emerging trends of operating strategies*. Lean manufacturing, Just-In-Time production, and Six Sigma programs make production systems more vulnerable for disturbances.
- *Toughening societal expectations*. Increased awareness of environmental issues as well as of people's safety and health increases the demand of stable processes.
- *Technological changes*. Non-destructive testing and various techniques for condition monitoring create new opportunities for maintenance optimization.

Maintenance types

A common overview of maintenance types and their relations is illustrated in the standard SS-EN 13306 (see Figure 5).

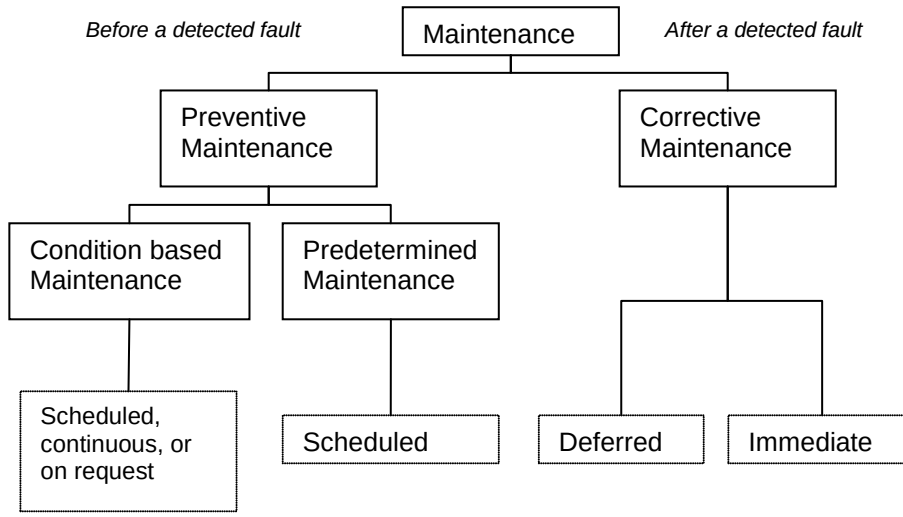

Figure 5: Overview of different maintenance types (SS-EN 13306, 2001).

As indicated in Figure 5, maintenance is divided in two main categories, preventive and corrective. Preventive maintenance is further divided into two main categories: Predetermined (periodic) maintenance and Condition based maintenance.

Corrective maintenance

One definition for Corrective maintenance is: "*Maintenance carried out after fault recognition and intended to put an item into a state in which it can perform a required function.*" (SS-EN 13306, 2001, p.15). In other words, Corrective maintenance is essentially the repair of broken equipment. This approach is of course costly. The total cost for a breakdown or other unplanned outage of equipment includes the following (Wireman, 1990):

- Operator time loss
    - Time to report failure
    - Time for maintenance to arrive
    - Time for maintenance to make repairs
    - Time required to start equipment
- Cost of repairing or replacing the failed part or component
- Maintenance costs

    - Time to get to the equipment
    - Time to repair the equipment
    - Time to get back to dispatch area
- Lost production or sales costs or both
- Cost of scrap due to maintenance action

Starr (1997) means that corrective maintenance is only suited for non-critical areas with low capital costs, slight consequences of failures, no safety risk, the quick identification of failures, and fast repairs.

Preventive maintenance

One definition of Preventive maintenance is: "*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.*" (SS-EN 13306, 2001, p.14). Another, similar definition is given by Wireman (1990, p.98), who defines preventive maintenance as *"...any planned maintenance activity that is designed to improve equipment life and avoid any unplanned maintenance activity."*

According to Wireman (1990), the following types of preventive maintenance may serve as a progressive method of implementing a comprehensive preventive maintenance program:

- Routine – lubrication, cleaning, inspections, etc; aims to take care of small problems before they cause equipment failures.
- Proactive replacements; replacement of deteriorating or defective components before they can fail.
- Scheduled refurbishing; during a shutdown or outage, all known or suspected defective components are replaced.
- Predictive maintenance; an advanced form of routine inspections, using technologies like vibration analysis, and spectrographic oil analysis.
- Condition-based maintenance; maintenance based on "real-time" inspections through sensors installed on the equipment.
- Reliability engineering; design engineering studies performed to discover possible modifications of the equipment to prevent failures from occurring.

Wireman (1990) argues that preventive maintenance increases maintenance personnel costs as well as repair parts costs while, on the other hand, it decreases the costs for scrap/quality, downtime, and lost sales. The following reasons make preventive maintenance important (Wireman, 1990):

- Increased automation
- Just-in-time manufacturing
- Business loss due to production delays
- Reduction of equipment redundancies
- Reduction of insurance inventories
- Cell dependencies
- Longer equipment life
- Minimize energy consumption
- Produce higher quality product
- Need for more organized, planned environment

For starting a preventive maintenance program, Wireman (1990) proposes the following steps:

1. Determine critical units.
2. Classify units into types of components.
3. Determine preventive maintenance procedures for each type of component.
4. Develop detailed job plan for each of the procedures.
5. Determine schedules for each of the preventive maintenance tasks.

Also, Wireman states that "*No preventive maintenance program will be truly successful without strong support from upper management of the plant or facility*." (Wireman, 1990, p.102)

Condition Based Maintenance

One definition for Condition based maintenance is: "*Preventive maintenance based on performance and/or parameter monitoring and the subsequent actions.*" (SS-EN 13306, 2001, p.15). The idea behind CBM is to assess the condition of technical systems and/or components by monitoring its condition, and perform maintenance only when potential failures are predictable. For condition monitoring, techniques like vibration analysis and oil analysis are used. Figure 6 shows an example of the interval between detectable potential failures and real failure on a ball bearing.

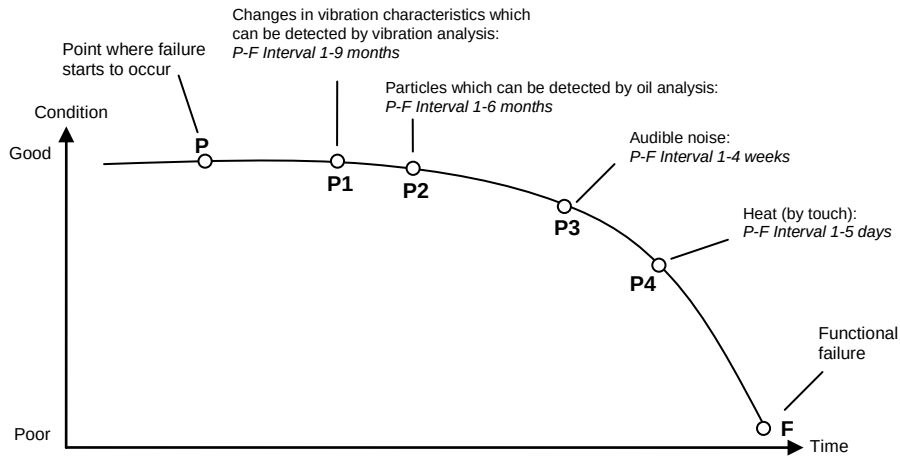

Figure 6: The potential failure to failure curve of a ball bearing (Moubray, 1997).

Maintenance concepts

In order to increase the effectiveness of maintenance and to focus the maintenance activities various concepts have been developed, e.g. Reliability centered maintenance (RCM), Total Productive Maintenance (TPM), Tero technology, Lean maintenance, and Value Driven Maintenance (VDM). Below, the ideas behind RCM and TPM, (the two most common of these concepts) are briefly described.

