STRATEGIC MAINTENANCE DEVELOPMENT
IN MANUFACTURING INDUSTRY

Antti Salonen

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STRATEGIC MAINTENANCE DEVELOPMENT IN MANUFACTURING INDUSTRY

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Fakultetsopponent: Professor Pra Murthy, The University of Queensland, School of mechanical and mining engineering
Abstract

Industrial maintenance is a substantial financial post. The total value of maintenance budgets in Europe has been estimated to be approximately 1500 billion € per year. At the same time, there are indications that about a third of these costs are wasted due to poor planning, overtime costs, inferior use of preventive maintenance and so forth. However, the diversity between different types of industry is substantial.

While the process industry, which is rather vulnerable to disturbances, has a tradition of viewing its maintenance as a strategic resource, the picture is quite different in discrete item manufacturing industry. Historically, manufacturing industry has had a surplus of finished goods and Work-In-Progress buffers between machinery. Therefore, the manufacturing industry has been able to fulfil its production demand despite unreliable production equipment. In the last few decades, the concept of lean production has started to spread within the manufacturing industry as a means to improve competitiveness. Manufacturing companies apply lean tools such as flow oriented production layout, Just-In-Time production and Demand-Flow-Technology. As a consequence, the vulnerability to system disturbances increases and hence, the demand for dependable production equipment increases. Despite this increasing demand on reliable production equipment, few manufacturing companies work with strategic maintenance development. One reason for this may be that the existing methods and concepts for maintenance development are quite resource demanding.

The main objective with this research is to develop a simple and cost effective approach aimed to formulate, implement, and evaluate maintenance strategies for the manufacturing industry. In five case studies the following has been studied: (1) The industry’s view on strategic maintenance development, (2) Formulation of maintenance strategies, (3) Implementation of maintenance strategies, (4) Cost of Poor Maintenance, and (5) Results from strategic maintenance development.

As a result from this research, a process for the formulation of maintenance strategies has been developed. Further, a number of driving forces and obstacles, that influence the implementation of maintenance strategies, have been identified. The concept of Cost of Poor Maintenance has been introduced as a means for evaluating the financial contribution of maintenance. Finally, three years of studies in three companies has shown substantial benefits from strategic maintenance development.
ABSTRACT

Industrial maintenance is a substantial financial post. The total value of maintenance budgets in Europe has been estimated to be approximately 1500 billion € per year. At the same time, there are indications that about a third of these costs are wasted due to poor planning, overtime costs, inferior use of preventive maintenance and so forth. However, the diversity between different types of industry is substantial.

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SAMMANFATTNING

Underhåll av produktionssystem utgör en substantiell kostnad i industrin. Värdet av Europas underhållsbudgeter uppskattas till ca 1500 miljarder € per år. Samtidigt finns indikationer på att ungefär en tredjedel av dessa kostnader är slöserier i form av dålig planering, övertidsarbete, felaktigt utfört underhåll och liknande. Skillnaderna mellan olika typer av industri är dock stor i detta avseende.


Syftet med detta forskningsprojekt har varit att utveckla ett resursnärt arbetssätt för formulering, implementering och utvärdering av underhållsstrategier i tillverkningsindustrin. I fem fallstudier har följande studerats: 1) Industriens syn på strategisk underhållsutveckling, 2) Formulering av underhållsstrategier, 3) Implementering av underhållsstrategier, 4) Underhållsbristkostnader, samt 5) Resultat av strategisk underhållsutveckling.

Forskningen har resulterat i att en metod för formulering av underhållsstrategier framarbetats. Vidare har ett antal hinder och framgångsfaktorer, som inverkar på implementeringen av underhållsstrategier, identifierats. Konceptet Cost of Poor Maintenance har introducerats som ett möjligt sätt att värdera underhållets finansiella bidrag till företaget. Slutligen har tre års studier av tre företag visat på stora förtjänster med strategisk underhållsutveckling.

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ACKNOWLEDGEMENTS

Ending a five year journey of research, but also of personal growth, there are some reflections to be made and obviously a lot of people to thank. I have had quite a clear path to explore with my long industrial experience as a road map. Still, my supervisors Professor Mats Deleryd, Dr. Marcus Bengtsson, and Professor Mats Jackson, have made the journey much easier. Mats Deleryd has provided clear structures and insights, while Mats Jackson has provided a more visionary perspective. Marcus Bengtsson has taken a closer, more personal role, as being a former PhD-student fellow, but still provided very good guidance.

Except for my supervisors, various industrial representatives have provided invaluable experiences, opinions and facts. All industrial informants have been very keen on sharing their views on maintenance with me in an honest manner, not always flattering themselves. Especially I would like to thank Lena, Annica, Rickard, Pelle, Patrik and last, but not least, Roger, for all your help. Further, I thank the European Regional Development Fund and the Knowledge foundation for funding my research projects.

When my journey started in 2006, I shared room with four fellow PhD-students, of which two were nearly finished. The first years a research assistant and two more PhD-students joined us. Then suddenly the department got crowded with new PhD-students and a new research school was started. It is great to see how our research group has expanded, but still, we were a tighter group when we all shared one room. Good company, good whisky, and some nice practical jokes, preferably including dried peas. Therefore I thank Anders, Anna, Erik, Jocke, Micke, Sofie and Yuji by name, but still include you other fellow PhD-students in my thoughts.

Except for my research studies, I have also been lecturing our under graduates. I must say, I really love to share my knowledge in, and experiences from, industrial maintenance. And for me, the lectures have provided good opportunities to learn how to formulate thoughts and insights in maintenance in an understandable way. Therefore, I would like to thank all my students, and especially those that have challenged my statements, thereby forcing me to improve as a tutor. Also, here is the place to thank the department manager Anders Hellström, who has given me the opportunity to lecture the students.
Life is not all about research studies however; during these studies also one’s personal life is heavily affected. Therefore, it is invaluable that the family and friends show their support. My parents have been very supportive through the entire journey, even when I have not had the time to show them the gratitude they deserve. Also, my sister Helena and her family have shown good support and interest in my studies.

Last, I want to thank Eva, my lovely wife to be, for voluntarily sharing her life with me. She is my primary coach in my research studies, as well as in my life. Thank You!

Västerås, March, 2011

Antti Salonen
The dissertation is based on the following, appended papers.

**Paper I:** Salonen, A. (2008), “Maintenance Strategy – An Enabler for Improved Competitiveness” In the proceedings from the 18th International Conference on Flexible Automation and Intelligent Manufacturing, FAIM, Skövde, Sweden.


Other publications, not appended in this dissertation:


ABBREVIATIONS

CBM      Condition Based Maintenance
CM       Corrective Maintenance
CMMS     Computerized Maintenance Management System
CoPM     Cost of Poor Maintenance
CoPQ     Cost of Poor Quality
DRM      Design Research Methodology
DS       Descriptive Study
EFNMS    European Federation of National Maintenance Societies
JIPM     Japan Institute of Plant Maintenance
KPI      Key Performance Indicator
MTO      Man, Technology, Organization
OEE      Overall Equipment Effectiveness
PdM      Predictive Maintenance
PM       Preventive Maintenance
PS       Prescriptive Study
QFD      Quality Function Deployment
RCA      Root Cause Analysis
RCM      Reliability Centered Maintenance
RQ       Research Question
RTF      Run To Failure
SWOT     Strengths, Weaknesses, Opportunities, Threats
TPM      Total Productive Maintenance
TQM      Total Quality Management
<table>
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<th>Acronym</th>
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<tr>
<td>TQMain</td>
<td>Total Quality Maintenance</td>
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<td>VDM</td>
<td>Value driven Maintenance</td>
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CHAPTER 1

1 INTRODUCTION AND POSITIONING

This chapter is intended to give the reader an understanding of why this dissertation 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, the delimitations, and the outline of this dissertation.

1.1 BACKGROUND

Industrial maintenance is a substantial financial post. However, if strategically managed, the maintenance of manufacturing equipment contributes to the competitiveness of a company. The total value of maintenance budgets in Europe has been estimated to be about 1,500 billion € per year (Parida, 2006). For Swedish industry, Ahlmann (2002) has presented a similar study. However, his study also includes the indirect costs of maintenance. Ahlmann (2002) has estimated that the total cost of maintenance in Swedish industry constitutes 6.2% of the industry’s turnover; in effect, close to 20 billion € per year. Relating to these estimations, it is worth paying attention to Wireman (1990), who states 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.

The efficiency and effectiveness of maintenance activities differs between process industry and discrete item manufacturing industry. Within process industry, a strategic view on maintenance is well established, since a malfunctioning sub-system often immediately disturbs the whole production process. In such production systems, the operators and maintenance staff are more or less fully integrated. The use of maintenance concepts, such as Reliability Centered Maintenance, RCM, and advanced technologies, like on-line condition monitoring and computerized decision support systems, is common. Further, dependability is a key requirement when investing in new equipment.

In the manufacturing industry, the status of maintenance has been quite different. In this dissertation, the term manufacturing industry refers to the traditional discrete item manufacturing industry. Ever since mass production was introduced, the manufacturing industry has had a surplus of finished goods, as well as buffers of work in progress between

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1 The original reference, Altmannshoffer (2006), has not been available for review.
machinery. Also, the workshop layout has been functionally oriented and, in many cases, has allowed products to have several alternative flows. As a consequence, the manufacturing industry has been able to disregard deficiencies in the production equipment, rather than improving the dependability. In large parts of the manufacturing industry, these conditions are still a reality. However, the situation is changing.

In the last few decades, the concept of lean production has started to spread in the manufacturing industry, as a means of improving competitiveness. Manufacturing companies apply lean tools like flow-oriented production layout, Just-In-Time production and Demand-Flow-Technology. Further, they minimize the amount of work in progress and the stores of finished goods. As a consequence, the manufacturing industry is starting to resemble the process industry, regarding its vulnerability to system disturbances. This means that the demand for dependable production equipment, and, hence, good maintenance, suddenly increases.

In order to cope with the new challenges of lean production, companies have to develop their maintenance on a strategic level. Several researchers have argued for the importance of maintenance strategies. For example, Walker (2005) argues that if maintenance issues are taken seriously at board room level, and seen as a key business-driver, the profitability of the company will improve. 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 hydropower organization. Similar conclusions are described in a study of the implementation of Total Quality Management, TQM, Total Productive Maintenance, TPM, and Reliability Centered Maintenance, RCM (Hansson, et.al, 2003). Also, Rao (2009) contends that one of the challenges of maintenance is to continuously improve maintenance management efficiency.

Despite the obvious importance of maintenance strategies, a survey among 284 Swedish manufacturing companies shows that only 48% of the respondents had a written maintenance strategy and 23% had no maintenance strategy at all (Jonsson, 1997). In a study by Alsyouf (2009), 48% of the respondents again had a written maintenance strategy and 28% had no maintenance strategy at all. In his study, Jonsson (1997) also remarks that many of the respondents considered the quality standard ISO 9000 to be a maintenance strategy. This indicates that the true proportion of companies with full maintenance strategies is less than 48%. The fact that companies consider a quality standard to be a maintenance strategy clearly shows the low awareness of maintenance issues among manufacturing industry. Even among those companies that do have a strategy, it is not evident that their maintenance strategies are clearly linked to the production- and business strategies. According to Jonsson (1997), one reason for the low interest for maintenance among management might be the lack of visible connections between maintenance activities and profitability.
1.1.1 Problem statement

Based on the described background, clear incentives for the active improvement of maintenance performance have been identified. Still there seems to be a low amount of interest for structured maintenance improvement work in manufacturing industry. There are several reasons for this. One reason is that many proposed methods or concepts for maintenance improvements are rather resource-demanding, which makes them less suitable for use within manufacturing industry, especially in small and medium-sized companies. This is a problem that may relate to low interest in participating in research projects among smaller manufacturing companies. Because of this reluctance, most maintenance research takes place in larger companies, which in many cases have the necessary resources and maturity within maintenance management. This, in turn, creates an image that all types of industry are ready and mature enough to use advanced technologies and methods for improving the dependability of their production equipment. Further, the implications of the implementation of maintenance strategies are poorly studied. Even though such implementation to a large extent resembles the implementation of concepts such as TPM, or RCM, there might be implications that are specific to the implementation of maintenance strategies.

Another reason is that manufacturing companies seldom realize the potential financial contribution of their maintenance activities. The financial metrics for maintenance activities still focus on direct maintenance costs and neglect costs induced by poor maintenance.

1.2 OBJECTIVE

The main objective of this research is to develop a simple and cost-effective approach aimed to formulate and implement maintenance strategies for the manufacturing industry.

1.2.1 Research questions

In order to fulfill the research objective, the following research questions have been formulated.

