Managing the Introduction of Reliability-Centred Maintenance, RCM

RCM as a Method of Working within Hydropower Organisations

FREDRIK BACKLUND
Doctoral Thesis no. 7
Division of Quality & Environmental Management

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Fredrik Backlund

Luleå University of Technology
Department of Business Administration and Social Sciences
Division of Quality & Environmental Management
”...there is a difference between knowing the path and walking the path...”

Morpheus
ACKNOWLEDGEMENTS

The work presented in this thesis has been carried out at the Division of Quality & Environmental Management. During this time I have received generous support from a large number of people, who in different ways have contributed to the completion of this thesis.

First I would like to thank my supervisor Professor Bengt Klefsjö and my co-supervisor Adjunct Professor Per Anders Akersten. Their support and encouragement during the research project have been valuable and greatly appreciated. I would also like to thank my colleagues at the Division of Quality & Environmental Management, who have helped me to improve the contents of the thesis during a number of seminars. In particular, I would like to thank Dr. Jonas Hansson and Dr. Rickard Garvare for many fruitful discussions and for their support during the work on this thesis. I would like to thank Anita Hanno for her administrative support throughout the research project. Among people from other departments of the university I would like to express my gratitude to are Dr Håkan Ylinenpää for his support during previous parts in the research project and Hans Bylesjö for his important contribution during the final preparatory seminar held prior to the dissertation. I would also like to thank Gunnar Persson, Emeritus Professor of English, for helping me to improve my English.

I would like to thank the organisations that have shared their experiences with me and made this research project possible. Vattenfall AB Vattenkraft has set a good example of a company that supports and promotes research studies. My stationing at the company was inspiring and pleasant and I would like to thank all the people that made this possible. In particular, I would like to thank Tord Eriksson, Thomas Sjödin and Ulf Wollström for many interesting discussions and for their constant support. The management and co-workers at Vattenfall Service have also showed great interest and openness during the research. I would like to thank the RCM project group for letting me participate in their work. In particular, I would like to thank the two project managers, Rolf Pettersson and Patrik Holmgren, for many fruitful discussions. The research studies have also included studies of other hydropower companies introducing RCM. I would like to thank the informants for taking time with me during visits and telephone interviews. In particular, I would like to thank Jørn E. Johnsen at Statkraft, Larry Pope and Nick VanderKwaak at BC Hydro, and Peter Church at Snowy Hydro.

I gratefully acknowledge the financial support from the Polhem Laboratory and VINNOVA, The Swedish Agency for Innovation Systems.
Finally, I would like to thank my wife Linda for her patience, love and encouragement during the research studies. I know that it has not been easy to share your life with a doctoral student. Without your support this thesis would never have existed. I am grateful that our children, Vilhelm and Maria, have accepted a father that has unfortunately been working too much. It will be wonderful to have time to devote to my family again.

Luleå, April 2003

Fredrik Backlund
ABSTRACT

Due to a competitive environment, many companies are required to reduce their overall costs while maintaining the value and reliability of their assets. The use of Reliability-Centred Maintenance, RCM, can help organisations to develop a systematic maintenance programme, meeting these requirements in a cost-effective manner. RCM basically combines different techniques and tools in a systematic approach to manage risks as a basis for maintenance decisions.

When introducing RCM with the aim of changing the overall way of working with maintenance in the organisation, i.e. on a full-scale basis, a long-term introduction approach should preferably be used. In addition to improving the performance of the assets, this approach uses RCM to improve knowledge, motivation and teamwork among the personnel. In this way the approach could increase the commitment of managers and employees, making an RCM based maintenance programme far more likely to endure. However, in several cases organisations have experienced severe difficulties when introducing RCM on a full-scale basis. Some of the reasons are technical in nature, but the majority are managerial obstacles. In the research project presented in this thesis, an overall aim has been to facilitate for organisations introducing RCM. The focus has been on identifying managerial factors that affect an RCM introduction.