RCM

Reliability Centered Maintenance, (RCM), is a maintenance concept developed in the aviation industry. Moubray defines RCM as *"…a process used to determine what must be done to ensure that any physical asset continues to do what its user want it to do in its present operating context"* (Moubray, 1997, p.7). RCM is applied by asking seven basic questions about the asset or system reviewed:

- What are the functions and associated performance standards of the asset in its present operating context?
- In what way does it fail to fulfill its functions?
- What causes each functional failure?
- What happens when each failure occurs?
- In what way does each failure matter?
- What can be done to predict or prevent each failure?
- What should be done if a suitable proactive task cannot be found?

TPM

Total Productive Maintenance, TPM, is a Japanese concept for maintenance, developed from the American concept Preventive Maintenance. According to Nakajima (1988), TPM may be defined as "*productive maintenance involving total participation*" (Nakajima, 1988, p.10). Further, Nakajima gives five elements for the TPM definition:

1. TPM aims to maximize equipment effectiveness (over-all effectiveness).
2. TPM establishes a thorough system of PM for the equipment's entire life span.
3. TPM is implemented by various departments (engineering, operations, and maintenance).
4. TPM involves every single employee, from top management to workers on the floor.
5. TPM is based on the promotion of PM through motivation management: autonomous small group activities.

Maintenance management

Kelly gives the following generic expression for the maintenance objective: *"...to achieve the agreed plant operating pattern, availability and product quality within the accepted plant condition (for longevity) and safety standards, and at minimum resource cost."* (Kelly, 2006, p.26)

Crespo Marquez and Gupta (2006) claim that maintenance management must align with business activities at strategic, tactical, and operational levels (see Figure 7).

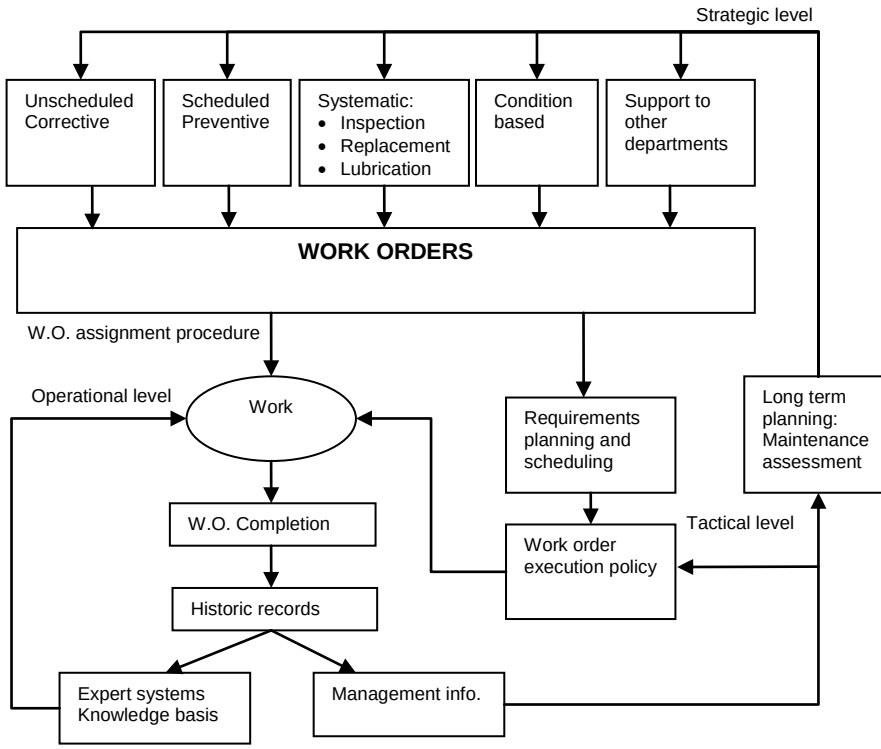

Figure 7: Maintenance process (Crespo Marquez and Gupta, 2006).

According to Crespo Marquez and Gupta (2006), business priorities are transformed into maintenance priorities at the strategic level. This is achieved by establishing critical targets in current operations, and will result in a generic maintenance plan. At a tactical level, actions are performed to determine the sufficient amount of maintenance resources (skills, equipment, etc.) necessary to fulfil the maintenance plan. This will result in a detailed maintenance program with scheduled assignments of the sufficient resources for each asset. Actions at operational level are performed to ensure that the correct tasks are performed in accordance with a schedule, following the proper procedures, by skilled technicians using the proper tools.

Coetzee (1999) proposes another model for explaining the inner processes of a typical maintenance system (see Figure 8).

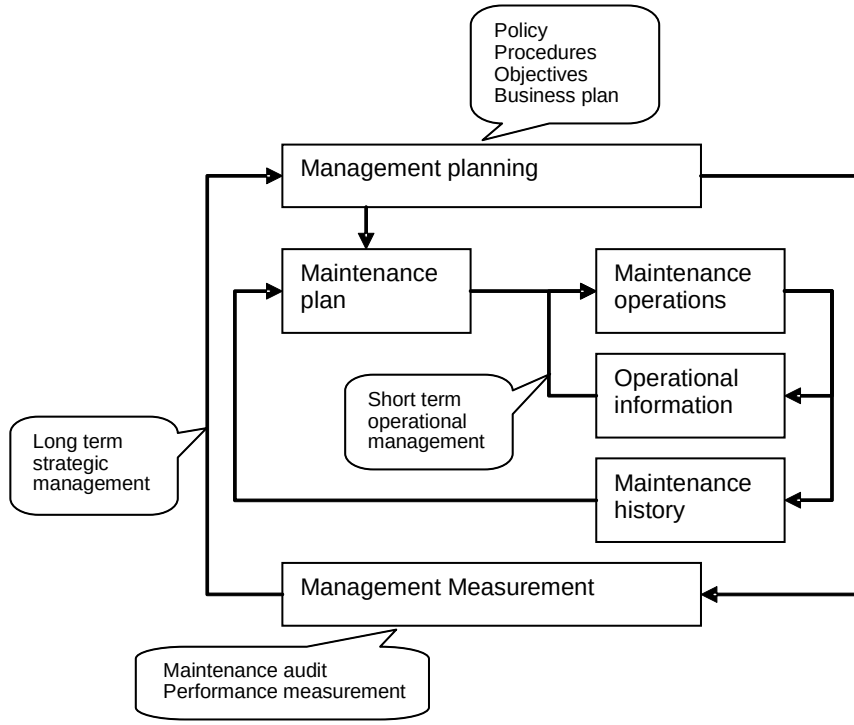

Figure 8: The maintenance cycle (Coetzee, 1999).

The model consists of two cycles. The outer cycle describes the process of overall managerial planning and measurements, used by management in order to lead and control the maintenance organization (Coetzee, 1999). The managerial planning consists of maintenance policy setting, maintenance procedure definition, objective setting and business planning. Objectives and business plans are set regularly (according to Coetzee, 1999, typically annually). Measurements consist of regular maintenance audits as well as performance measurements. The audits are performed to assess how well the operational processes fulfill the goals determined in the maintenance policy and procedures. Maintenance performance measures are used to direct the organization when necessary.

The inner cycle of the model consists of the maintenance plan and the maintenance operation (Coetzee, 1999). Based on failure history and experience, a maintenance plan is set. The plan is then implemented through maintenance operations. Information regarding the results is fed back to the operational management for corrective actions to be made when necessary.