RQ 1 How to formulate a maintenance strategy that supports companies’ over-all business goals?

In process industry, production maintenance is usually an integrated part of operations. Hence, maintenance strategy is an essential part of production strategy as well as over-all business strategy. In manufacturing industry, production maintenance is in general not regarded as strategically important. Companies often lack strategies to guide maintenance
work. In order to facilitate the strategic management of production maintenance, a process for the formulation of maintenance strategies is developed and tested.

RQ 2 Which driving forces and obstacles influence the implementation of maintenance strategies?

The implementation of maintenance strategies is essentially a form of change management. Hence, general implications for change management apply to the implementation of maintenance strategies. However, it is fair to believe that some implications, driving forces, and obstacles are contextually specific for production maintenance. Therefore, it is of interest to identify these implications in order to handle them when implementing maintenance strategies.

RQ 3 How may management in manufacturing industry become aware of the financial contribution of a well-formulated and well-implemented maintenance strategy?

A large part of the manufacturing industry views maintenance as a cost driver, rather than a contributor to competitiveness. One reason for this view is the lack of balanced financial performance indicators for maintenance. A concept for visualizing the financial contribution of maintenance is proposed.

1.2.2 Delimitations

The research conducted has focused on the maintenance of production equipment in organizations within the traditional manufacturing industry. The scope has been to provide a maintenance management approach for companies with limited material and financial resources and/or limited knowledge of maintenance management. However, the approach may fit organizations with sufficient resources and maintenance management skills as well.

1.3 EXPECTED RESULTS

This dissertation is based on applied industrial research and, hence, it presents results for industry as well as for academia.

Scientific contribution: Research on industrial maintenance tends to focus on technological issues today. A great deal of effort is placed on various techniques for condition monitoring, diagnostics, and prognostics. Also, the organizational aspects of maintenance are often studied in large organizations and/or in the process industry. Therefore, the results are not always applicable to small and medium-sized manufacturing organizations.
The performed research has shown how a relatively simple and non-resource demanding process may be used to formulate maintenance strategies that align with the over-all strategic goals of the company. Further, the implementation work has been studied in order to identify some of the driving forces and obstacles that may be associated with strategic maintenance improvement work.

Within academia, there is no consensus as to how to visualize the financial aspects of maintenance. Even though several models are presented in various publications, all having their merits, they do not fully distinguish between the costs necessary for upholding the agreed dependability and costs that really do not add any value to the production department. For example, the models analyzed in the literature study do not consider costs for excessive preventive maintenance, nor do they consider poorly performed preventive maintenance. That means that the models are still not fully applicable to the optimization of maintenance programs. The research presented in this dissertation presents a concept for the classification of all maintenance-related costs, which contributes to the optimization of maintenance programs.

**Industrial contribution:** The scope of this applied research is well-appreciated in industry. There seems to be awareness among manufacturing companies that they have a large improvement potential within their maintenance programs. Still, many companies do not know how to work systematically with maintenance improvements in a strategic way. The conducted research may provide guidance for such efforts.

One aspect of maintenance that seems to obstruct any development programs is the fact that maintenance is seldom looked upon as a business contributor. Most companies only quantify the direct cost of maintenance, neglecting the indirect cost of poor maintenance. This research provides a concept for quantifying the true cost of poor maintenance so that maintenance may be discussed as a business case rather than a cost center.

The participating companies, as well as other companies in the region, have been very keen on contributing to the performed research, as well as on getting information regarding the results from the research. The results are intended to be useful for manufacturing companies in general.

### 1.4 OUTLINE OF THE DISSERTATION

Chapter 2 presents the research methodology used in the research that is the subject of this dissertation. Thereafter, the theoretical frame of references is presented in Chapter 3. Chapter 4 summarizes the results of the conducted case studies. Then, in Chapter 5, the conclusions from the conducted research are presented and discussed. Further, some personal reflections from the journey are presented. Finally, the dissertation finishes by proposing some future research topics.


CHAPTER 2

2 RESEARCH METHODOLOGY

The research presented in this dissertation is intended to generate results that are valid not only for academia, but also for industry. During the research process, the researcher has moved continuously between research of the theoretical aspects and the industrial context. This movement is essential in order to produce results valid in both the scientific and the industrial community.

This chapter presents the research methodology this research rests on. Research methodology is a vast scientific discipline, and it is neither possible nor desirable to cover all aspects of this discipline in this dissertation. Instead, the researcher describes his scientific view and the methods used in the performed research.

By way of introduction, the researcher's scientific view is presented, followed by a description of the research approach. Then the research process is presented, including the different case studies. A discussion of the activities performed to ensure the good quality of the conducted research concludes this chapter.

2.1 SCIENTIFIC VIEW

Research can be conducted using various methodological approaches. The method to use depends largely on the researcher’s ontological and epistemological views, as well as the nature of the research questions at hand. Arnbor and Bjerke (1994) present three methodological approaches: (1) The analytical approach presumes that reality is objective. This approach aims to explain causal relationships on isolated phenomena. (2) The systems approach presumes that reality is objectively achievable. It aims to find final relationships in complex systems in which a component cannot be treated as isolated. (3) The actors’ approach regards reality as a social construction. It aims to create an understanding of the relationships between different actors’ interpretations of the studied phenomenon. The three approaches are associated with different views of knowledge, as shown in Figure 1.
The explanatory view of knowledge is also known as positivism (Arbnor and Bjerke, 1994) or naturalism (Moses and Knutsen, 2007). This view is usually associated with natural science and aims for universally applicable explanations. It is based on an ontological view of reality as being objective. Hence, explanaticists believe that truth is achievable (Moses and Knutsen, 2007). The hermeneutical view is also known as constructivism (Moses and Knutsen, 2007). This view is more related to social science, and implies that explanations are products of our own interpretations. Therefore, hermeneutics have an ontological view that reality is subjective, and their epistemological view is that there is no truth. All knowledge is dependent on its context. The polarized description of explanaticists and hermeneutics, presented above, is a theoretical model. In reality, most researchers are somewhere in between the two previously described views, as shown in Figure 1.

The performed research deals with companies in different contexts regarding parameters such as culture, size, and competition. Since these contexts differ from each other and also vary over time, the researcher applies a more hermeneutic view rather than a positivistic view, as shown in Figure 1. During the performed research, the researcher has applied different approaches in different stages. Mainly, the researcher's approach has been inspired by the systems approach, especially for creating an understanding of the maintenance system in manufacturing industry. This has also been the case when developing the concept Cost of Poor Maintenance. However, when studying the implementation of maintenance strategies, and also in certain parts of the studies of the maintenance system, an approach resembling the actors’ approach has been applied.
2.2 RESEARCH APPROACH

A common distinction to be made in research is between the use of quantitative or qualitative data. The research presented in this dissertation is mainly based on qualitative data. Quantitative data was used for evaluating achieved results in the form of improved Key Performance Indicators, KPIs. As stated in Section 1.2, Objective, the performed research aims to develop an approach for the strategic management of maintenance activities for companies in the manufacturing industry. It also deals with the understanding of the strategy formulation process, and it aims to increase the understanding of how to influence the strategic development of maintenance programs.

Yin (2009) points out two reasons for considering quantitative data as relevant in case studies. First, the data may show actual outcomes in evaluative studies. Second, the quantitative data may relate to an embedded unit of analysis within the case study. However, qualitative data is more commonly associated with case studies. Maxwell (2005) describes five scientific goals for which qualitative studies are better suited.

- Understanding the meaning of the events, situations, experiences and actions the participants of the study are involved in.
- Understanding the context within which the participants act and how this context influences their actions.
- Identifying unanticipated phenomena and influences, and generating new grounded theories about the latter.
- Understanding the process by which events and actions take place.
- Developing causal explanations.

This research is performed through case studies. According to Yin (2009), case studies have a distinct advantage when attempting to answer how or why questions about contemporary events over which the researcher has little or no control. These descriptions fit the research questions of the performed research, which is why case studies have been the chosen strategy. The design and nature of the case studies is further presented in next section, Section 2.3 “The Research Process”.

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2.3 THE RESEARCH PROCESS

The performed research has been structured in accordance with the Design Research Methodology, DRM, suggested by Blessing and Chakrabarti (2009). The methodology aims to link research questions together and address them in a systematic way. The methodology is based on a framework, depicted in Figure 2.

![Diagram of the research process]

**Figure 2: The performed research, structured in accordance with the Design Research Methodology framework, adapted from Blessing and Chakrabarti (2009).**

The performed research has been structured as shown in Figure 2. This structure is based on the Design Research Methodology, which, in its basic form, consists of four main stages, each having its basic means for creating knowledge and its main outcome:

1. **Research clarification**, in which the researcher searches for evidence or indications that support the researcher's assumptions on which the research goals are based.
2. **Descriptive study I**; a stage in which the researcher collects evidence to describe the current situation of the studied phenomenon.
3. **Prescriptive study**; in which the researcher proposes how to improve the situation.

---

*Research clarification*

- Literature analysis
- Empirical data analysis
- Assumption Experience Synthesis
- Empirical data analysis

*Descriptive study I*

- Research clarification
- Descriptive study I

*Prescriptive study I*

- Descriptive study I
- Prescriptive study I

*Descriptive study II*

- Prescriptive study I
- Descriptive study II

*Prescriptive study II*

- Descriptive study II
- Prescriptive study II

*Descriptive study III*

- Prescriptive study II
- Descriptive study III

**Main outcomes**

- The need for strategic maintenance development
- The industry's view on strategic maintenance development
- Formulation of maintenance strategies
- Implementation of maintenance strategies
- The Cost of Poor Maintenance
- Results from strategic maintenance development
4. *Descriptive study II*; the final stage, in which the impact of the proposed improvements is studied.

As shown in Figure 2, the performed research has been extended through two additional studies. Feedback loops are also noticeable in the model, indicating possible iterations during the research process.

The relationships between the framework for the design research process proposed by Blessing and Chakrabarti (2009), the performed case studies, and the included papers, in relation to the research questions, are illustrated in Figure 3.

**Figure 3:** Design research methodology in relation to research questions and included papers.

The research questions for this dissertation are the following:

**RQ 1** How to formulate a maintenance strategy that supports companies’ over-all business goals?

**RQ 2** Which driving forces and obstacles influence the implementation of maintenance strategies?

**RQ 3** How may management in manufacturing industry become aware of the financial contribution of a well-formulated and well-implemented maintenance strategy?
To answer the questions and achieve the overall goals of the research, seven studies were performed. Except for a literature study, five major case studies and one smaller (PS 1a) were performed. Table 1 shows the different stages of the performed research, in which context they were performed, what focus each study had, and which data sources were used.

**Table 1: Research structure**

<table>
<thead>
<tr>
<th>Stage</th>
<th>Company</th>
<th>Focus of the study</th>
<th>Data sources</th>
<th>RQ</th>
<th>Paper</th>
</tr>
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<tr>
<td>RC</td>
<td>N/A</td>
<td>The need for strategic maintenance development</td>
<td>Literature</td>
<td>I</td>
<td>I, II, III, IV, V</td>
</tr>
<tr>
<td>DS 1</td>
<td>A</td>
<td>View on strategic maintenance</td>
<td>Interviews, Direct observations, Documents</td>
<td>1</td>
<td>I</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>Factors, strategically important for maintenance</td>
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<td></td>
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<td></td>
<td>C</td>
<td>The use of maintenance performance indicators</td>
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<td>D</td>
<td>Sourcing of maintenance</td>
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<td>F</td>
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<tr>
<td>PS 1a</td>
<td>C</td>
<td>Usability of consensus method for the identification of maintenance performance measures</td>
<td>Interviews, Participant observations</td>
<td>1</td>
<td>II</td>
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<tr>
<td>PS 1b</td>
<td>A</td>
<td>Development and test of the process for the formulation of maintenance strategies</td>
<td>Participant observations, Documents, Workshop</td>
<td>1</td>
<td>II</td>
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<td></td>
<td>B</td>
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<td>C</td>
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<tr>
<td>DS 2</td>
<td>A</td>
<td>Driving forces for strategy implementation</td>
<td>Interviews, Survey</td>
<td>2</td>
<td>III</td>
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<tr>
<td></td>
<td>B</td>
<td>Obstacles for strategy implementation</td>
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The companies participating in DS1 are further described in Appended Paper I (Salonen, 2008a). The companies participating in PS1, DS2, PS2, and DS3 are further described in Appended Paper II (Salonen, 2010).
2.3.1 Research clarification: The need for strategic maintenance development

To clarify the scope of the performed research, a literature study was performed to establish how different authors define maintenance strategy and what components such a strategy should contain. In addition to maintenance strategy, theories on the financial aspects of maintenance have been studied, as well as theories on change management and strategy implementation. In addition to relevant books, an extensive amount of scientific articles and publications has also been reviewed. 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. The search was based on the following main words: “maintenance”, “strategy”, “implementation”, and “change management”. Further, the previously mentioned words have been combined with each other, as well as with the following words: “cost”, “development”, “economy”, and “management”. The following terms have been used in the searches: “CBM”, “CoPQ”, “RCM”, “TPM”, “TQM”, and “Teqtechnology”. In addition to the sources described above, the study includes relevant articles published in proceedings from conferences attended by the researcher and relevant dissertations. The outcome of the study is presented in Chapter 3 Frame of references.