In the research project, a longitudinal single-case study has been performed during 1997 - 2003, studying the introduction of RCM in a Swedish hydropower company. Many of the findings in the single-case study have been validated by a multiple-case study, including three other hydropower organisations introducing RCM. The findings are basically different kinds of managerial factors, which affect the introduction in form of obstacles and driving forces. These factors could be managed in four management perspectives, which indicates the need for a holistic approach when managing RCM introduction. An RCM introduction process has also been identified during the research, where the managerial factors can be structured according to different phases. Based on these findings, an RCM introduction strategy framework has been developed, with the aim of facilitating the work of organisations going to introduce RCM. The strategy framework is structured in accordance with the different phases in the RCM introduction process, with requirements and recommendations to be considered in each phase.
SAMMANFATTNING

I en konkurrensutsatt omgivning tvingas många företag att på en övergripande nivå sänka sina kostnader, medan anläggningstillgångars värde och driftsäkerhet måste bibehållas. Med hjälp av ”Reliability-Centred Maintenance”, RCM, kan ett systematiskt och kostnadseffektivt underhållsprogram uppnås. RCM består av olika tekniker och verktyg som på ett systematiskt sätt kombineras i syfte att fatta riskbaserade beslut om underhållsinsatser.


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APPENDED PAPERS

I Can we make maintenance decisions on risk analysis results?
Fredrik Backlund and Jesper Hannu
Published in Journal of Quality in Maintenance Engineering, (2002), Vol. 8 No. 1, pp. 77-91

II Conclusions from planning and preparation of RCM implementation
Fredrik Backlund
In the Proceedings of The International Conference of Maintenance Societies, ICOMS, 2002, Brisbane, Australia, Paper 042, 1-8

III RCM introduction - Process and requirements management aspects.
Fredrik Backlund and Per Anders Akersten
To be published in Journal of Quality in Maintenance Engineering

IV Managing commitment: Increasing the odds for successful implementation of TQM, TPM or RCM
Jonas Hansson, Fredrik Backlund and Liselott Lycke
To be published in International Journal of Quality & Reliability Management (2003), Vol. 20 No. 9.

APPENDIX

Questionnaire multiple-case study
DEFINITIONS AND ABBREVIATIONS

Some definitions and abbreviations are presented below with the intention to facilitate for the understanding of the content in the thesis. Other more specific definitions will be provided in the respective chapters.

Definitions:

- **Maintenance**: 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 (CEN, 2001).

- **Maintenance management**: All activities of the management that determine the maintenance objectives, strategies, and responsibilities and implement them by means such as maintenance planning, maintenance control and supervision, improvement of methods in the organisation including economical aspects (CEN, 2001).

- **Maintenance programme**: Methods, procedures and resources required for sustaining the support of an item throughout its life cycle (*IEC60300-3-11, 1999*).

- **Preventive maintenance**: Maintenance carried out at predetermined intervals or according to prescribed criteria and intended to reduce the probability of failure or the degradation of the functioning of an item (CEN, 2001).

- **Corrective maintenance**: Maintenance carried out after fault recognition and intended to put an item into state in which it can performed a required function (CEN, 2001).

- **Availability (performance)**: Ability of an item to be in a state to perform a required function under given conditions at a given instant of time during a given time interval, assuming that the required external resources are provided. Note – This ability depends on the combined aspects of the reliability, the maintainability and the maintenance supportability (CEN, 2001).

- **Reliability**: Ability of an item to perform a required function under given conditions for a given time interval (CEN, 2001).

- **Maintainability**: Ability of an item under given conditions of use, to be retained in, or restored to, a state in which it can perform a required function, when maintenance is performed under given conditions and using stated procedures and resources (CEN, 2001).