Performance measurements

Neely *et al.* (1995) give the three following definitions, relating to performance measurements:

- Performance measurement can be defined as the process of quantifying the efficiency and effectiveness of action.
- A performance measure can be defined as a metric used to quantify the efficiency and/or effectiveness of an action.
- A performance measurement system can be defined as a set of metrics used to quantify both the efficiency and the effectiveness of actions.

Wisner and Fawcett (1991) point out the following properties for performance criteria in order to be capable of guiding a company into realizing its strategic objectives. They have to be; flexible, easy to implement, timely, clearly defined at all management levels, and derived from the firm's strategic objectives. According to Wisner and Fawcett (1991), apart from traditional financial measures, an effective performance measurement system should contain tactical performance criteria in order to be able to assess the firm's current level of competitiveness. A set of performance criteria, consistent with its particular characteristics and strategic objectives should be developed in each functional area. Wisner and Fawcett (1991) suggest the following method for developing effective performance measurement systems:

1. Clearly define the firm's mission statement.
2. Identify the firm's strategic objectives using the mission statement as a guide (profitability, market share, quality, cost, flexibility, dependability and innovation).
3. Develop an understanding of each functional area's role in achieving the various strategic objectives.
4. For each functional area, develop global performance measures capable of defining the firm's overall competitive position to top management.
5. Communicate strategic objectives and performance goals to lower levels in the organization. Establish more specific criteria at each level.
6. Assure consistency with strategic objectives among the performance criteria used at each level.
7. Assure the compatibility of performance measures used in all functional areas.
8. Use the performance measurement system to identify competitive positions, locate problem areas, assist the firm in updating strategic objectives and making tactical decisions to achieve these objectives, and supply feedback after the decisions are implemented.

9. Periodically re-evaluate the appropriateness of the established performance measurement system in view of the current competitive environment.

According to Atkinson (1998), performance measurement on a strategic level defines the focus and scope of management accounting. A specific requirement is that the accounting practice recognises and reflects the strategic choices of the organization. Atkinson (1998) means that the process of strategic performance measurement has four steps – identifying:

1. The organization's primary objectives as established by its owners or principals,
2. The role the organization's stakeholders play as the organization pursues its primary objectives —which defines a second level of objectives which we will call secondary objectives,
3. What each stakeholder requires in exchange for undertaking its role in supporting the organization's strategy, and
4. How to measure the organization objectives and stakeholder roles.

Maintenance performance measurements

Tsang *et al*. (1999) argue that since maintenance spending constitutes a large part of the operating budget in organizations with heavy investments in machinery and equipment, tracking the performance of maintenance operations in such organizations should be a key management issue. Another reason for linking the measurements to the organization's strategy, according to Tsang, is the influence of the used performance measurements on employee behaviours (Tsang, 1998).

However, in a study performed by Tsang (Tsang *et al*. 1999), the following characteristics of the maintenance performance measurement system were shared by the studied companies:

- It is an exception rather than the norm that the maintenance organization uses a structured process to identify measures of its performance. Management is typically not aware of the part the measurement system can play in achieving the vertical alignment of goals and horizontal integration of activities across organizational units.
- The performance measures are primarily used for operational control purposes.
- The commonly used measures are financial indicators such as operational and maintenance (O&M) costs, and equipment-based or process-oriented measures such as equipment availability, labour productivity, and the number of incidents caused by in-service failures.
- Benchmarking is gaining acceptance as a methodology for evaluating performance and establishing targets by making reference to the achievements of best-in-class organizations.

Kutucuoglu *et al*. (2001) have identified the following key design features for a qualitative performance measurement system for maintenance:

- Appropriateness of the performance indicators in relation to the strategic objectives of an organization. Selection criteria: each performance measure should have an organizational goal or objective to feed back.
- Vertical alignment of performance indicators to translate the strategic objectives into different levels of hierarchy. Deployment criteria: Recognition of different hierarchies.
- Balanced view of the maintenance system.
- Integration of objective and subjective measures.
- Employee involvement.
- Cross-functional structure.

Alsyouf (2006) points out that the maintenance actions affect not only the maintenance department itself but also other parts of the organization. Therefore, Alsyouf (2006) argues, there is a need for a holistic performance measurement system that can:

- Assess the contribution of the maintenance function to the strategic business objectives.
- Identify the weaknesses and strengths of the implemented maintenance strategy.
- Establish a sound foundation for a comprehensive maintenance improvement strategy using quantitative and qualitative data.
- Re-evaluate the criteria that are employed in benchmarking maintenance practice and performance with the best practice within and outside the same branch of industry.

Examples of measures

There is a huge amount of maintenance-related performance measures described in literature. The following are intended to be used for benchmarking within European industry (EFNMS, 2002):

- I:01 Maintenance costs as a % of Plant replacement value
- I:02 Stores investment as a % of Plant replacement value
- I:03 Contractor costs as a % of Maintenance costs
- I:04 Preventive maintenance costs as a % of Maintenance costs
- I:05 Preventive maintenance man-hours as a % of Maintenance man-hours
- I:06 Maintenance costs as a % of Turnover
- I:07 Training man-hours as a % of Maintenance man-hours

- I:08 Immediate corrective maintenance man-hours as a % of Maintenance man-hours
- I:09 Planned and scheduled man-hours as a % of Maintenance man-hours
- I:10 Required operating time as a % of Total available time
- I:11 Actual operating time as a % of Required operating time
- I:12 Actual operating time / Number of immediate corrective maintenance events
- I:13 Immediate corrective maintenance time / Number of immediate corrective maintenance events.

Strategy

Mintzberg *et al*. (1999) state that there is no single definition for the term strategy. However, they choose to use the following definition in their book: *"A strategy is the pattern or plan that integrates an organization's major goals, policies and action sequences into a cohesive whole. A well-formulated strategy helps to marshal and allocate an organization's resources into a unique and viable posture based on its relative internal competencies and shortcomings, anticipated changes in the environment and contingent moves by intelligent opponents.*" (Mintzberg *et al*. 1999, p.5).

Mintzberg *et al*. (1999) describe four basic dimensions of formal strategies:

1. Effective formal strategies contain three essential elements: goals to be achieved; policies for guiding or limiting actions; and the major action sequences that accomplish the defined goals within the limit sets.
2. Effective strategies develop around a few key concepts and thrusts, which give them cohesion, balance and focus.
3. Strategy deals not only with the unpredictable but also with the unknowable.
4. All complex organizations should have a number of hierarchically related and mutually supporting strategies. These strategies must be more or less complete in themselves.

Further, Mintzberg *et al*. (1999) present the following criteria for effective strategies:

- Clear decisive objectives
- Maintaining the initiative
- Concentration
- Flexibility
- Coordinated and committed leadership
- Surprise
- Security

Hill (2000) defines four levels of strategy present within a firm's context and its environment:

- Industrial level strategy – concerns issues of an industrial sector, or reflecting the level and nature of government intervention.
- Corporate level strategy – concerns the market sectors in which a company competes and to what degree the company prioritizes its resources to each sector.
- Business level strategy – concerns the identification of the markets in which each of the businesses compete and the dimensions of competition involved.

- Functional level strategy – concerns investment and the development of the necessary capabilities in order to fulfill the business level strategy.

Porter (2004) states that competitive strategy is a combination of the goals for which the firm is striving and the means by which it tries to get there (see Figure 9).

Figure 9: The wheel of competitive strategy (Porter, 2004).

The hub of the wheel in Figure 9 contains the firm's goals. These goals are the firm's definition of how to compete and which specific objectives to focus on (Porter, 2004). The spokes of the wheel are the key operating policies, used to achieve the goals. For each spoke, statements of the key operating policies should be derived from the company's activities. These policies must radiate from and reflect the goals formulated in the hub. In addition, the spokes must be connected to each other (Porter, 2004).