2.3.2 Descriptive study 1: - The industry’s view on strategic maintenance development

The first study was performed to compare the view on maintenance strategies in companies with and without formulated maintenance strategies. It was performed as an embedded multiple case study. The studied companies were selected in order to reflect different sizes and branches within manufacturing. Two companies with a reputation for high standards within their production maintenance were selected as reference companies. For comparison, four companies, less satisfied with their maintenance, were selected. Below, a short company description follows. The description is based on the state of the companies when DS 1 was performed in the winter of 2006-2007.

Company A

Company A is a manufacturer of mechanical components for hydraulic valves. At the time of the study, the company had 90 employees, of which two were maintenance personnel. The responsibility for maintenance management was assigned to one of the production managers. In addition to their own staff, they used external contractors for additional

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competence as well as for pure manpower. The company had a Computerized Maintenance Management System, CMMS, which at the time was used only to log performed maintenance. The company had no maintenance strategy and used no performance indicators for evaluating their maintenance performance. The production manager was well aware of the potential benefits of improving the maintenance performance. However, with a strained economy, it was hard for the company to justify the necessary investments.

Company B

Company B manufactures electro mechanical components for power generation and mining industry. When the study was made, the company had 85 employees, including two maintenance personnel, managed by one of the production managers. Additional maintenance manpower and expertise was contracted when necessary. The company had recently purchased a CMMS system, which was not fully implemented. At the time, it had no maintenance strategy, but the industrial group the company belongs to was about to formulate a group generic maintenance strategy. Even though the company had started to derive measures from the CMMS system, these measures were not obviously tied to any strategic goals. The company in-sourced their maintenance over two years earlier, 2004, and had recently discovered that some of the equipment had not had any preventive maintenance performed since then. One of the main challenges this company faced was to set up and systemize their preventive maintenance in order to achieve higher availability of their equipment.

Company C

Company C is a supplier of mechanical components for the automotive and electromechanical industry. During the time of the study, they had 175 employees, of which six were maintenance personnel, including one maintenance manager. An additional five maintainers were periodically contracted for additional manpower. The company belonged to the same industrial group as Company B, and had also recently started to use CMMS as a base for improving their maintenance. Also, the company would apply the industrial group’s generic maintenance strategy once it was formulated. In contrast to Company B, Company C had always had their own maintenance staff. Consequently, it had better control and clearer structures of their maintenance activities than Company B. Still, Company C realized that the potential for improvement was great, and one of their main challenges was to create a maintenance program that fully supported the strategic goals of the company.

Company D

Company D manufactures electromechanical products for industrial applications. At the time of the study, the company had 400 employees and no maintenance personnel; instead, they bought their maintenance from an external contractor. The contract with the maintenance supplier had historically been based on work hours and included an expressed
aim to decrease the downtime for breakdowns and to improve the OEE level. OEE had never been measured. Further, even though downtime had been measured, no specific target values had been stated. The company had been very dissatisfied with the performance of the contractor and had on several occasions studied the possibilities of in-sourcing the maintenance. Just prior to the study, the company and the supplier had agreed on a new contract in which the aim of strategic development of the maintenance was a part of the formulation. Relevant measurements were to be developed, based on specified strategic goals and, in a longer perspective, target values were to be incentives for parts of the contract cost. The main challenge for company D was to formulate relevant demands on the maintenance contractor, based on the overall strategic goals of the company.

Company E

Company E is a manufacturer of mechanical components for commercial vehicles. They had 1,100 employees when the study took place, of whom roughly 50 were in the maintenance organization. In addition to the in-house staff, they used external contractors for expert competence and additional manpower during workload peaks. The company won the award from the Swedish maintenance organization (UTEK) for best maintenance organization in Sweden. A formulated maintenance strategy was a part of the management documentation, and a balanced scorecard was used for performance checks and improvement. However, a huge increase in production demand had made it difficult to give the maintenance staff the time required in the machines to perform adequate preventive maintenance. The company recognized that these difficulties would increase when the company implemented the concept of Lean production.

Company F

Company F is a manufacturer of commercial vehicles. They had 4,000 employees and no maintenance personnel. Instead, they bought their maintenance from a contractor owned by the company. Even if maintenance was outsourced, the manufacturer was represented on the board of the contractor and the manufacturer had a very clear view of the strategic impact of maintenance. Hence, Company F had no maintenance strategy of their own, but rather specified target values for some strategically important performance measures. Based on this, the contractor set up its own strategy for achieving the specified goals. The manager of the contractor’s maintenance staff was awarded best maintenance manager in Sweden by the Swedish maintenance organization (UTEK).
Based on the literature study and the researcher's own 12 year experience from industrial maintenance, interviews were conducted within the six companies in order to find out their view on maintenance management and its strategic implications. The questions are appended in Appendix A, Interview guide 1. 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 (Yin, 2009). The respondents were managers responsible for maintenance in the companies, and the interviews were directed and open. Each interview took on average one hour and was recorded on audio-tape. In addition to the interviews, observation notes were taken during the company visits. By observing the studied system, the researcher may verify or dismiss data obtained through other sources such as interviews and documents (Merriam, 1998). Further, additional documentation was provided by the companies in some cases. Yin (2009) finds that documents play an explicit role in any case study. Relevant documents provide reliable data as to the formal structures and real outcomes of the system. The collected data was analyzed through pattern matching logic and cross-case analysis. Pattern-matching logic is one of the better analysis methods available for case studies (Yin, 2009). This technique is essentially about comparing empirically observed patterns with predicted ones. The predictions in this case were based on results from the literature study, as well as the researcher’s own experiences from industry. Cross-case synthesis is an analysis technique in which the researcher aggregates findings from a series of individual studies (Yin, 2009). This technique is especially relevant when a case study consists of more than one case.

The study showed how different companies viewed their maintenance as a contributor to the companies’ overall goals. Further, it revealed how the companies viewed maintenance-related KPIs and the sourcing of maintenance.

Based on the findings of the research clarification and the first descriptive study, a three-year research project was launched. The aim of the project was to develop tools and methods for strategic maintenance management. These tools and methods have to be simple and easy to use, so that manufacturing companies, with relatively scarce resources, can increase the performance of their maintenance activities. Thereby, the maintenance may contribute to the competitiveness of the company. The research project was conducted in close cooperation with companies C, D, and E from the first, descriptive study. One of the companies belongs to the reference companies, and the other two belong to the companies with less developed maintenance programs. For the new research project, the companies were re-labeled so that the previous Company D was labeled Company A, previous Company C was labeled Company B, and previous Company E was labeled Company C.
2.3.3 Prescriptive study 1: - Formulation of maintenance strategies

The first prescriptive study developed and tested a work process for the formulation of maintenance strategies. The study, conducted in 2008, was for the most part performed as an embedded multiple case study. One exception was a smaller study labeled *Prescriptive study 1a* in Figure 3. That was a small study of stakeholder involvement in the identification of strategic performance indicators for production maintenance. This study, further described in Salonen and Bengtsson, (2008), was performed in only one of the companies, as a holistic single case study.

The case study was performed over a period of six months. Participants in the study were three researchers and two people from each company. The participants from the companies were all people responsible for maintenance at their respective company. Except for the previously mentioned part, *Prescriptive study 1a*, the study was performed in close cooperation with the three companies. During this period, the researchers and representatives from the three case companies developed and tested a work process for the formulation of maintenance strategies. In three workshops, various steps of the process were discussed. Between the workshops, the companies tested steps that were suggested during the previous workshop, and the result was discussed at the following workshop. At this stage of the research, participant observations were a major data source. By participating, the researcher becomes a part of the studied system, which provides data otherwise hard to obtain (Yin, 2009). The data was analyzed through pattern-matching logic, comparing the outcome of the steps with the predictions based on the team members’ experiences and knowledge.

2.3.4 Descriptive study 2: - Implementation of maintenance strategies

As a result of *Prescriptive study 1*, the participating companies formulated maintenance strategies. The next step in the project was to follow the implementation of the formulated maintenance strategies in the companies. This second descriptive study was performed during the spring of 2010 to identify some of the driving forces and obstacles associated with the implementation of maintenance strategies. The study is based on observations, interviews and, in one of the companies, a survey. The interviews were performed both with individual respondents and group interviews. All of the interviews were partially directed open and partially semi-structured. The questions are appended in *Appendix A, Interview guide 2*. Since the maintenance staff in one of the companies consists of about 50 people, a small survey was performed in order to capture as much as possible of their opinion of the implementation work. The survey questionnaire is appended in *Appendix A, Survey*. The data analysis was performed through clustering, 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. In addition to driving forces and obstacles, the study also covers some of the attitudes of the personnel effected by the strategy implementation. This study is directly linked to RQ2.

2.3.5 Prescriptive study 2: - The Cost of Poor Maintenance

This study intended to test and evaluate the concept Cost of Poor Maintenance as a basis for the improvement of maintenance performance. The concept is based on a well-known model for measuring the cost of poor quality. A theoretical model was presented during the autumn of 2009 for the industrial participants, and was discussed regarding its usability, pros and cons. Further, the theoretical model was discussed in a workshop with fellow researchers to further strengthen the validity of the concept. Cost of Poor Maintenance has been applied in the case companies to varying extents, but is not yet fully tested. The initial results have proven promising, though, and serve as an initial verification of the concept.

2.3.6 Descriptive study 3: - Results from strategic maintenance development

The last study was performed in order to analyze and describe the results in the case companies, achieved through the use of the developed processes. Also, the study shows what their experiences are from working with structured strategic maintenance development. The data used for this study is collected through document studies and directed open interviews, conducted during the autumn of 2010 with the maintenance managers of the companies. The interview questions are appended in Appendix A, Interview guide 3. The data analysis is based on Pattern-matching logic and Cross-case analysis.
2.4 THE QUALITY OF THE RESEARCH

It is important that researchers reflect on the quality of their conducted research. This reflection should take place throughout the whole research process. The term quality has many definitions. However, in this dissertation, Juran’s definition has been chosen, stating that: “Quality is fitness for use” (Juran, 1989; p.15). In other words, the research performed should be fit for use. Further, since this is applied industrial research, there are two categories of users, academia and industry. In this section, the researcher reflects on how the quality of the performed research may be assessed and what steps the researcher has taken in order to strengthen the different quality criteria. The outcome of the performed research will be discussed in Section 5.3. Finally, the researcher discusses his own role in the research process.

2.4.1 Validity

The term validity describes to what extent a researcher’s chosen method is feasible for the studies of the intended phenomenon (Gummesson, 2000). Validity is often divided into the sub-groups of internal and external validity, and, in some cases, even face validity. The three sub-groups are briefly described below.

Face validity

According to Arbnor and Bjerke (1994), face validity means to subjectively evaluate the plausibility of the research results. This has been done by letting the industrial partners assess the findings of the researcher.

Internal validity

According to Merriam (1998), internal validity deals with the degree to which the research results describe reality.

Merriam (1998) lists six basic strategies for ensuring inner validity:

- **Triangulation** – using multiple investigators, multiple data sources, or multiple methods to confirm findings.
- **Member checks** – letting the people, from whom the data originates, confirm the plausibility of the findings.
- **Long-term observation** – gathering data over a period of time.
- **Peer examination** – Asking for colleagues’ opinions concerning the findings.
- **Participatory or collaborative modes of research** – involving participants in all stages of the study.
• Researcher’s bias – clarifying the researcher’s assumptions and theoretical orientation.

In order to strengthen the internal validity of this research, multiple data sources have been used. This has enabled the researcher to triangulate the findings. Also, the findings have continuously been confirmed as plausible by the industrial participants, as well as by research colleagues. Further, the majority of this research has been conducted in a collaborative mode over a period of three years, which further strengthens the internal validity.

External validity

According to Merriam (1998), external validity deals with the degree to which the research results can be generalized. A prerequisite for external validity is that internal validity is achieved.

When working with case studies, it is always difficult to ensure the possible generalization of the results. Each studied case is unique, and, therefore, it might be difficult to identify the similarities between different cases. However, by using multiple cases, the probability for generalization increases. In the first stage of this research, six companies participated. Later, three companies were selected in order to reflect different challenges and conditions.