- **Maintenance supportability**: Ability of a maintenance organisation of having the right maintenance support at the necessary place to perform the required maintenance activity at a given instant of time or during a given time interval (CEN, 2001).
- **Risk**: Combination of the frequency, or probability, of occurrence and the consequence of a specified hazardous event (IEC60300-3-9, 1995).
- **Risk Management**: Systematic application of management policies, procedures and practices to the tasks of analysing, evaluating and controlling risk (IEC60300-3-9, 1995).

**Abbreviations:**

- **CMMS**: Computerised Maintenance Management System
- **FMECA**: Failure Mode, Effects, and Criticality analysis
- **I&C**: Instrumentation and Control
- **ILS**: Integrated Logistic Support
- **RCM**: Reliability-Centred Maintenance
- **TPM**: Total Productive Maintenance
- **TQM**: Total Quality Management
1 INTRODUCTION

In this chapter the background to the research area will be described. In addition, a problem discussion, the aim, the research questions, and the structure of the thesis are presented.

1.1 Background

Humans depend, to a large extent on the wealth generated by highly mechanised and automated businesses. People are also becoming more and more dependent on services such as the supply of electricity and means of transport such as trains and aircraft (Moubray, 1997). The technical systems providing these services are many times complex and expensive, which makes a system, or a plant, vulnerable. Such vulnerability involves, for example, power, aviation and military industry, but also production facilities such as automobile manufacturers. A major breakdown in such a system affects the production and the quality of products, and can also generate serious damage to the environment and personnel (Horton, 1993). The awareness of serious risks in machine systems has increased the demands for verification of quality and reliability of products. The use of, for example, the EC directives focusing on machine safety, product safety and product liability, has become more common (Høyland & Rausand, 1994).

Besides the increased verification demands and external directives, most industries are today facing a competitive environment in a global perspective (Miyake & Enkawa, 1999). This in turn gives rise to increased demands on productivity, quality and cost-efficiency in companies, while maintaining the value and reliability of the assets, see e.g. Ben-Daya & Duffuaa (1995) and Beehler (1997). Any corporation that uses complex facilities in producing products realises that without sustained equipment performance, long-term profitability and competitiveness cannot be achieved. Therefore, preventive maintenance plays a key role in maintaining equipment performance and consequently final product quality, see e.g. Smith (1993) and Ben-Daya & Duffuaa (1995). The complexity of many physical assets, and the need for optimisation of resources, has promoted research in the interrelated engineering fields of reliability engineering and maintenance engineering. These fields deal with methods to control risks associated with competition, safety and legal obligations connected with a product, equipment, process or system. They are multidisciplinary engineering sciences related to areas of safety, design, operational research, statistics, quality, production and management (Kumar, 1996).
Efficient and effective maintenance programmes are needed to meet the demands of, for example, safety and quality, in a cost-effective manner (Anderson & Neri, 1990; Thomas, 1994). With a large number of technical systems within a plant, there may be difficulties in prioritising maintenance activities. Using risk assessment to identify severe risks within a plant, in combination with different maintenance strategies, is one course of action to facilitate the prioritising of maintenance tasks (Kumar, 1998). The importance of maintenance management and performance, and the need of effective and efficient maintenance methods, have promoted the development of Reliability-Centred Maintenance, RCM, see e.g. Nowlan & Heap (1978), Smith (1993) and Hipkin & DeCock (2000). RCM can be described as a systematic approach to identifying effective and efficient preventive maintenance tasks for objects in accordance with a specific set of procedures (IEC60300-3-11, 1999). RCM basically combines several well-known techniques and tools, in a systematic approach managing risks, as a basis for maintenance decisions. The RCM concept was originally developed in commercial aircraft industry during the 1970:ies, and has later become used in various industrial sectors, for example, the nuclear, offshore, manufacturing, and hydropower sectors, see e.g. Smith (1993), Moubray (1997) and August (1999). The many application areas, and the long-time use of RCM, points to the importance and usefulness of RCM when developing an effective and efficient maintenance programme. The use of RCM can, among other matters, improve system availability and reliability, reduce the amount of preventive maintenance and unplanned corrective maintenance, and increase safety, see e.g. Smith (1993), Bowler & Leonard (1994a) and Moubray (1997). These are all important performance characteristics for most companies to sustain in a competitive environment.