Strategy formulation

When formulating a competitive strategy, Porter (2004) finds that four key factors have to be considered:

1. The company's strengths and weaknesses.
2. The personal values of the key implementers.
3. The industry opportunities and threats.
4. The broader societal expectations.

The first two factors are internal to the company, while the latter two are external.

Atkinson (1998) argues that the stakeholders of an organization have two characteristics. They affect the ability of an organization to achieve its objectives, and they also require something in return for helping the organization to achieve its objectives.

By strategic planning exercises, organization planners may evaluate the efficacy of alternative strategies (Atkinson, 1998). Each tested strategy will have its own set of costs and benefits. The organization planner chooses the strategic plan that seems best among those that are tested and meet the organization's primary objectives.

Functional strategies

As examples of functional strategies, Bowman (1998) mentions marketing strategies, manufacturing strategies, and finance strategies. Bowman (1998) means that business strategies are implemented through appropriate functional strategies. In other words, the functional strategies have to be derived from the business strategy.

A set of formal and informal contracts can be set up between the organization and its stakeholders from the chosen strategic plan (Atkinson, 1998). These contracts specify the exchange between the organization and its stakeholders needed to fulfil the primary objectives of the organization. The exchanges between the organization and the stakeholders (other than its owners) are the organization's 'secondary objectives'. The importance of the secondary objectives depends on their perceived impact on the primary objectives. Atkinson (1998) points out that the secondary objectives are important since they are the variables used by the employees to promote success. The secondary objectives act as drivers for the fulfilment of performance goals for the primary objectives.

Atkinson (1998) suggests that secondary objectives should be considered on several levels. As an example, the first level of secondary objectives might be customer satisfaction, employee satisfaction, supplier satisfaction, or community satisfaction. Since

any measure for these objectives is too aggregate to manage, they might be decomposed on a second level (for example, product quality, customer turnover, or order cycle time).

Maintenance strategy

Maintenance strategy is not well-defined in literature. Some authors define it as the choice between corrective, preventive and condition based maintenance. Others, like Gallimore and Penlesky (1988) argue that maintenance strategy is formulated through the combination of (1) reactive maintenance, (2) regularly scheduled preventative maintenance, (3) inspection, (4) backup equipment, and (5) equipment upgrades. The mix of these elements is specific to each facility, the nature of the facility or equipment to be maintained depending on the goals of the maintenance, and the work environment. Swanson (2001) distinguishes between three different types of maintenance strategies; Reactive (CM), Proactive (PM and PdM), and Aggressive (TPM).

Based on a model by Visser (1998), Tsang identifies four strategic dimensions of maintenance (Tsang, 2002):

- Service-delivery options: the choice between in-house capability and outsourced service.
- Organization of the maintenance function and the way maintenance tasks are structured.
- Maintenance methodology: the selection of maintenance policies.
- Design of the infrastructure that supports maintenance.

Crespo Marquez and Gupta (2006) state that maintenance strategies are a means to transform business priorities into maintenance priorities. By addressing current or potential gaps in maintenance performance, a generic maintenance plan will be developed.

"*Maintenance strategies are needed because plant and building performance influences quality, costs, and customer needs, and thereby has a direct input to the bottom line.*" (Wilson, 1999, p.i)

Jonsson (1997) points out the importance of goals and strategies to develop a maintenance management framework. These goals and strategies should support the corporate strategy and business drivers considered critical success factors by the company. Maintenance strategies co-ordinate and integrate when related to corporate and production strategies and maintenance knowledge. Further management and personnel should support them. The fact that many companies have no clear goals for their maintenance activities is serious, since goals and strategies are the driving forces for increasing the maintenance effectiveness (Jonsson, 1997).

Wilson (1999) stresses that it is of primary importance that the maintenance objectives and strategy align with the business goals. As such, they should reflect:

- What the customers need in terms of the business targets for plant performance, quality, production demands, cost savings, and so on.
- Whether the resources match the strategy objectives.
- What the functions capabilities, and the people involved, aspire to. Can they deliver?
- What changes the maintenance function must make and how quickly they can be implemented.

According to Wilson (1999), an asset maintenance strategy is based on a co-ordinated set of objectives and major policies of the maintenance operation. All objectives will have targets to be aimed at, resulting in hard figures for the goals to be achieved.

Pinjala *et al*. (2006) discuss the relationship between business and maintenance strategies. They define maintenance strategy as a *"...coherent, unifying and integrative pattern of decisions in different maintenance strategy elements in congruence with manufacturing, corporate and business level strategies; determines and reveals the organizational purpose; defines the nature of economic and non-economic contributions it intends to make to the organization as a whole."* (Pinjala *et al.* 2006, p.216). Like Tsang (2002), Pinjala *et al.* (2006) find that there is a set of strategic decision elements that have to be dealt with when designing maintenance strategy. However, where Tsang (2002) identifies four strategic dimensions, Pinjala et al. (2006) suggest ten decision elements. They are as follows:

Structural decision elements:

- Maintenance capacity
- Maintenance facilities
- Maintenance technology
- Vertical integration

Infrastructure decision elements

- Maintenance organization
- Maintenance policy and concepts
- Maintenance planning and control systems
- Human resources
- Maintenance modifications
- Maintenance performance measurements and reward systems

In their paper, Pinjala et al. (2006) show indications of a relationship between business and maintenance strategies.

Formulation of maintenance strategies

Kelly (2006) argues that the ways in which the maintenance function might be affected by its dynamic relationship with the production need to be clearly understood. When this understanding is achieved, the maintenance objective can be established. Since the maintenance and production objectives are inseparable, the maintenance objective has to be set in conjunction with the production department. As illustrated in Figure 10, Kelly (2006) states that both the maintenance objective and the production objective need to be compatible with the corporate objectives, associated with the maximization of long term profitability.

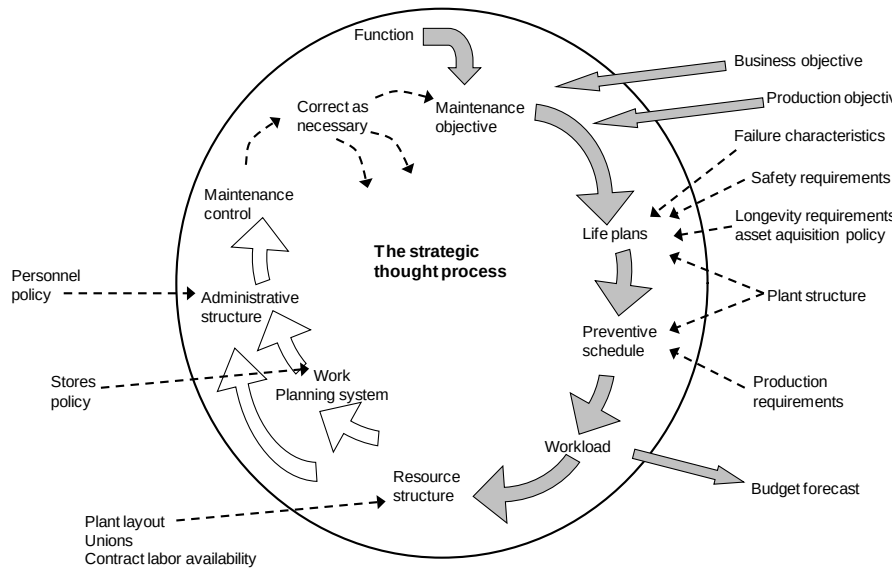

Figure 10: A Business-centered maintenance methodology (Kelly, 2006).