2.4.2 Reliability

Reliability describes to what degree a study may be repeated and provide the same results. When dealing with qualitative research, reliability is always problematic. One reason for this is that the researcher seeks to explain how the studied phenomenon is perceived by its actors, rather than how it is objectively constructed (Merriam, 1998). Another problem is that it is impossible to recreate the state of the company and its actors exactly as they were when the company was studied. Nonetheless, the interview guides and questionnaire used are appended in the dissertation to make repeated interviews possible.
2.4.3 The researcher’s role in the research process

It is unavoidable that the researcher influences his or her research. This is especially true when conducting case studies through participant observations. In addition to the researcher’s epistemology and ontology, his or her background and pre-understanding of the research area influence the research in various ways. This influence may contribute to the research results; it may also induce bias on the performed research, as well as on the achieved results.

The researcher has 21 years of experience from manufacturing industry, of which ten years was in practical maintenance work and two years in maintenance development. This means that the researcher has vast experience of maintenance in manufacturing industry. Such a long experience most certainly has given the researcher a pre-understanding of the research area. With such a pre-understanding, the researcher has had some obvious advantages, both when designing and when conducting the case studies. By using previous experiences, the researcher has, for example, been able to pinpoint critical issues that the respondents have not always have been aware of themselves. Also, the researcher has identified some of the answers being based on assumptions rather than facts.

However, such a pre-understanding may also cause bias. To avoid, or at least minimize, possible bias, the researcher started his Ph.D. studies by performing a thorough literature study that focused on finding studies with diverse views on strategic maintenance management in manufacturing industry, in order to challenge his pre-understanding.

Also, during the case studies, the researcher has taken active precautions to avoid bias, as well as to avoid biased influence on the industrial participants. The latter has been especially important in the early stages of the research process within the less mature maintenance organizations. This has been achieved by discussing research results with all the industrial participants in order to get verification from several experienced sources within industry. Also, some of the results have been discussed with other industrial maintenance experts, formally and informally.

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3 Years 1980 - 2002
CHAPTER 3

3 FRAME OF REFERENCES

This chapter presents the theoretical frame of references on which this dissertation rests. The framework covers theories and definitions in the fields of maintenance, strategy, implementation of strategies and performance measurements. As depicted in Figure 4, the first two sections, maintenance and strategy, are chosen to provide the basic understanding necessary to comprehend the concept of maintenance strategies, which is central to RQ1. As a theoretical base for RQ2, theories on the implementation of strategies, change management and the implementation of maintenance concepts are reviewed in addition to maintenance. The last part of this literature study, performance measurements, provides theories connected to RQ1 and RQ3. The chapter ends with some reflections regarding the literature study.

Figure 4: The main areas of literature studies in relation to the research questions.
3.1 MAINTENANCE

The term maintenance is quite well-defined in literature. Other maintenance related terms, however, are quite loosely defined. For example, maintenance strategy, maintenance concepts, and maintenance approaches are terms that authors seem to define in different ways, and sometimes it is hard to know which definition a given author refers to when using the terms. Therefore, it is necessary to describe which definitions of the terms are used in this dissertation.

3.1.1 Maintenance definitions

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” (SS-EN 13306, 2001, p.7).

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).

Gits (1994) describes industrial maintenance as a process that supports the production process, in which input, in the form of material and manpower, for example, is transformed into output; in effect, into finished products. Maintenance is a secondary process that contributes to the achievement of production, see Figure 5.

![Figure 5: The relationship between Production and Maintenance (Gits, 1994).]
3.1.2 Maintenance approaches

Maintenance may be performed according to various approaches. A common overview of maintenance approaches and their relationships is illustrated in the standard SS-EN 13306, as shown in Figure 6.

![Figure 6: Overview of different maintenance approaches (SS-EN 13306, 2001).](image)

As indicated in Figure 6, maintenance is divided in two main approaches, preventive and corrective. Preventive maintenance is further divided into two sub-categories: Predetermined (periodic) maintenance and Condition based maintenance.

**Corrective maintenance**

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

**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, who defines preventive maintenance as “...any planned maintenance activity that is
designed to improve equipment life and avoid any unplanned maintenance activity.” (Wireman, 1990, p. 98).

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, decreasing the costs for scrap/quality, downtime, and lost sales.

3.1.3 Maintenance concepts

In order to increase the effectiveness of maintenance and to focus the maintenance activities, various concepts have been developed. Examples include Reliability Centered Maintenance, RCM, Total Productive Maintenance, TPM, Terotechnology, and Total Quality Maintenance, TQMain. The ideas behind these concepts are briefly described below.

**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 wants 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?

**Total Productive Maintenance**

TPM is a Japanese concept for maintenance. There are several definitions of the concept. According to Nakajima (1988), who introduced the concept, TPM may be defined as “productive maintenance involving total participation” (Nakajima, 1988, p. 10). Several elaborations of the definition may be found in literature. One descriptive definition is presented by Pomorski, who defines it as “… a structured equipment-centric continuous improvement process that strives to optimize production effectiveness by identifying and eliminating equipment and production efficiency losses throughout the production system life cycle through active team-based participation of employees across all levels of the operational hierarchy.” (Pomorski, 2004, p. 6).

According to Pomorski (2004), the Japanese Institute of Plant Maintenance (JIPM) defines the aims of TPM as:

1. Establishing a corporate culture that will maximize production system effectiveness.
2. Organizing a practical shop-floor system to prevent losses before they occur throughout the entire production system life cycle, with a view to achieving zero accidents, zero defects and zero breakdowns.
3. Involving all functions of an organization including production, development, sales and management.
4. Achieving zero losses through the activities of “overlapping small groups.”

**Terotechnology**

Terotechnology evolved in Great Britain in the early 1970s as a reaction to a report from the Ministry of Technology that emphasized the importance of the link between maintenance costs and the feedback of information to plant designers (Kelly et al., 1982). Terotechnology has been defined as: “A combination of management, financial, engineering and other practices applied to physical assets in pursuit of economical life cycle costs. Its practice is concerned with the specification and design for reliability and maintainability of plant, machinery, equipment, buildings and structures, with their installation, commissioning, maintenance, modification and replacement, and with the feedback of information on design, performance and costs” (Kelly et al., 1982, p. 132).

Basically, from Kelly et al.'s (1982) definition, it is understood that the concept attempts to widen the scope of maintenance from the traditional operations view to a lifetime perspective, as illustrated in Figure 7.

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4 The original reference (Japan Institute of Plant Maintenance, 1996) has not been available for review.
Total Quality Maintenance

TQMain is a concept developed and introduced by Al-Najjar (1996). The concept is defined as: “...a means for monitoring and controlling deviations in a process condition and product quality, and for detecting failure causes and potential failures in order to interfere when it is possible to arrest or reduce machine deterioration rate before the product characteristics are intolerably affected and to perform the required action to restore the machine/process or a particular part of it to good as new.” (Al-Najjar, 1996, pp. 10-11).

TQMain is based on the use of condition monitoring and the utilization of a common database in order to coordinate and utilize the condition monitoring data together with data from Quality control, Environmental conditions, and Production operations.

3.1.4 Maintenance management

Kelly expresses the maintenance objective as: “...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) This objective is not fulfilled haphazardly. Rather, it has to be thoroughly managed, and there are a number of models suggested for maintenance management. As examples, two models are presented below.

Crespo Marquez and Gupta (2006) mean that maintenance management has to align with business activities at strategic, tactical, and operational levels. 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. Actions are performed at a tactical level to determine the sufficient amount of maintenance resources (skills, equipment, and so on) necessary to fulfill the maintenance plan. The result should be a detailed maintenance program with scheduled assignments of the sufficient resources for each asset. At operational level, actions 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) presents another model for explaining the inner processes of a typical maintenance system, see Figure 8. Coetzee’s (1999) 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. The managerial planning consists of maintenance policy setting, maintenance procedure definition, objective setting and business planning. Objectives and business plans are set regularly, 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.

![Diagram of the maintenance cycle](image)

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

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.
Murthy et al. (2002) present a model for strategic maintenance management, based on two assumptions:

1. Maintenance management is a vital core business activity and must be managed strategically.
2. Effective maintenance management has to be based on quantitative business models, integrated with other focus areas such as production.

In Murthy’s et al (2002) model, maintenance is described as a multi-disciplinary activity. It deals with:

- Scientific understanding of the mechanisms of degradation, including condition monitoring and analysis.
- Quantitative models for the prediction of what impact actions such as operations and maintenance have on the equipment degradation.
- Strategic management of maintenance.

The management model starts by assessing the state of the equipment based on the inherent reliability of the equipment. In addition to the reliability, the maintenance demand depends on the operations load on the equipment, which in turn is influenced by commercial decisions on overall business level (Murthy et al. 2002).

### 3.1.5 Financial implications of maintenance

There is large economical potential in optimum production maintenance. According to Maggard and Rhyne (1992), the maintenance costs can represent 10-40% of the production cost in a company. Coetzee (2004) asserts that the numbers should be 15-50%, and Bevilacqua and Braglia (2000) state that maintenance costs can represent as much as 15-70% of the total production cost. According to Parida (2006), Altmannshoffer estimates the total value of maintenance budgets in Europe to be about 1,500 billion € per year.\(^5\) Ahlmann (2002) has estimated that the total cost of maintenance in Sweden constitutes 6.2% of the industry’s turnover, which in year 2002 meant close to 200 billion Swedish krona. At the same time, Wireman (1990) claims that as much as one-third of the maintenance cost is unnecessarily spent due to bad planning, overtime costs, the bad use of preventive maintenance, and so on. Such waste also leads to increased production costs.

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\(^5\) The original reference (Altmannshoffer, 2006) has not been available for review.
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

Despite the large maintenance costs, shown above, there is no consensus on how to visualize the full financial aspects of maintenance. Financial models for maintenance do exist, though, and this chapter presents some of them.

The basic models of maintenance costing divide the maintenance costs into direct and indirect costs. Direct costs consist of labor costs, spare parts, and other costs that clearly are directly linked to maintenance activities. Indirect costs include the cost of recovering for lost production (due to equipment failures), the cost of insufficient quality, etc. Even though this division is well-known, not much attention is paid to the indirect maintenance costs.

One exception from this is presented by Ahlmann (2002). Not only does Ahlmann (2002) consider the indirect costs, but he adds a third category of maintenance costs, non-realized revenue. This category refers to the income loss due to reduced sales volumes, missed delivery dates and such, caused by poor maintenance. According to Ahlmann (2002), a study conducted by the Swedish Centre for Maintenance Engineering and Management, UTC, showed that 55% of the maintenance costs were direct costs, 24% indirect costs and 21% non-realized revenue. In relation to the industry’s turnover, the average direct maintenance cost was 3.5%, the indirect maintenance cost was 1.4% and non-realized revenues constituted 1.3% of turnover. This added up to a total of 6.2%, equating to an economic influence of maintenance of about 190 - 200 billion Swedish krona annually, see Figure 9.
Ahlmann’s model gives a comprehensive understanding of the impact maintenance has on profitability. However, there are other models as well of financial implications of maintenance presented in the literature. For example, Oke (2005) presents a model for measuring the maintenance profitability performance. The model is based on fixed prices per amount of service provided, as well as per amount of utilized resources. This model attempts to show the profitability from an internal accounting perspective, rather than the financial contribution on the production department.

Another approach for quantifying the financial impact of maintenance is proposed by Haarman and Delahaye (2004). Value-driven maintenance, VDM, is basically focused on a formula derived from the Present Value model, used for the calculation of return on investments. The VDM concept is built on the assumption that there are four value drivers in maintenance: Asset utilization; Safety, Health & Environment; Cost control; and Resource allocation.

Kommonen (2002) builds his cost model on three sets of variables:

- **Internal objective variables**: (downtime costs + maintenance costs)/ replacement value of production equipment.
- **Exogenous variables**: the amount of production equipment, the downtime costs of production, the utilization of production equipment, and technology factor.
- **Action variables**: preventive maintenance and sub-contracting.

Based on this model, Kommonen (2002) proposes a benchmark tool for the evaluation of the profitability of a company’s maintenance activities.
Finally, Liyanage and Kumar (2003) apply the balanced scorecard concept to maintenance, trying to identify different value drivers in maintenance with a focus on the oil and gas industry. Some researchers propose models for the formulation of optimum selection between the approaches of run to failure (RTF), periodic preventive maintenance (PM), condition-based maintenance (CBM), and for the optimization of PM intervals (Löfsten, 1999; Al-Najjar, 1999; Percy and Kobbacy, 2000; Khalil et al., 2009).
3.2 STRATEGY

This section describes the basic theories on strategies, starting with definitions of the term and continuing with strategy formulation and functional strategies. The last parts of the section describe theories on maintenance strategies and how to formulate them.