1.2 Problem discussion

When introducing RCM with the aim of changing the overall way of working with maintenance in the organisation, i.e. on a full-scale basis, a long-term introduction approach should preferably be used. In addition to improving the performance of the assets, this approach uses RCM to improve knowledge and motivation of individuals, and to improve teamwork among technical personnel, operators and maintenance personnel. This may involve many teams working with RCM and may even involve most of the workforce. Such an approach also promotes, for example, the involvement and commitment of management and workforce. In that way, the maintenance performance based on an RCM analysis is far more likely to endure (Moubray, 1997). However, a long-term approach may be difficult to manage since it involves many people. Although RCM is an organised common sense approach to improvements of preventive maintenance, it still represents a very new and revolutionary idea for many

---

1 For a more comprehensive description of RCM, see Section 3.1.
people (Schawn & Khan, 1994). According to August (1997) and Johnston (2002), major problems often arise during the introduction of RCM, since it represents a significant change for the organisation, such as the maintenance people, the engineers, and the operations staff.

Several examples of failed introductions of RCM exist in various lines of business and types of organisations. Some of the main reasons why the RCM introduction becomes problematic or fails are technical in nature, but the majority of problems are managerial and organisational (Worledge, 1993b; Schawn & Khan, 1994; Moubray, 1997). Some companies have failed to adopt RCM because of high initial costs. The underestimation of these costs has led to withdrawal of management support (Worledge, 1993a; Bowler et al., 1995). An RCM introduction can be going on for several years, where RCM usually is a long-term goal, but with short-term expectations (August, 1997; Latino, 1999). Some companies have failed to introduce RCM because of the lack of evaluation of a return on investment (Bowler et al., 1995; Hipkin, 1998; Hipkin & DeCock, 2000). There are also several examples of where analysis recommendations never got implemented (August, 1997; Hipkin & DeCock, 2000). For example, resources for new equipment and operator training, based on RCM analysis recommendations, are not always available. As a consequence, the RCM introduction is limited or abandoned (Smith, 1993).

The industrial context contributes to different preconditions for introducing RCM. An overall division of the industrial context is safety-driven industry versus basic industry. RCM introductions and applications in different kinds of so-called safety-driven industries are described by, for example, Nowlan & Heap (1978) and Hollick & Nelson (1995) concerning RCM in aircraft industry, Jacquot (1996) and Simola et al. (1998) concerning RCM in nuclear industry, and Sandtorv & Rausand (1991) and Adjaye (1994) concerning RCM in offshore industry. Examples of RCM introduced and applied in basic industry sectors are, for example, RCM in de-regulated power industry environments such as hydropower and coal-based power plant auxiliaries (Srikrishna et al., 1996; August, 1997), electric utility industry (Beehler, 1997), and rail infrastructure (Hardwick & Winsor, 2002).