According to Kelly (2006), a maintenance strategy involves the identification, resourcing, and execution of repair, replace and inspect decisions. It is concerned with:

- Formulating the best life plan for each unit.
- Formulating a maintenance schedule for the plant.
- Establishing the organization to enable the scheduled and unscheduled maintenance work to be resourced.

The maintenance objective serves as a starting point when formulating a maintenance strategy (see Figure 11). Kelly (2006) argues that while theoretically the objective might be to achieve an optimum balance between the allocation of maintenance resources and the achievement of plant outputs, the formulation is more complex than this in reality. It usually starts with negotiations between the maintenance department and users, owners, and safety departments. Then a strategy may be formulated in order to achieve the specified requirements at minimum cost. This process, Kelly (2006) states, provides the basis for maintenance budgeting and cost control.

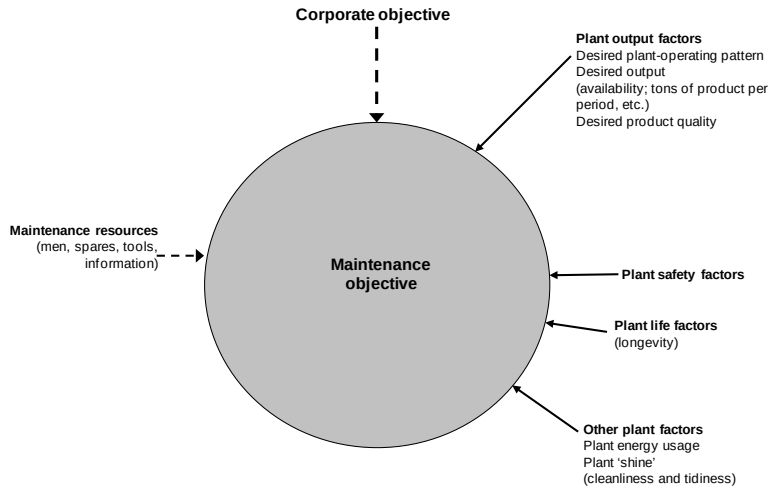

Figure 11: Factors influencing maintenance objective setting (Kelly, 2006).

Conclusions from the theoretical review

The theoretical review led to some important conclusions for the following research. One is that the term maintenance strategy lacks a unanimous definition among researchers. Also, although there are a number of strategic approaches suggested in literature, few descriptions of how to formulate a maintenance strategy that supports the overall company goals exist. Further, in the cases where formulation processes are suggested, they are quite complex and resource demanding, indicating that the processes are mainly developed for large organizations.

CHAPTER 4

EMPIRICAL STUDIES

This chapter presents the conducted case studies on which this thesis is based. Each case is described in terms of objectives, methodologies, findings, and conclusions.

Case A: The industry's view on maintenance strategy

Case A is mainly based on an interview study in which respondents from six manufacturing companies were interviewed in relation to their view on maintenance strategy.

Case study objective

The objective with this study was mainly to compare what current research says on maintenance strategy with the industry's view on the subject. Also, the study was designed to include a comparison between companies with high standards of maintenance and companies with self-proclaimed lower levels of standards.

Methodology

The case study was performed as an embedded, single case design (Yin, 1994). It involved six companies, selected to get a broad diversity in company size as well as maintenance excellence. The study was conducted through semi-structured interviews with people responsible for maintenance at each company. The interviews, each taking between one and two hours, were conducted in secluded environments at the companies, and between one and three respondents were interviewed at each company. The questions were divided into domains relating to maintenance organization, maintenance strategy, management and control of maintenance, and sourcing of maintenance.

To strengthen the validity of the study, observation notes were taken during visits to the companies' production and maintenance departments. Also, documentation relating to maintenance strategies and maintenance sourcing was collected and used in the analysis.

Findings

The findings from this case were diverse. One major finding involved which factors the respondents considered to be strategically important for their maintenance activities. Another finding was how the perceived status of the maintenance activities coincided with the use of strategies and performance measures in the participating companies.

Strategic factors

In total, 16 factors were identified by the respondents in the interviews. Of these, seven were considered important by all six respondents (see Table 1).

Table 1: Factors, considered strategically important (Appended Paper II).

	Company					
Factor	**A**	**B**	**C**	**D**	**E**	**F**
Sourcing	X	X	X	X	X	X
Maintenance organization		X	X	X	X	X
Control/Information systems				X		
Policies	X	X	X	X	X	X
Concepts		X	X	X	X	
Technology level		X	X		X	X
Financial considerations	X	X	X	X	X	X
Workforce size	X	X	X	X		X
Workforce availability	X	X	X	X		X
Technological skills	X	X	X	X	X	X
Organizational availability	X	X	X	X	X	X
Focus areas		X	X	X	X	X
Spare parts handling	X	X	X	X	X	X
Education and training	X	X	X	X	X	X
Measurements		X			X	X
Communication		X				

Usage of strategies

Four of the companies (A, B, C, and D) had no maintenance strategy, nor did they use relevant measures for controlling their maintenance. Even though companies B, C, and D

were using maintenance performance measures, the measures were not evidently tied to any strategic goals of the company. In companies A and B, production managers with scarce knowledge of maintenance managed the maintenance. At these companies, the maintenance is at a low level and not developing. In company D, with outsourced maintenance, the maintenance supplier has no manager on site. There is no evidence of development for the maintenance activities here either.

Companies E and F have both been awarded for their maintenance excellence. They use written maintenance strategies well-aligned with the overall goals of the companies. In the case of company F, they let their maintenance supplier formulate the maintenance strategy, but through a dialog with the customer. Both companies use performance measures for control on strategic as well as tactical and operational levels. In both companies, the maintenance standard is continuously increases because of strategic development programs.

Conclusions from case study A

In the same way as the findings, the conclusions from this case study may be divided into the areas of strategic factors and the usage of strategies. The conclusions, presented below, are published in Appended Papers I and II.

Strategic factors

To a large extent, there is a consensus among the participating companies as far as which factors to consider strategically important for their maintenance activities.

The knowledge of maintenance management and maintenance technologies is quite low in smaller manufacturing companies. This may be an obstacle for the development of maintenance strategies that fully utilize the possibilities within the company.

Companies that lack skills and strategies in maintenance and at the same time view financial considerations as the most important factor for their maintenance may focus on fast cost cutting without realizing how good maintenance could contribute to the competitiveness of the company.

A process for the formulation of maintenance strategies may benefit from a set of strategic factors to consider. However, this set should not be viewed as a fixed set, but rather as factors to consider if relevant in the companies' specific contexts.

Usage of strategies

Some factors seem to be important to consider for companies that want their maintenance to truly contribute to their competitiveness.

- A maintenance strategy should be formulated.
- The strategy should be well-aligned with the overall business strategy of the company, as well as with the strategic goals of the production department.
- Strategic performance indicators should be used for controlling the strategic development of maintenance.
- The maintenance strategy should periodically be revised in order to remain dynamic.
- Maintenance managers should have time, not only to manage the maintenance department but also to develop it.
- Maintenance has to be regarded as strategically important at the top management level in the company.

Case B: Stakeholder involvement

Case B was performed as a pre-study in one company in order to test stakeholder involvement in the process of identifying relevant maintenance performance measures.

Case study objective

The main objective with this study was to test stakeholder involvement in the process of identifying relevant maintenance performance measures. This is because stakeholder involvement might lead to a higher degree of consensus between all stakeholders in the maintenance process. In turn, this would lead to a high degree of acceptance for the formulated maintenance strategy, thereby increasing the probability of its fulfillment.