Mintzberg et al. (1999) state that there is no single definition for the term strategy. However, they choose to use the following definition: “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:

- 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.
- Effective strategies develop around a few key concepts and thrusts, which give them cohesion, balance and focus.
- Strategy deals not only with the unpredictable but also with the unknowable.
- 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) point out that strategies should fulfill the following criteria in order to be effective: clear decisive objectives; maintaining the initiative; concentration; flexibility; coordinated and committed leadership; surprise; and 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 the firm strives for and the means by which it tries to get there.
3.2.1 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, and (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: (1) they affect the ability of an organization to achieve its objectives, and (2) 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.

3.2.2 Maintenance strategy

Maintenance strategy is not well-defined in literature. Some authors define it as the choice between corrective maintenance and various kinds of preventive maintenance see, for example, Ratnayake and Markeset (2010), Chelbi et.al. (2008), and Eti et.al. (2006)). 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 (Corrective Maintenance), 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 of transforming business priorities into maintenance priorities. By addressing current or potential gaps in maintenance performance, a generic maintenance plan will be developed.

Jonsson (1997) emphasizes 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 (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 divided in two groups 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 article, Pinjala et al. (2006) show indications of a relationship between business and maintenance strategies.

3.2.3 Formulation of maintenance strategies

Few authors have presented any models for the formulation of maintenance strategies. Some models do exist, though, and two are presented in this section.

Kelly (2006) argues that the ways in which the maintenance function might be affected by its dynamic relationship with 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 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).](image-url)
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.

![Diagram](attachment:image.png)

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

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.

Wilson (1999) also points out the importance of having the maintenance function aligning with the overall business goals. As a starting point for a maintenance strategy, Wilson (1999) suggests that the need for change be assessed. Figure 12 describes the range of maintenance policy sectors that Wilson (1999) argues have to be considered when identifying the key objectives of the maintenance function. From the customer requirements, the strengths and weaknesses of the current practices may be assessed. The functional requirements of the equipment and the various needs for maintenance should then be considered.

When the need for change is established, the maintenance strategy may be developed. This development starts with stating the maintenance philosophy. Such a statement may define
some overall performance standards. Next, the aims and objectives of the maintenance should be considered. The third step is to assess and evaluate the maintenance practices and issues. For this assessment, the various policy sectors shown in Figure 12 may be considered. From the assessment, a maintenance program may be developed. Then tactics may be formed in order to integrate the new practices with the existing ones. In the final step, an implementation plan is set.

Figure 12: The range of maintenance policy sectors and their practices (Wilson, 1999)
3.3 IMPLEMENTATION OF MAINTENANCE STRATEGIES

A well-formulated strategy is only effective if properly implemented. This section presents theories on strategy implementation, change management and the implementation of maintenance and quality management concepts.

3.3.1 Implementation of strategies

Over the years, researchers have noted that many companies fail to implement their strategies. Still, various authors have pointed out that the subject of strategy implementation is not much studied (Alexander, 1985; Aaltonen & Ikävalko, 2002; Galpin, 1997). However, some published material does indeed exist that addresses the issues of strategy implementation. For instance, Beer and Eisenstat (2000) identify six barriers to strategy implementation: (1) top-down management style, (2) unclear strategy and conflicting priorities, (3) an ineffective senior management team, (4) poor vertical communication, (5) poor coordination across functions, businesses or borders, and (6) inadequate down-the-line leadership skills and development.

Aaltonen & Ikävalko (2002) propose a model for the implementation of strategies that focus on the components: communication, interpretation adoption, and action. Among the findings of their studies was a common concern among the interviewees regarding the creation of shared understanding of strategy among the organizational members. A lack of understanding of strategy was one of the obstacles of strategy implementation observed in their study. The main problem seemed to be when the strategic issues were to be applied in every day decision-making (Aaltonen & Ikävalko, 2002). Other important findings of their study include obstacles such as conflicting activities, lack of time, and lack of alignment between strategy and organizational compensation systems. Among other published material regarding strategy implementation are, for instance, Reed and Buckley (1988), Crittenden and Crittenden (2008), and Cocks (2010).

When looking at functional strategies, common change management theories may very well be applied. Further, when looking at maintenance strategies specifically, there are a great deal of studies published on the implementation of maintenance and quality management concepts like TPM, RCM, CBM, and TQM. These concepts are not to be looked upon as fully identical to maintenance management strategies. However, it is fair to assume that the implications of implementing these concepts could very well be valid for other strategic change programs within maintenance.
3.3.2 Implications of change management

Change management is widely studied, and there is an extensive amount of published work on the subject. Change management may be considered “... the art or science of making sense of the organizational chaos that change brings upon a company's stakeholders” (Ledez, 2008, p. 112). Within change management, there are several approaches presented for managing change by authors such as Kotter (1996), Bechtle & Squires (2001), and Stanleigh (2007). The authors mentioned give rather similar advice. As an example, Kotter (1996) has suggested an eight-stage process for effective change management:

1. Establishing a sense of urgency
2. Creating the guiding coalition
3. Developing a vision and strategy
4. Communicating the change vision
5. Empowering employees for broad-based action
6. Generating short term wins
7. Consolidating gains and producing more change, and
8. Anchoring new approaches in the culture

In addition to these various pieces of advice regarding how to facilitate change, some authors also try to identify possible pitfalls of change management. Ledez (2008) lists ten ways to fail at change management, and all ten are examples of bad management. Examples include demanding change rather than arguing for it or never giving any good feedback to the staff. Stanleigh (2007) also provides examples of possible pitfalls, such as not engaging all employees, or managing change only at the executive level.

3.3.3 Implications of maintenance concepts implementation

In order to find studies of change management in a maintenance context, there are several studies of the implementation of TPM, RCM, CBM, and TQM to be analyzed. Coetzee (1999) contends that it is rather common for organizations to try increasing maintenance efficiency through some highly publicized philosophy or maintenance technique, such as RCM, TPM, CBM, CMMS, an auditing system, etc. However, he concludes that: “While each of these will certainly contribute to the success of the maintenance organizations, the haphazard way in which they are introduced is a certain formula for sub-optimality (Geraerds, 1990).” (Coetzee, 1999, p. 276). Most works concerning the implications of maintenance concept implementations are

6 The original reference (Geraerds, 1990) has not been available for review.
published before 2003. Most of the later works focus on cultural contexts. Examples from the latter group include Ahuja & Khamba (2008) and Salaheldin (2009).

Hansson et al. (2003) have focused on the organizational change related to obtaining employee and management commitment. They consider the following types of activities to be important for the commitment (Hansson et al. 2003):

*Support and leadership:* the management should visibly show their commitment to the implementation and also secure that sufficient resources are assigned to the implementation work.

*Strategic planning:* secure that the development work is clearly linked to the strategic goals of the company. Employee commitment is further promoted if the employees are involved in the strategic planning process.

*Planning the implementation:* develop a clear scope so that obstacles and driving forces may be identified. The use of cross-functional teams for planning and implementation promotes involvement.

*Buying-in and empowerment:* sell the concept to each group. By giving the involved personnel increased responsibility, and sufficient means to carry the responsibility, the groups mature and get further involved.

*Training and education:* all successful TQM initiatives have in common that they have applied extensive education and training of all employees.

*Communication and information:* communication and information promote understanding and involvement. Open communication must be allowed in order to detect any misunderstanding regarding the implementation. Using informal forums for discussing the concept implementation promotes the acceptance of the concept.

*Monitoring and evaluation:* good monitoring and evaluation provides feedback on results that motivate the management. This in turn motivates and engages the employees. Visualization of the results increases motivation.

Most studies on the implementation of concepts such as TPM, TQM, CBM, and RCM identify rather similar driving forces and obstacles (Park & Han, 2001; Tsang & Chan, 2000; Davis, 1996; Lycke, 2000; Nord et al., 1997; Hodggets et al., 1999; Bengtsson, 2007; Yusof & Aspinwall, 2000; Koochaki & Bouwhuis, 2008). The driving forces mostly concern good leadership, information, communication, and assigning the necessary resources to the change. In the same manner, the obstacles are mainly in the same categories, but also include cultural aspects.

Chan et al. (2005) point out that bad communication between shifts, in combination with different work habits in different shifts, made the implementation cumbersome. Among the driving forces, Chan et al. (2005) mention sufficient guideline/training in order to sell the
concept. Other driving forces are: the selection of positive team members, a well-developed maintenance training system for transfer of maintenance know-how to operators, management support, and the use of model machine implementation. Anthony et al. (2002) point out that a lack of awareness of quality at management level is a weakness when implementing TQM.

By analyzing the results from three surveys, Sohal and Terziovski (2000) identify five obstacles to the adoption of quality management practices: benefits less than cost, resistance by managers, resistance by employees, lack of government assistance, and resistance by unions. Further, they conclude from three different surveys that:

- Organizational performance suffers when responsibility for quality is allocated to a specialized quality department.
- Quality management practices are most implemented in the operations area and least in the area of human resources.
- There is a significant jump in quality management practices implementation in the administration area.
- The popularity of tools and techniques has diminished even though they are believed to have a positive impact on performance.
- Companies that have invested in leadership training are more likely to succeed than those that did not.

The following factors are considered critical to the successful implementation of TQM programs:

- Positive attitudes towards quality among managers at all levels, as well as staff.
- Managers in a leadership role must have appropriate education and training in quality management principles and techniques.
- Continuous customer and supplier feedback.
- Development of appropriate performance indicators and rewards.
3.4 PERFORMANCE MEASUREMENTS

When improving maintenance, as well as any other industrial function, performance measurements are essential. This section presents some theories on performance measurements in general, as well as maintenance performance measurements.

3.4.1 Properties for performance measurements

Wisner and Fawcett (1991) identify several properties for performance indicators 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.

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 recognizes 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 we will call secondary objectives.
3. What each stakeholder requires in exchange for undertaking its role in supporting the organization’s strategy.
4. How to measure the organization objectives and stakeholder roles.

3.4.2 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 behaviors (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, labor 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.

Tsang (1998) and Ahlmann (2002) utilize the balanced scorecard (Kaplan and Norton, 1992) for setting up a maintenance performance measurement system. Both attempt to cover a broader view of the maintenance scope. Kutucuoğlu et al. (2001) base their performance measurement system on the matrix structure of Quality Function Deployment, QFD. They 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) notes 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.

In order to catch different aspects of maintenance as well as their impact on different levels of the business, Parida and Chattopadhyay (2007) suggest a multi-criteria hierarchical framework for maintenance performance measurement. The framework is built as a matrix between three hierarchical levels and seven criteria considered essential to the maintenance program of a company. The three hierarchical levels are strategic, tactical and operational. The seven criteria are: equipment/process related; cost/finance related; maintenance task related; learning, growth & innovation; customer satisfaction related; health, safety & environment; and employee satisfaction.

**Examples of measures**

There is a huge amount of maintenance related performance measures described in literature. Below, 13 performance measures, intended to be used for benchmarking within European industry, are presented as examples (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.
3.5 REFLECTIONS FROM THE THEORETICAL REVIEW

When conducting this literature study, it was somewhat surprising that maintenance seemed to be poorly studied from a management perspective. While other parts of manufacturing organizations are rather well-studied, there are very few academic published works dealing with maintenance management. The main part of maintenance research deals with either mathematical models for the optimization of maintenance intervals or various technologies for condition monitoring.

Also, it is striking how little small and medium-sized companies in the manufacturing industry are studied. Almost all studies and their concluding models and proposals are designed with process industry or large manufacturing companies in mind. Frameworks, models and processes proposed are often too complex and resource demanding for small and medium-sized manufacturing companies to use.

Small and medium-sized companies in the manufacturing industry represent a considerable proportion of the industry. Therefore, it is of great interest to study their terms and increase the understanding for the business as a whole.
CHAPTER 4

4 RESULTS

This research on strategic maintenance development started in June of 2006 and finished in December of 2011. As described in Chapter 2 Research methodology, five case studies have been performed in a total of six companies. The companies have been selected from their differences in size, branch, production techniques, and so on. In this chapter, the results from the five case studies are presented.

The chapter is structured in accordance with Section 2.3 The research process, containing one sub-section for each phase of the research. The results presented in the sub-sections are condensed from the appended papers.

4.1 THE NEED FOR STRATEGIC MAINTENANCE DEVELOPMENT

In order to clarify the scope of the research, a literature study was performed. The results of the study, presented in Chapter 3, are the following:

4.1.1 Results from the review of maintenance literature

From the review of maintenance related literature, it is apparent that basic definitions of maintenance and related terms are quite well-defined. However, terms like maintenance concepts and maintenance approaches lack uniform definitions. The concepts presented in this section focus on different aspects of asset dependability and, therefore, have their respective pros and cons.

In the literature on maintenance management, as presented in Section 3.1.4, some authors build maintenance management models, focusing on the technical aspects with less regard to the organizational aspects of management.

As shown in this section, there are several financial models for maintenance. Even though the models presented in this section all have their merits, they do not fully distinguish between the costs necessary for upholding the agreed dependability and those costs that
really do not add any value to the production department. That means that the models still are not fully applicable for the optimization of maintenance programs.

4.1.2 Results from the review of strategy literature

One important result from the literature review is the insight that the term maintenance strategy lacks a unanimous definition among researchers. One reason for this is probably that it is unclear whether the term should refer to the maintenance of a single machine or even single component or if it should refer to the overall maintenance management. For this research, Pinjala’s (2006) definition is used. 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 often quite complex and resource demanding, indicating that the processes are mainly developed for large, or at least resourceful, organizations.

4.1.3 Results from the review of implementation literature

An important result from this review is the fact that researchers point out that even though many companies fail when implementing strategies, the subject of strategy implementation is not studied to any larger extent. Also, there seem to be a rather small amount of published works on functional strategies in general, and especially on maintenance strategies.

The obstacles and driving forces mentioned in literature on strategy implementation, change management, and concepts implementation are more or less the same, focusing on (1) Vision and goal setting, (2) Leadership, (3) Resource assignment, (4) Training and education, (5) Communication, and (6) Cultural aspects. Several of the published works studied mention a lack of insight and awareness as obstacles for the successful implementation of strategies and maintenance concepts. Sohal and Terzievski (2000) also argue that management should have sufficient education and training in quality management principles and techniques in order to succeed in the implementation of TQM.

4.1.4 Results from the review of performance measurement literature

There is a consensus that performance measures in general should reflect the overall strategic goals of the company. Also, there is a consensus that maintenance performance measures should cover different aspects of the organizations goals, such as monetary, quality, productivity, etc. In addition to the maintenance performance indicators shown in the chapter, there is a vast amount of metrics to choose from. Notable is that the costs,
mentioned in the benchmarking measures, proposed by EFNMS (2002), are all direct costs. In the studied literature, no mentioned performance indicator shows the indirect cost of maintenance.

4.2 THE INDUSTRY’S VIEW ON STRATEGIC MAINTENANCE DEVELOPMENT

Descriptive study 1 was performed to compare the view toward maintenance strategies in companies with and without formulated maintenance strategies. The study is mainly based on interviews with maintenance managers in the companies. The results of the study are fully presented in Appended Paper I, Salonen (2008a) and in Salonen (2008b). A summarized version of the results is presented below.

As a reference for comparison, companies E and F, both awarded for their excellence in maintenance management by the Swedish maintenance society (UTEK), were studied. Both companies had written maintenance strategies that were well-aligned with the companies’ business strategies, although one of them let their maintenance supplier formulate the strategy. Also, these companies used performance indicators for control on strategic as well as tactical and operational levels. The companies worked with continuous improvements of their maintenance activities and were both satisfied with their maintenance activities. Nonetheless, both companies were aware of the remaining improvement potential. In companies E and F, the maintenance managers and the top-level management shared the view of maintenance as a strategically important function.

Companies A, B, C, and D were compared with the reference companies. All four lacked expressed maintenance strategies. In these companies, the maintenance was managed by persons, in different positions, without any formal training in maintenance management or maintenance engineering. In companies A and B, the managers were also responsible for parts of the production. In the conducted interviews, companies C and D stated that they often tend to prioritize production over maintenance issues. The maintenance managers at these four companies all expressed concern over the status of their production maintenance. Also, these companies lacked relevant performance indicators for controlling their maintenance. All four companies used Computerized Maintenance Management Systems, CMMS, for their maintenance activities, but none of them utilized the full functionality of the system. All four companies were more or less dissatisfied with the outcome of their maintenance activities. The maintenance managers at these companies had a clear view of the strategic importance of maintenance. However, they had not been able to communicate this view to the top-level management.
4.3 FORMULATION OF MAINTENANCE STRATEGIES

Prescriptive study 1 developed and tested a work process for formulation of maintenance strategies. The study was mainly based on workshops and participative studies. A full description of the process is presented in Appended Paper II, Salonen (2010), and below follows a condensed version. Based on the findings from Descriptive study 1 and the research clarification, a proposed process for the formulation of maintenance strategies emerged.

Figure 13: A schematic view of the maintenance strategy formulation work-process, Appended Paper II, Salonen (2010).

This process, depicted in Figure 13, starts with the (1) company vision and mission, top left in the figure. Based on the company vision and mission, the (2) company’s strategic goals are formulated. These goals are supposed to be supported by all functional strategies. For the maintenance strategy, it is essential not only to consider the overall strategic goals of the company, but also the strategic goals of the production, the maintenance organization’s customer. Considering the strategic goals of both the company and the production department allows (3) the strategic goals of maintenance to be defined for the organization. To satisfy all stakeholders, the strategic goals of the maintenance organization should reflect both efficiency and effectiveness, see Figure 14.
In order to evaluate the fulfillment of the strategic goals, they have to be tied to (4) strategic performance indicators. There are advantages to involving all stakeholders, such as the production department and the owners, when choosing performance indicators. Such an approach increases the acceptance of the strategy among the stakeholders. Also, the performance indicators have to be well-defined in order to avoid misinterpretations, the use of different definitions at different departments, or drifting definitions. Further, data sources, data collection methods, and responsibilities may be defined in the strategy formulation. Once the performance indicators are defined, their current status may be measured. Current or potential gaps in maintenance performance should be addressed by (5) the overall GAP-analysis when setting up a maintenance strategy. Next, the organization has to identify which factors may potentially influence the gap between current and desired levels.

In the suggested work process, depicted in Figure 13, the gaps are matched against a set of factors, considered to be strategically important by various manufacturing companies (see further in Salonen (2008b)). These factors are probably different in different companies, depending on factors such as company size, branch and so on. A set of factors identified by Salonen (2008b) are suggested as a base to start from. These factors have further been categorized as relating to Man, Technology, or Organization (MTO7) as shown in Figure 15. In this work, the MTO concept has been used in order to avoid a situation in which companies build their maintenance strategies solely on investments in new technology. This has been considered important as research, Bengtsson (2007) for example, has shown that companies tend to rely on technological solutions without regard to organizational or human factors.

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7 The concept of MTO originates in the Swedish nuclear power industry and is the Swedish equivalent to the English term “Human factors.” Its aim is to include human and organizational aspects within the technological aspects of safety (Rollenhagen, 1997).
In the proposed model, a (6) Strengths, Weaknesses, Opportunities, Threats, SWOT, analysis is performed, addressing the identified gaps in relation to the factors considered strategic for the maintenance development. A list of actions may be identified from the result of the SWOT analysis. By prioritizing these actions in an appropriate way, a (7) strategic development plan may be set up. With this plan in place, the (8) maintenance strategy may be formulated. For such a document, the following structure is proposed:

- **Strategic alignment**
  - 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**
  - Definition of measures
  - Current status
  - Targets for the coming year
  - Strategic targets

- **Strategic action plan with time plans and assigned responsibilities within the areas of:**
  - Man (Human resources)
  - Technology
  - Organization

When the maintenance strategy is formulated, it should be reviewed by the Board of the company. By getting approval from the Board, it will be easier to invest the time and money
necessary to implement the proposed strategy. As depicted in Figure 13, the strategy should be periodically reviewed to ensure its validity.

4.4 IMPLEMENTATION OF MAINTENANCE STRATEGIES

Descriptive study 2 was performed to study the implementation of maintenance strategies with regards to driving factors and obstacles. The study is described in Appendix Paper III, (Salonen, 2011), and Table 2 summarizes the findings from the case study.

Table 2: Driving forces and obstacles, identified in Descriptive study 2. DF indicates a Driving Force, while Ob indicates an Obstacle.

<table>
<thead>
<tr>
<th>Factor</th>
<th>Company A</th>
<th>Company B</th>
<th>Company C</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Vision and goal setting</td>
<td>DF</td>
<td>DF</td>
<td>DF</td>
</tr>
<tr>
<td>2. Leadership</td>
<td>Ob/DF</td>
<td>DF</td>
<td>DF</td>
</tr>
<tr>
<td>3. Planning the implementation</td>
<td>Ob</td>
<td>Ob</td>
<td>Ob</td>
</tr>
<tr>
<td>4. Resource assignment</td>
<td>Ob</td>
<td>Ob</td>
<td>Ob</td>
</tr>
<tr>
<td>5. Training and Education</td>
<td>Ob</td>
<td>DF</td>
<td>Ob/DF</td>
</tr>
<tr>
<td>6. Communication</td>
<td>Ob/DF</td>
<td>DF</td>
<td>Ob/DF</td>
</tr>
<tr>
<td>7. Culture</td>
<td>Ob</td>
<td>Ob</td>
<td>Ob</td>
</tr>
<tr>
<td>8. Outsourced maintenance*</td>
<td>DF</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>(Business relationship)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9. New business strategy*</td>
<td>N/A</td>
<td>DF</td>
<td>N/A</td>
</tr>
<tr>
<td>10. New production concept*</td>
<td>N/A</td>
<td>N/A</td>
<td>DF</td>
</tr>
<tr>
<td>11. Lack of stakeholder awareness*</td>
<td>Ob</td>
<td>Ob</td>
<td>Ob</td>
</tr>
</tbody>
</table>

* Factors not found in literature study.

The first seven factors in Table 2 are presented in earlier literature on strategy implementation, change management and concepts implementation. The four last factors were identified through the case study, but are not mentioned in the previously studied literature.

As shown in the top row in Table 2, all companies had clear (1) *Vision and goal setting* through the formulated maintenance strategy and its KPIs. Also, within (2) *Leadership*, all companies viewed this as a driving force. The only exception was Company A, which suffered from poor leadership in the maintenance supplier organization. Even though all companies (3) *planned their implementations*, the planning was not as thorough as it should have been. Probably some of the obstacles due to poor (4) *Resource assignment* originated in the insufficient planning. It should be noted though that one major reason for poor resource assignment was the financial crisis that struck the industry hard during the study. The (5) *Training and education* suffered from the poor leadership in the maintenance supplier of
Company A. In Company B, the training of operators was a driving force, as well as in Company C. However, parts of the maintenance staff felt that they did not get sufficient training for their new roles. Most of the (6) Communication was regarded as good and therefore seen as a driving force in the strategy implementation. Once again, the problematic leadership in the maintenance supplier company made communication troublesome for Company A. In Company C, the personnel felt that the communication was a bit erratic in the beginning of the implementation work.

(7) Cultural obstacles were found in all three companies. These obstacles originated in an old view of maintenance craftsmen as being repair men, in effect people, who repair broken machinery, rather than preventing them from failing. This view was fostered by giving attention to those who repair the broken machinery, rather than those who obstruct production for the maintenance of functioning machinery.

For Company A, with its (8) Outsourced maintenance, the obvious business relationship between the production company and its maintenance supplier was seen as a driving force. Company B introduced a (9) New business strategy, which increased the demand for dependable production equipment. That was a strong driving force for the implementation of the new maintenance strategy. In a rather similar way, the (9) new lean production concept in Company C was a strong driving force for the strategy implementation in their maintenance program. Finally, there were those among the stakeholders in all three companies who showed (10) Low awareness of maintenance issues in general and especially lacked the insight into maintenance being a potential contributor to the competitiveness of the company.

4.5 COST OF POOR MAINTENANCE

Prescriptive study 2 introduced the concept of Cost of Poor Maintenance, CoPM, as a financial maintenance KPI. The idea behind the concept is to apply a well-known concept from the area of quality costing to the field of maintenance management. CoPM is a concept for visualizing the potential financial benefits of strategic maintenance development. The concept is based on the process model, used in quality costing, which distinguishes between costs of conformance and non-conformance. By setting these cost categories in a matrix with Preventive and Corrective maintenance, the costs are divided into four categories, as shown in Figure 16: Indispensable corrective maintenance, Non-accepted corrective maintenance, Valid preventive maintenance, and Poor preventive maintenance.
### Cost of Conformance

Corrective maintenance:
- Indispensable corrective maintenance: Corrective Maintenance due to:
  - Failures with random distribution and no measurable deterioration.
  - Failures which are not financially justified to prevent.

Valid preventive maintenance:
- Preventive Maintenance, necessary to uphold necessary dependability.
- Improvements intended to increase the reliability of equipment.