Methodology

Case study B is based on qualitative data, collected through document studies and interviews. The scope of the document studies and the interviews was to find out which maintenance performance indicators were used by the company and, further, which measures might be interesting for the various stakeholders to follow. The interviews contained question areas like the respondents' insight into what is being measured today, how they are measured and followed up, suggestions on additional indicators to measure, and examples and suggestions on other improvement potential possible in the area of performance indicators.

Findings

The study indicated that by stakeholder involvement and via company strategies and key result areas, a set of maintenance performance measurements could be suggested for use in the company (see Table 2).

Table 2: Maintenance-related measures at the case company, presented in no order of importance. CM is an abbreviation for corrective maintenance, while PM is preventive maintenance, and M(PM) is Mean Preventive Maintenance Time (from Paper III).

Hierar-chical	Maintenance			Production	
Criteria	Strategic	Tactical	Operational/ Functional	Strategic	Tactical
Efficiency	Ratio between CM and PM (%)	Ratio between CM and PM	Ratio between CM and PM (%)	Ratio between CM and PM (%)	
	Number of performed PM versus planned	Number of performed PM versus planned	Number of performed PM versus planned	Number of performed PM versus planned	
	Maintenance cost per component (SEK/comp.)		Repair costs (SEK)	Expected maintenance-related costs (SEK)	Expected maintenance-related costs (SEK)
			Spare part costs (SEK)		Spare part costs (SEK)
			Number of jobs waiting		
			Incidents/accidents		
Effectiveness	Number of breakdowns	Number of breakdowns	Number of breakdowns	Number of breakdowns	Number of breakdowns
		MTTR (h)	MTTR (h)	M(PM) (h)	MTTR (h)
	Availability (%)	Availability (%)	Availability (%)		Availability (%)
			OEE (%)	OEE (%)	OEE (%)
			MDT (h)		
			Number of operation disturbances		
			MTBF (h)		
			Machine and equipment vibration levels		

Conclusions from case study B

The main conclusion from this case study was that the involvement of the stakeholders increased their enthusiasm for the maintenance department agenda. This is an important conclusion for two reasons: it clearly relates to RQ 3 and it contributes to the answer of RQ 2.

Another important conclusion from case study B is that stakeholder involvement may lead to a unanimous view of the expected deliveries from the maintenance department to its customer (that is, the production department). This consensus may contribute to an increased level of cooperation between the departments, which, in turn, will benefit company productivity. The conclusions were presented in Appended Paper III.

Case C: Formulation of maintenance strategies

Based on the findings from case studies A and B, as well as the performed theoretical review, case study C was performed as a prescriptive study. The study was a joint effort with three manufacturing companies working together with the researcher in their efforts to formulate maintenance strategies.

Case study objective

Case study C is a prescriptive case study, with the main objective to test a process for the formulation of maintenance strategies in manufacturing enterprises. The process is based on the findings in the previous studies (that is, the theoretical review together with case studies A and B).

Methodology

The study was performed as action research over a period of six months. During this period, the three case companies worked together, with the researcher acting as a participating observer. The companies adopted a work-process for strategy formulation suggested by the researcher. All the participants discussed different steps in the formulation process in workshops. After each workshop, the discussed steps of the process were tested in the company settings. The next workshop always started by assessing the different companies' experiences of the performed steps.

Findings

The study led to a process for the formulation of maintenance strategies feasible for manufacturing enterprises. All three participating companies provided input to the shaping of the process. Still, the resulting model seemed to work for all three companies.

Conclusions from case study C

The conclusions from case study C are mainly confirmations of the results from the previous studies. Through the case study, a possible process for the formulation of maintenance strategies has been tested in three industrial settings with their respective contextual demands. All companies have confirmed that the model fits their needs; however, the formulated strategies are not yet implemented and hence not tested. Case study C is further described in Appended Paper IV.

Reflections on the case studies

Applying Blessing and Chakrabati's (2007) model for design research, seems to have worked well. The findings from the initial descriptive study gave valuable input to the assumptions used in the prescriptive study. Also to the performance of the prescriptive study was influenced by the results from the descriptive study. The prescriptive model, tested in case study C, was only slightly adjusted during the case study. One reason for this might be that the researcher/author has long experience from working with development of production maintenance.

CHAPTER 5

THE FORMULATION OF MAINTENANCE STRATEGIES

In this chapter, a process for the formulation of maintenance strategies is proposed. It is mainly intended as an example of a formulation process that applies the results of the research presented in this thesis.

A model for strategic maintenance development

In literature, several models for maintenance management and maintenance strategies are proposed. A model of strategic maintenance development has been drawn as a support for the conducted research, depictured in Figure 12. This model has been used in two ways during the performed research: to structure thoughts and to visualize the different stages in the strategic development work.

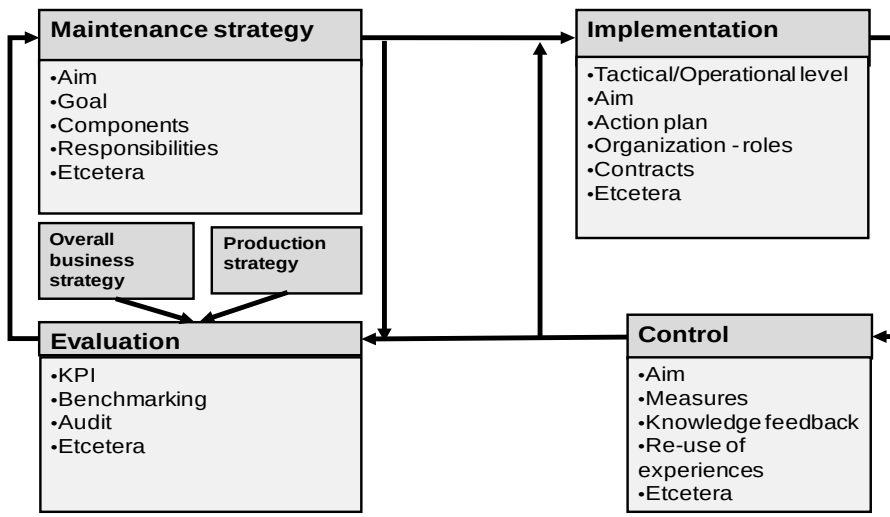

Figure 12: The strategic maintenance development loop (Appended Paper IV).

The research presented in this thesis has focused on the left part of the model in Figure 12. This part describes the formulation of maintenance strategies based on the current situation. The right part of the model is concerned with the implementation of the formulated maintenance strategy, which constitutes the practical development of the maintenance standards.

A process for the formulation of maintenance strategies

Based on the findings from the case studies and the literature study performed, a proposed process for the formulation of maintenance strategies emerges, depicted in Figure 13.

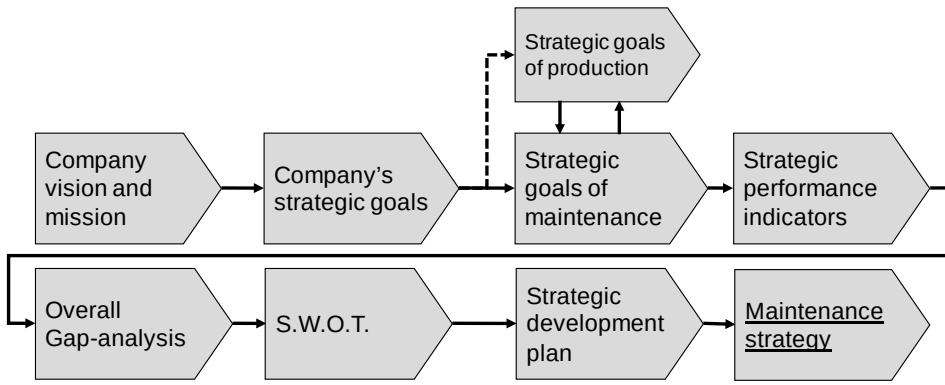

Figure 13: A schematic view of the maintenance strategy formulation work-process (Appended Paper IV).