Non-accepted corrective maintenance:
- Corrective Maintenance due to:
  - Lack of preventive maintenance
  - Poorly performed preventive maintenance
  - Poor equipment reliability

Poor preventive maintenance:
- Unnecessary Preventive Maintenance
- Poorly performed Preventive Maintenance

### Cost of Non-conformance

Costs of non-conformance refer to the costs associated with unwanted deviations in equipment dependability. There are two categories of costs of non-conformance, as shown in Figure 16. One of them is costs for Poor preventive maintenance, the costs for preventive maintenance, PM, that does not prevent equipment from malfunctioning. This category includes poorly performed PM and unnecessary PM. The other category is Non-accepted corrective maintenance, which refers to the corrective maintenance of components, for which preventive maintenance could have prevented the component from malfunctioning. The costs may either relate to the maintained entity or to affected production equipment up-stream and/or down-stream in a production system.
Examples of which costs relate to which categories in the CoPM model are presented in Table 3.

**Table 3: Categories of costs related to CoPM (Appended Paper IV, Salonen and Deleryd, 2011).**

<table>
<thead>
<tr>
<th>Cost of conformance</th>
<th>Cost of non-conformance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Man-hours for maintenance (including administration)</td>
<td>X</td>
</tr>
<tr>
<td>Exchange parts</td>
<td>X</td>
</tr>
<tr>
<td>Lubricants</td>
<td>X</td>
</tr>
<tr>
<td>Other material for maintenance, e.g., rags, cleaning solvents, etc.</td>
<td>X</td>
</tr>
<tr>
<td>Lost production time</td>
<td>X</td>
</tr>
<tr>
<td>Logistics, e.g., for spare parts or entrepreneurs</td>
<td>X</td>
</tr>
<tr>
<td>Breakdown-related scrap and/or re-work</td>
<td>X</td>
</tr>
<tr>
<td>Scrap and/or re-work due to poor maintenance</td>
<td></td>
</tr>
<tr>
<td>Breakdown-related overtime for recovery production</td>
<td>X</td>
</tr>
<tr>
<td>Speed losses due to poor maintenance</td>
<td></td>
</tr>
</tbody>
</table>

For the ease of use, some of the costs in the concept are aggregated. One example is the cost of lost production time, which could be further divided into various fixed production costs. This aggregation is intentionally made in order to keep the concept as easy as possible to use within organizations with limited resources.
As the Cost of Poor Quality truly has increased the awareness of the financial contribution of proactive quality work, the idea is that CoPM should increase the awareness of the financial contribution of strategic maintenance development. By increasing the costs of conformance, a larger decrease of the costs of non-conformance may be realized, as shown in Figure 17.

![Figure 17: The expected outcome of structured use of the concept of CoPM, from Appended Paper IV, Salonen and Deleryd (2011).](image)

### 4.6 RESULTS FROM STRATEGIC MAINTENANCE MANAGEMENT

Descriptive study 3 was undertaken in order to summarize how the participating companies experienced the strategic maintenance management work. All companies expressed the importance of analyzing the maintenance in relation to the overall goals of the company and in relation to its stakeholders. By formulating a maintenance strategy and get it approved by management, the maintenance program gets a legitimacy that it previously has lacked. A problem to achieve this has in two of the companies been the lack of formal knowledge in maintenance management among the managers.

The strategic maintenance development that the companies have performed has in their own opinion contributed to the achievement of the companies’ overall goals. This has in turn increased the awareness of the importance of maintenance in manufacturing companies. Further the strategic development of maintenance has influenced the relation between the maintenance organizations and the production departments.

In Company A, the unplanned stop time due to CM has decreased by 200 h/month. Even though the difference in cost between a planned and an un-planned stop not has been quantified in the case companies, they all agree that the planned stop time is much cheaper than the un-planned stop time. Further, the production ability has become more predictable and, hence the delivery precision increases due to better planning.

In Company B, the equipment availability has increased by 3.2%. This increase makes it possible to increase the production by 3.2% with constant fixed costs. Also, the amount of
unplanned down time has gone from 4.8% to 1.1% which means that the equipment has become more reliable.

Company C has reduced the amount of unplanned stops by more than 50%. For a company that implements lean production principles in their manufacturing, predictable production capabilities are crucial.

The strategic maintenance development work has generated results that clearly show how well performed maintenance may contribute to the competitiveness of a manufacturing company.
CHAPTER 5

5 DISCUSSION & CONCLUSIONS

This chapter presents and discusses the main conclusions from the conducted research. The first section relates to the main objective and the research questions of the dissertation. Then the contribution of the conducted research is discussed. Following that is a reflection on the quality of the performed research, some personal reflections from the research journey, and, finally, some proposals for future research.

5.1 MAIN CONCLUSIONS

This section is divided into four sub-sections. The first sub-section presents and discusses the conclusions in relation to the objective of the performed research. The following three sub-sections present and discuss the conclusions in relation to each of the three research questions.

5.1.1 The strategic maintenance development loop

As stated in Section 1.2, the objective of the conducted research has been to develop a simple and cost-effective approach aimed to formulate and implement maintenance strategies for the manufacturing industry. An overall model for such an approach is illustrated in Figure 18. The approach starts with (1) an Evaluation of to what degree the current maintenance activities support the overall goals of the company. Then the (2) Strategy formulation is undertaken. These two first steps may be further divided into the steps in the strategy formulation work-process, depicted in Figure 13. Once formulated, (3) the strategy has to be successfully implemented and the maintenance development should be (4) controlled by a sufficient system of KPIs.
Similar models are presented by researchers, such as Tsang (1998) or Kumar et al. (2006). Still, when speaking with industrial maintenance professionals within manufacturing industry, many of them do not use any structured models for their maintenance management. Further, most of the work is managed on an operational level or, at best, on a tactical level. One reason for this is probably that few maintenance managers in the manufacturing industry have any formal education or training in maintenance management. Even the maintenance staff, which in Sweden is often composed of very capable technicians, in some cases seems to lack sufficient knowledge or awareness in proactive maintenance work.

Although some of the maintenance managers have no formal education in maintenance management, all participating companies have really wanted to improve themselves. All the respondents in the concluding interview in Descriptive study 3 expressed that the structured strategic maintenance development truly has contributed to the companies’ strategic goals. Further, all companies appreciated the exchange of experiences and methods between themselves.
5.1.2 The formulation of maintenance strategies

As a means to fulfill the objective of the dissertation, three research questions are formulated, of which the first one is the following:

**RQ 1** How to formulate a maintenance strategy that supports companies’ over-all business goals?

In order to answer this question, *Prescriptive study 1* was performed. In this study, a process for the formulation of maintenance strategies was developed and tested in cooperation with three case companies. This study showed that companies with no major previous knowledge of strategic maintenance management could easily formulate a feasible maintenance strategy by using a simple process based on well-known tools, see Figure 13. The result in the studied companies was a clear sense of direction, and it became clearer to all stakeholders how maintenance contributes to the overall goals of the company.

5.1.3 The implementation of maintenance strategies

Once a maintenance strategy is formulated, it has to be implemented in order to provide the desired effect. As with all major change initiatives, both obstacles and driving forces will influence the implementation. Hence, the second research question is the following:

**RQ 2** Which driving forces and obstacles influence the implementation of maintenance strategies?

Not surprisingly, the results from this study include factors identified as significant for strategy implementation, change management and concepts implementation. One common shortcoming among the three companies was the insufficient implementation plan. Even though the companies coped rather well with the implementation of their respective strategy, the efficiency of the implementation could probably been higher with a thorough implementation plan. The implementation study also showed some difficulties in establishing new strategic KPIs. All companies had to re-define their KPIs along the implementation. Also, in some cases it was difficult to delegate responsibility and ownership of the measures. Another severe problem is that all companies historically have implemented CMMS systems without regards to how to aggregate and analyze the logged data. Therefore, the data structure in the data bases is rather random.

It is difficult to improve an activity regarded as a mere cost driver. In order to successfully implement self-developed maintenance strategies, it is vital that the strategies be approved by top management in order to achieve the proper leverage.

As mentioned in Section 4.3 *Implementation of Maintenance Strategies*, the relationship between Company A and their maintenance supplier was rather strained. It should be pointed out
that this problem does exist even in the companies with in-house maintenance. Within the manufacturing industry, there seems to be a historical, prevailing cultural conflict between production and maintenance. One reason for this might be that production and maintenance does not share a common vision of what maintenance should deliver in terms of quality, up-time or other deliverables. Another problem is that the maintenance staff often has a reactive focus, rather than working proactively. Also, the production managers are often unwilling to stop production for preventive maintenance. The last problem was solved in the case companies by assigning time for preventive maintenance in the production schedule data base.

5.1.4 The financial contribution of maintenance

The industry’s view on maintenance as being a cost driver indicates that the industry does not realize that maintenance contributes to the profit of the production. This problem is addressed by the third research question:

RQ 3 How may management in manufacturing industry become aware of the financial contribution of a well-formulated and well-implemented maintenance strategy?

Although alarming, it is far from surprising that a majority of the manufacturing industry considers their maintenance department to be a cost center. There seems to be no financial performance measures for maintenance that fully distinguish between necessary maintenance costs and those costs that potentially could be saved if maintenance were optimal. Companies often focus on the direct cost of maintenance, while neglecting the indirect cost of poorly performed maintenance or the lack of preventive maintenance. When discussing the lack of financial performance measures for maintenance, all industrial practitioners show great interest in such metrics. In an attempt to create a balanced view of the financial contribution of maintenance, the concept of Cost of Poor Maintenance is introduced. By applying a well-known approach from quality costing to maintenance activities, the costs of necessary maintenance are distinguished from the unnecessary costs of poorly performed preventive maintenance and unnecessary corrective maintenance due to a lack of preventive maintenance or poor equipment reliability. One problem discovered during the empirical evaluation of the model is that the data structure in the companies’ CMMS systems often is too poor. Except for the poor data structure, the companies regarded the implementation of CoPM as rather difficult. This is by no means surprising, since most companies describe similar experiences when implementing Cost of Poor Quality systems. It should be noted, though, that the maintenance managers in all three companies greatly appreciated the CoPM measure as a means to discuss maintenance from a financial perspective.
5.2 CONTRIBUTIONS

As stated in Chapter 2, this research intends to generate results that are valid in both academia and industry.

5.2.1 Scientific contribution

Industrial maintenance research tends to focus on technological issues today. A great amount of effort is put on various techniques for condition monitoring, diagnostics and prognostics. Also, when studying the organizational aspects of maintenance, they are often studied in very large organizations and/or in the process industry. Therefore, the results are not always applicable on small and medium-sized manufacturing organizations. This research contributes to an understanding of what conditions maintenance departments in manufacturing organizations, large and small, deal with.

The performed research has shown how a relatively simple and non-resource demanding process may be used to formulate maintenance strategies that align with the overall strategic goals of the company. This process is based on a set of factors that six manufacturing companies regard strategically important for their maintenance. The list is not to be viewed as complete, but rather as a sample of key factors.

Further, the implementation work has been studied in order to identify some of the driving forces and obstacles that may be associated with strategic maintenance improvement work. Even though the driving forces and obstacles to a large extent were previously known from studies of change management and implementation of maintenance concepts, some additional aspects were identified, as shown in Table 2.

Within academia, there is no consensus regarding how to visualize the financial aspects of maintenance. Although several models are presented in various published material, all having their merits, they do not fully distinguish between the costs necessary for upholding the agreed dependability and those costs that really do not add any value to the production department. That means that the models still are not fully applicable for the optimization of maintenance programs. The research in this dissertation presents a concept for the classification of all maintenance-related costs, which have been shown to contribute to the optimization of maintenance programs.
5.2.2 Industrial contribution

The scope of this applied research is well-appreciated in industry. There seems to be a growing awareness among manufacturing companies that they have a large improvement potential within their maintenance programs. Even though top-management generally still view maintenance as a cost center, middle management and maintenance management are aware of the improvement potential in maintenance. Still, many companies do not know how to work systematically with maintenance improvements in a strategic way. The conducted research may provide guidance to such efforts.

One aspect of maintenance that seems to obstruct any development programs is the fact that maintenance is seldom viewed as a business contributor. Most companies only quantify the cost of maintenance, but neglect the Cost of Poor Maintenance. This research provides a concept for quantifying the true Cost of Poor Maintenance, so that maintenance may be discussed as a business case rather than a cost center.

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 get information on the results from the research. As described in Section 4.6, the results from the case studies have been very positive for the case companies and should be useful for manufacturing companies in general.

5.3 THE QUALITY OF THE CONDUCTED RESEARCH

When discussing the quality of the performed research, both users --- academia and industry --- have to be regarded. The presented research has been performed through an approach that resembled the systems approach and the actors’ approach. Case studies have been performed, and the data has mainly been qualitative. Such an approach demands extra caution regarding the quality of the research.

One concern is the selection of case companies. Not all companies are willing to participate in this kind of research. However, the companies that have participated in the performed case studies have represented a sufficient diversity in aspects, such as size, type of production, type of maintenance organization, and so on. It is therefore fair to state that the companies represent a large proportion of the manufacturing industry. Furthermore, it is therefore also reasonable to believe that the external validity of the research is acceptable both for academia and industry.

Several methods for data collection have been used during the studies. This has made it possible to triangulate some of the findings, which strengthens the validity of the findings. All findings have been discussed with the company informants. In addition, some of them
have been discussed with other maintenance professionals and peer researchers. This has enabled continuous member checks and peer examinations of the results, which further increases the validity. The member checks and peer examinations have also been important in order to avoid unwanted types of bias.

It is always difficult to estimate the reliability of applied industrial research based on qualitative data. It would not be possible to fully repeat the case studies in the same companies, as the state of the companies has changed since the original studies were performed.

5.4 REFLECTIONS FROM THE RESEARCH JOURNEY

I worked for 12 years within maintenance in the manufacturing industry. I have now performed maintenance research for an additional five years. One thing that strikes me is how little maintenance practices have evolved over these years, especially since the high utilization of production equipment is central in automated manufacturing. The current status of maintenance practices resembles the status of quality assurance practices some 30 years ago. Large parts of Swedish industry view maintenance organizations as cost centers and accept that close to 85% of their work is reactive rather than proactive. Those organizations that have an ambition to improve their maintenance often believe that either outsourcing or investments in new advanced technology are the answers. Of course, a thoroughly performed outsourcing may achieve great improvements in maintenance practices. However, it is essential that the manufacturing company and the maintenance supplier know exactly which strategic goals the maintenance should contribute to. Further, other researchers, for instance Bengtsson (2007), have shown how companies may fail when trying to invest in advanced maintenance technologies without considering the organizational or managerial aspects of maintenance. These findings apply not only to advanced technology, but also to rather ordinary products such as CMMS systems. All companies I have studied have lacked data structures that support the analysis of specific failure modes. Still, most of the maintenance-related research focuses on advanced technical solutions that are foremost applicable in very mature maintenance organizations and are seldom found in small or medium-sized manufacturing companies.

It should be noted, though, that there seems to be a growing awareness among companies in the manufacturing industry that they should improve their maintenance. The companies that participated in the performed research have really shown how industry can improve its maintenance and also how they can quantify the true financial contribution of maintenance. In turn, this justifies investments in preventive maintenance activities.
5.5 FUTURE RESEARCH

As previously stated, most maintenance research deals with advanced technical solutions. Further, they are primarily intended for use within very mature and resourceful maintenance organizations. However, there is increasing demand for effective maintenance in traditional manufacturing industry, especially with lean and green production concepts raising concerns about equipment dependability.

5.5.1 The status of maintenance in manufacturing SMEs

A survey to study the status of maintenance in manufacturing industry would be interesting. Such a survey should not only cover the maintenance activities, but also the attitudes towards maintenance and the formal knowledge in maintenance management and maintenance engineering.

5.5.2 Integrated maintenance in Lean environments

Many companies with low awareness in maintenance matters tend to forget to develop their maintenance when implementing Lean production. Sometimes, the consequences are rather severe, with the loss of customers due to low delivery precision. Even though the TPM concept is developed in a lean environment, quite many organizations fail to implement TPM in their operations. It is not obvious if these failures are due to implementation problems or if the TPM concept simply does not fit all organizations.

5.5.3 Cost of Poor Maintenance

So far, the concept of the Cost of Poor Maintenance is not fully tested in an industrial context. Even though three companies have performed smaller pilot tests of the concept, there is still much research left to do in order to improve and operationalize the concept.

5.5.4 Maintenance as a contributor to green production

Finally, well-performed maintenance contributes to sustainable production in a number of ways. For instance, it minimizes the waste of non-utilized production time. Well-performed maintenance also decreases energy waste in machinery and increases the life time of equipment. All of these aspects should be further examined and quantified in order to visualize the potential environmental earnings of well-performed maintenance.
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APPENDIX A

This appendix presents the interview guides and a survey, used in the case studies presented in this dissertation. All interview guides and the survey were originally written in Swedish but are here presented in English.

Interview guide 1 (used in Descriptive study 1)

Interviews conducted with maintenance managers and other persons with direct responsibility for maintenance in six companies within manufacturing industry. The interviews were directed, open, and each interview took on average one hour.

Interview guide 2 (used in Descriptive study 2)

Interviews conducted with maintenance managers and maintenance personnel in three companies within manufacturing industry. The interviews were directed, open, and each interview took on average one hour.

Interview guide 3 (used in Descriptive study 3)

Interviews conducted with maintenance managers and other persons with direct responsibility for maintenance, in three companies within manufacturing industry. The interviews were directed, open, and each interview took on average one hour.

Survey questionnaire (used in Descriptive study 2)

Survey conducted with maintenance staff and maintenance engineers, in one company within manufacturing industry. Approximately 30 respondents answered the survey.
INTERVIEW GUIDE 1 (TRANSLATED FROM SWEDISH)

Company presentation

Company name:

Geographic location:

Number of employees:

Annual turnover:

Products:

Number of maintenance personnel:

Annual maintenance budget:

Organizational belonging of maintenance:

External maintenance suppliers(man-hours or specialists):
Maintenance strategy

Is there a maintenance strategy?

Is it written or oral? (if written may I have a copy?)

Is it clearly tied to the business strategy?

Is it clearly tied to the production strategy?

How do You formulate the strategy (a team effort/ the maintenance manager/ other)?

Who approve the strategy (company board)?

Which components/aspects are/should be included in a maintenance strategy?

- Maintenance organization
- Control (Maintenance control/planning, spareparts planning, CMMS)
- Policies/concept (CM/PM, TPM/RCM)
- Material resources (tools, machinery etc.)
- Technological resources (Condition monitoring, expert systems)
- Economy (do You consider financial influences of maintenance)?
- Personnel (Numeral, competences)
- Work hours (shifts, on-call duty)
- Technological skills
- Are all departments served
- Focus areas
- Spare parts management
- Education and training
- Other

Are responsibilities defined in the strategy?

Is the strategy communicated (to whom, how)?
Implementation

How should the strategy be formed into tactical and operational levels?
Who should be responsible for that?

Management/Control

How do you monitor that the strategy is effective?
Do you use measures (which ones, do the relate to both maintenance and production, Do they relate to strategic goals)?
How are the measures used and by whom?
How do the production and maintenance departments exchange information?
How do you re-use experiences (documentation, databases etc)?

Evaluation

How do you assess the maintenance strategy with respect to its effectiveness/validity?
How is the assessment used in the formulation of new strategies?

Sourcing of maintenance

How to secure that a maintenance supplier actively contributes to the strategic goals?
What are the risks when outsourcing maintenance without having a maintenance strategy?
Which are the strengths with having a maintenance strategy when outsourcing maintenance?
How to communicate the maintenance strategy to a maintenance supplier?
Should the strategic goals be incorporated in the maintenance contract?
Should a maintenance supplier be evaluated with respect to its strategic contribution?
Interview guide Strategy implementation

How much of the implementation work is achieved?

How is the maintenance staff affected by the implementation?

Which obstacles have you encountered during the implementation?

Which driving factors have you encountered during the implementation?

How have you experienced the implementation?

How has the staff experienced the implementation?

How has the production line managers handled the implementation?

How has the company managers handled the implementation?

Which measures of control are used for the implementation?
Interview guide project evaluation

Questions:

How have You experienced working with this research project?

  What has been good?
  What could have been better?
  Have there been any difficulties?

Has the model for formulation of maintenance strategies helped You formulate relevant maintenance strategies?

Has the strategic maintenance development made the maintenance more obviously contribute to the overall strategic goals of the company?

  What is the board group’s view?
  What is the staff’s view

Has the strategic maintenance development changed the relations between the maintenance department and the production department?

Do You think You have chosen the right KPIs for the strategic development?

Are You satisfied with the development of the KPIs during this project?

Do You consider Cost of Poor Maintenance a possible concept for an improved discussion of the financial contribution of maintenance?

  Pros?
  Cons?

Should the CoPM concept be further developed or would it be better to develop another financial KPI for maintenance?
Check the best alternative in the following questions:

1. Which part of maintenance do you belong to?  
   - PM  
   - CM  
   - Team-tech.

2. Do you know the strategic goals of your maintenance?  
   - Yes  
   - No

3. One goal is to reach a distribution between PM/CM = 80/20.  
   Does it make sense (On a scale from 1 – 5).
   - No sense  
   - Much sense  
   - Don’t know

4. The distribution 80/20 should be reached by the end of 2010.  
   Is this achievable?  
   - Yes  
   - No  
   - Don’t know

5. One of your goals is to decrease the stop time for breakdowns (CM).  
   Does it make sense (On a scale from 1 – 5).
   - No sense  
   - Much sense  
   - Don’t know

6. What is a reasonable goal for maximum stop time for CM?  
   (Please try to set a reasonable goal)  
   ____ h
7. One of your goals is to reach a level of maximum 15 stops per week. Does it make sense (On a scale from 1 – 5).

<table>
<thead>
<tr>
<th>No sense</th>
<th></th>
<th></th>
<th></th>
<th>Much sense</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>Don’t know</td>
</tr>
</tbody>
</table>

8. The goal of 15 stops per week should be reached by the end of 2010. Is this achievable?

<table>
<thead>
<tr>
<th>Yes</th>
<th>No</th>
<th>Don’t know</th>
</tr>
</thead>
</table>

9. Is it good to let the operators perform some of the routine PM? (On a scale from 1 – 5).

<table>
<thead>
<tr>
<th>Not good</th>
<th></th>
<th></th>
<th></th>
<th>Very good</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>Don’t know</td>
</tr>
</tbody>
</table>

10. Operators can perform more PM than today? Agree (on a scale from 1 – 5).

<table>
<thead>
<tr>
<th>Don’t agree</th>
<th></th>
<th></th>
<th></th>
<th>Fully agree</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>Don’t know</td>
</tr>
</tbody>
</table>

11. How well functioning is your operator maintenance today? (on a scale from 1 – 5).

<table>
<thead>
<tr>
<th>Not well</th>
<th></th>
<th></th>
<th></th>
<th>Very well</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>Don’t know</td>
</tr>
</tbody>
</table>

12. What do you think about the concept of team-technicians? (on a scale from 1 – 5).

<table>
<thead>
<tr>
<th>Not good</th>
<th></th>
<th></th>
<th></th>
<th>Very good</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>Don’t know</td>
</tr>
</tbody>
</table>
13. How well functioning do you think the concept of team-technicians is today? (on a scale from 1 – 5).

<table>
<thead>
<tr>
<th>Not well</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>Don’t know</th>
</tr>
</thead>
</table>

14. What do you think of the idea of an order-desk? (on a scale from 1 – 5).

<table>
<thead>
<tr>
<th>Not good</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>Don’t know</th>
</tr>
</thead>
</table>

15. How well functioning is the order-desk today? (on a scale from 1 – 5).

<table>
<thead>
<tr>
<th>Not well</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>Don’t know</th>
</tr>
</thead>
</table>

16. How good is the cooperation with maintenance engineering today? (on a scale from 1 – 5).

<table>
<thead>
<tr>
<th>Not good</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>Don’t know</th>
</tr>
</thead>
</table>
17. Please rank the three areas that you consider most important for the maintenance organization to focus on in order to achieve the goals (1= most important, 2 = second most important, 3 = third most important). Leave the other areas blank.

<table>
<thead>
<tr>
<th>Method and tools for diagnostics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Extended PM-program</td>
</tr>
<tr>
<td>Extended or improved PM-instructions</td>
</tr>
<tr>
<td>Extended operator maintenance</td>
</tr>
<tr>
<td>Increased number of team-technicians</td>
</tr>
<tr>
<td>Extended spare parts storage</td>
</tr>
<tr>
<td>Root cause analysis</td>
</tr>
<tr>
<td>CBM</td>
</tr>
<tr>
<td>Training of maintenance personnel</td>
</tr>
<tr>
<td>Training of operators</td>
</tr>
<tr>
<td>Extended service agreements with experts</td>
</tr>
<tr>
<td>Guarantee handling</td>
</tr>
<tr>
<td>Continuous improvements</td>
</tr>
<tr>
<td>Internal knowledge distribution</td>
</tr>
<tr>
<td>Other (specify)</td>
</tr>
</tbody>
</table>

18. If you have any other remarks or notions on the subject of maintenance improvements, please specify here. 

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