The formulation process starts at the overall vision and mission of the company. From these, the company formulates its overall strategic goals, which all functional strategies are supposed to support. For the maintenance strategy, it is essential that, in addition to the overall strategic goals of the company, also the strategic goals of the customer (in effect the production department) are considered (see Figure 14). Not all manufacturing companies have formulated production strategies, but some strategic goals or a strategic focus may be identified. By analyzing the strategic goals of both the company and its production department, strategic goals for the maintenance department may be defined. There are two strategic maintenance goals. First, there are goals for the fulfilment of the customer demands (that is, to uphold the reliability of the production equipment). These goals reflect the effectiveness of the maintenance department. Second, the maintenance

department has to be competitive in terms of cost effectiveness. These goals reflect the efficiency of the maintenance department.

For the strategic goals, relevant performance measures may be identified. The measures should of course reflect the strategic goals of the maintenance department. One way to identify these measures is to involve all stakeholders. This approach will also increase the acceptance of the strategy among the stakeholders.

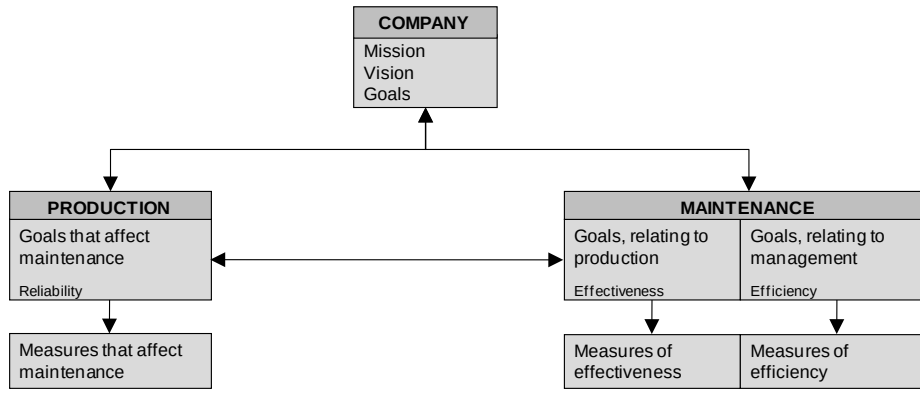

Figure 14: The relationship between goals and measures, used by the maintenance and production departments, and the company's overall goals (adapted from Appended Paper III).

The measures used by the company have to be well-defined. Some common maintenance performance measures are very loosely defined. Examples include OEE and Availability. Therefore, to avoid misinterpretations, the use of different definitions at different departments, or drifting definitions, the definitions have to be clarified. Also data sources, data collection methods, and responsibilities may be defined in a strategy formulation. Once the measures are defined, the current status of the measures may be defined.

Table 3 illustrates the matrix used in case study B to identify and categorize performance measures for the maintenance activities. While authors like Parida (2006), Alsyouf (2006), and Kutucuoglu *et al*. (2001) suggest multiple criteria for the measurement system, this model uses only two: Efficiency and Effectiveness. Further, in the matrix, measures are categorized as Strategic, Tactical, and Operational.

Table 3: Matrix for the identification of Maintenance Performance Measures (adapted from Appended Paper III).

Hierarchical	Maintenance			Production		
Criteria	Strategic	Tactical	Operational/ Functional	Strategic	Tactical	Operational/ Functional
Efficiency						
Effectiveness						

By defining the gap between the current and the desired level for the strategic measures, a sense of direction is achieved. Next, the organization has to identify which factors that may potentially minimize the gap between current and desired levels. In the proposed process, this is achieved through SWOT-analysis[2]. Which factors to consider strategically important for the production maintenance may vary between companies according to size, branch etc. For this purpose, a set of factors has been identified during case study A. The factors have further been categorized according to man, technology, and organization, MTO[3], see figure 15.

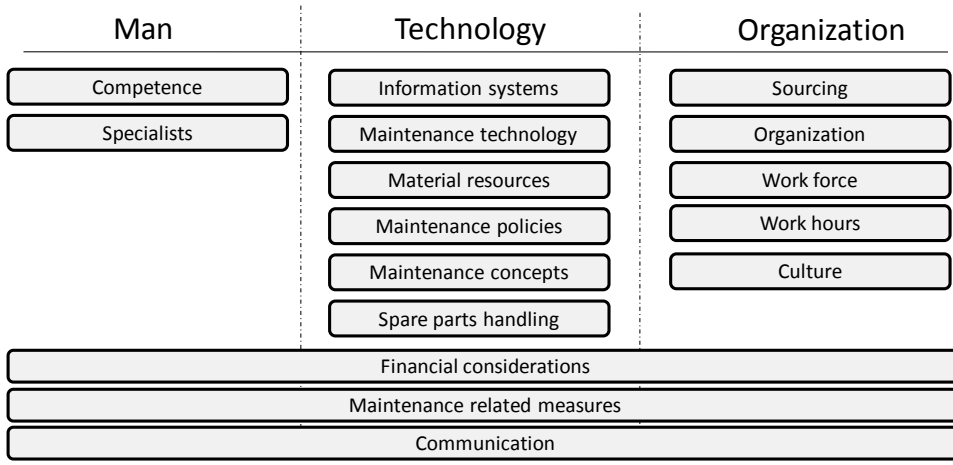

Figure 15: Factors identified as strategic for maintenance, mapped according to Man, Technology, Organization, MTO. (Appended Paper IV).

[2] Strengths, Weaknesses, Opportunities, and Threats

[3] The term MTO (Man, Technology, and Organization) is the Swedish equivalent of the English term "Human factors". It originates in the Swedish nuclear power industry, and is meant to tie human and organizational aspects to the technological aspects of security (Rollenhagen, 1997).

Once the SWOT is performed, a set of strategic factors for the maintenance activities is identified. Now a maintenance strategy may be formulated. A proposed structure of such a document is specified below:

- Strategic alignment
- It is important that the alignment of the goals is described in a transparent fashion. Any reader of the strategy document should be able to see how the strategic goals of the maintenance department support both the production department's goals and the company's overall strategic goals. Therefore, this part of the strategy document should contain at least the following statements:
    - Overall strategic goals of the company
    - Strategic goals of the production department
    - Strategic goals of the maintenance department
- Strategic performance indicators for the maintenance department
- The performance indicators, chosen to describe the fulfilment of the strategic goals, must be obviously linear to the strategic goals of maintenance. Also, the measures have to be defined with respect to how, where, when, and by whom they are measured. Finally, the actual starting levels of the measures, the strategic target levels and the goal levels for the coming year should all be stated.
- Strategic action plan
    - Man
    - Technology
    - Organization

When the maintenance strategy is formulated, the document should be approved by the Board of the company. This is essential, as the strategic plan may include investments and other costs. In addition, the strategy may require production time to be set off for planned maintenance activities.

CHAPTER 6

CONCLUSIONS, CONTRIBUTIONS, AND FUTURE WORK

This chapter presents the overall conclusions drawn from the research presented in this thesis. Later, the contribution and fulfilment of the research goals are discussed. Finally, some future research topics are proposed.

Conclusions

The main objective with this research is to suggest a work-process for the formulation of maintenance strategies for manufacturing organizations. To achieve this, a literature review has been performed in order to set the theoretical framework for the performed research. Further, one descriptive case study and two prescriptive case studies have been performed to further investigate both how industry currently works with maintenance strategies, and how they may work with a structured process for formulating their maintenance strategies.

The literature review showed the current academic view on maintenance strategy. The most important conclusion was that the term maintenance strategy lacks a unanimous definition among researchers. Another conclusion from the literature review was that there are few proposed processes for the formulation of maintenance strategies. Also, in the cases where formulation processes are suggested, they are quite complex and resource demanding, indicating that the processes are mainly developed for large organizations.

Case A explored some companies' views on maintenance and maintenance strategies. Among the author's conclusions was the sense that there seems to be a lack of competence in maintenance management among smaller organizations. Further, there seems to be a consensus among the studied companies as to which factors they consider strategically important for their maintenance operations. For companies that want their

maintenance to truly contribute to their competitiveness, the following factors should be considered.

- A maintenance strategy should be formulated.
- The maintenance strategy should be well-aligned with the overall business strategy of the company, as well as with the strategic goals of the production department.
- Strategic performance indicators should be used for controlling the strategic development of maintenance.
- The maintenance strategy should periodically be revised in order to remain dynamic.
- Maintenance managers should have time, not only to manage the maintenance department but also to develop it.
- Maintenance has to be regarded as strategically important by the top management level of the company.

Case B was performed in order to test stakeholder involvement in the process of the identification of relevant maintenance performance measures. The main conclusion from the study was that the involvement of the stakeholders increased their enthusiasm for the agenda of the maintenance department. Another important conclusion was that stakeholder involvement may lead to a consensus among the stakeholders on the expected deliveries from the maintenance department to its customer (the production department).

Case C was a joint effort with three manufacturing companies working together with the researcher in their efforts to formulate maintenance strategies. In case C, a possible process for the formulation of maintenance strategies has been tested in three industrial settings with their respective contextual demands. The three case companies have had quite varying preconditions to deal with the proposed work-process. For example, one of the companies has to negotiate all their proposed changes with an external maintenance organization. Another company has to consider the varying situations at five factories with individual needs and capabilities. Despite these different demands, all companies have confirmed that the model fit their needs. However, the formulated strategies are not yet implemented and hence not tested.

Fulfilment of objectives

As stated in Section 1.3, the main objective with this thesis is to propose a process for the formulation of maintenance strategies. Based on the results and conclusions from the three case studies, a process for the formulation of maintenance strategies has been

proposed. The process, described in Chapter 5, has been tested in, and verified by three manufacturing organizations.

Further, the research questions, stated in section 1.4, have been answered.

> RQ1 – What should a maintenance strategy include?

The question is based on the fact that there is no unanimous view in academia regarding which factors to consider when developing a maintenance strategy. From case studies A and C, the conclusion was drawn that the factors to consider when developing a maintenance strategy are context-dependent. Different companies need to consider different factors depending on the company's size, competitive environment, product types, among other things. Having a standard set of factors to choose from probably makes it easier to consider the proper factors for a given organization. A first, basic version of such a set has been identified through the performed research (also, see Figure 15).

> RQ2 – How should a maintenance strategy that supports the company's over-all business strategy be developed?

The question has been answered through both the literature study and the case studies. First and foremost, a company has to consider its overall strategy when formulating a maintenance strategy. Second, the strategic goals of the company have to be translated to strategic goals for the maintenance department. These goals must be related to both effectiveness and efficiency. Finally, the strategic goals of the production department have to be identified in order to determine the effectiveness goals of the maintenance department,.

> RQ3 – How may acceptance for a maintenance strategy among its stakeholders be gained?

The answer to this question is derived from all parts of the performed research. One key factor for the acceptance of maintenance strategies in general is the insight that maintenance may contribute to the competitiveness of a manufacturing organization. Another factor, which relates to the first one, is that the strategic goals for the maintenance department truly align with the overall goals of the company. To achieve this, relevant performance measures have to be defined so that all stakeholders can identify how the maintenance department meets their interests. One way to achieve this may be to involve the stakeholders in the identification of maintenance performance measures as described in case B. Also, the structure of the strategy document is important. When requesting approval of the formulated maintenance strategy, it is important that the stakeholders see how the suggested strategy may contribute to the achievement of the companies' overall strategic goals.

Research Contributions

As applied scientific research, this research is intended to contribute not only to the scientific community, but also to industry. This section presents the main contribution to the scientific community and to industry.

Scientific contribution

Organizational and managerial aspects of maintenance are often studied in large organizations and/or in the process industry, and may therefore not always be applied on small and medium-sized, discrete item manufacturing organizations. The research presented in this licentiate thesis focuses on discrete item manufacturing companies.

Case study A has given the view of six different manufacturing companies on maintenance from a strategic perspective. This view contributes to the understanding of current standards for maintenance management in manufacturing industry.

Industrial contribution

The scope of this research is well-appreciated in the industry. The participating companies, as well as other companies in the region have been very keen to contribute to the performed research, as well as to getting information regarding the research results. The results are intended to be useful for discrete item manufacturing companies in general.

The research has generated a work-process for the formulation of maintenance strategies. Three companies with different needs and capabilities have tried the work-process and approved of it as a means to formulate feasible maintenance strategies. Although the research focus has been on the serial production of discrete items, the results may very well apply to the process industry. However, this has not been tested; hence, the results should currently be considered applicable in traditional manufacturing settings alone.

Quality of the performed research

The performed research has been conducted using a systems approach, based on qualitative data. As such, the research has been designed with validity aspects in mind. The case companies were purposefully selected to represent varied contexts, as far as company type, competitive environments, and the status of their current maintenance

practices. The intent was to study different challenges in different contexts, all in order to increase the external validity.

It may be possible to criticize the fact that case study A involved only six companies, case study B one, and case study C three. However, when gathering qualitative data through interviews and case studies, it is difficult to include large amounts of data sources. Nevertheless, have three different manufacturing companies with different challenges tested and verified the work-process for the formulation of maintenance strategies. Further, all three companies intend to use the resulting maintenance strategies in their forthcoming maintenance development.

Future work

This thesis is the first summary of a PhD student's journey towards becoming a researcher. In the future, the following areas will be further studied.

Implementation of maintenance strategies

A maintenance strategy is of no practical use unless it is put into operational use in the company. However, as with all forms of organizational change, there are obstacles to overcome in order to succeed with the intentions of the changes. Studies of TPM implementations have shown both obstacles and driving forces in the implementation process. Similar obstacles and driving forces may be identified in the implementation of maintenance strategies. By identifying these obstacles and driving forces, guidelines for facilitating and maximizing the success of the implementation of maintenance strategies may be developed.

Cost of poor maintenance

According to Alsyouf (2004), 70% of Swedish industry regards maintenance as a cost center. One reason is that the financial impact of maintenance often is measured, by considering only direct maintenance costs (i.e. labor and materials costs). By the structured measuring of the indirect maintenance costs (i.e. the cost of poor maintenance) a truer view of the financial impact of the maintenance activities may be achieved. Finally, such a measurement may contribute to a view among management that maintenance contributes to the competitiveness of the company.

Information design in strategic maintenance development

As in other change projects, communication and information are key enablers for implementing maintenance strategies. Many scientific publications remark the importance of good information in maintenance development. However, few studies concern how to apply information design in the areas of maintenance management and maintenance development.

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