The successful application of RCM in the aircraft industry is probably due to some specific characteristics. For example, RCM has been applied already in the design stage, there have been few resource constraints, and mainly specialists have performed the RCM analyses. These preconditions are usually not found in more traditional basic industries, for example, the power, processing and manufacturing sectors. In these sectors, RCM is mostly applied to existing plants that have been individually designed, where the level and mix of available resources are usually established by custom and usage. The introduction of
RCM also takes place many times during rationalisation (Harris & Moss, 1994). The requirements for formality and details in safety systems and equipments, for example, in a nuclear power plant, are extreme (Smith, 1993). While, for example, fossil generation plants are less structured (August, 1997). The collection of data on reliability, availability and maintainability can usually be performed easily in safety-driven industry, as monitoring and measuring has been comprehensive, and where systems in different plants many times are similar. RCM assessment can be ‘borrowed’ from the history of already functioning similar systems, where considerable costs for the RCM exercise can be spread over the total fleet as regards aircraft, or plants. In basic industry, there are few ‘standard’ systems, where plants usually have unique designs to meet a wide range of output requirements. Therefore, in basic industry, it is clearly not possible to ‘borrow’ the basic information requirements for this initial assessment from the data on a similar functional system (Harris & Moss, 1994). Therefore, according to Srikrishna et al. (1996), the quantitative approach to RCM has taken a back seat compared to the qualitative approach because of the unavailability of plant-specific historical data, and appropriate statistical methods to interpret data. Based on the differences in preconditions, implementing RCM is a confounding and stressful change for many basic industry organisations (August, 1997).

However, several examples exist of problematic or failed RCM introductions within the nuclear sector as well, see e.g. Bowler & Malcom (1994) and Schawn & Khan (1994). There are also differences in preconditions between different industrial sectors within the safety-focused industry. Worledge (1993b) points to nuclear organisations that have had disappointing experiences when introducing RCM, problems that had not arisen historically in the aircraft industry. For example, lack of maintenance personnel acceptance of the RCM programme after contractors, or corporate engineering departments, performed the major part of the RCM introduction.

In general, there are few books or papers with a specific focus on RCM introduction, especially on full-scale basis. Findings available in the literature, concerning RCM introduction issues, are mainly based on experiences from a pilot project or RCM applied to some specific system, see, for example, Adjaye (1994), Basille et al. (1995), Choi & Feltus (1995) and Delzell et al. (1996). Literature findings on RCM introduction have also in general been gathered from so-called safety-driven industry, such as the nuclear sector. However, maintenance programmes and performance in that kind of industry context seem to be more systematic and comprehensive than in the basic industry. Therefore, the need of using RCM is probably larger in the basic industry sector. At the same time, the preconditions for introducing RCM within a basic industry context are probably less favourable compared with the safety-driven industry.
This situation indicates a need for some kind of RCM introduction strategy, facilitating for organisations in basic industry to introduce RCM. However, a comprehensive strategy is lacking in the literature (Backlund, 2003a). The lack of a strategy corresponds to the limited research relating to the introduction of maintenance technologies (Hipkin & Lockett, 1995).

1.3 Aim of the research

The aim of the research project described in the thesis is to develop an RCM introduction strategy. The strategy should facilitate the managing of RCM introduction, when the aim is to change the overall way of working with maintenance in an organisation.

It is the author’s belief that an RCM introduction strategy should be developed with a specific industrial sector’s characteristics in mind. As there are differences in the preconditions between safety-focused and basic industries, there also seem to be differences in preconditions between different industrial sectors. The theoretical frame of reference on RCM introduction and application includes experiences from different kinds of industry sectors, see Backlund (2003a). However, the choice of empirical studies, see Sections 2.3.2 and 2.3.3, are within the hydropower sector. Therefore, an introduction strategy will be developed with that sector particularly in mind, which to some extent might be seen as representative for the basic industry.

1.3.1 Delimitations

Delimitations of the aim of the research are:

- **RCM analysis.** The research is focused on management aspects when introducing RCM. Reliability issues of importance in the RCM analysis performance are not in focus.
- **In-depth reasoning on technical support systems.** There are some technical support systems needed when using RCM. The aim of the research is to identify and discuss the importance of these kinds of support systems, not to scrutinize them in-depth.
- **Analysis, implementation and continuous improvements.** A main focus is on the planning and preparation of RCM introduction. This implies that the research presented in the thesis is more focused on the preconditions when introducing RCM, and not on the managing of analysis, implementation, and continuous improvements.
- **Profits and costs.** Benefits and results on a general level are focused on, but not more specific figures.
1.4 Research questions

In this section, a number of research questions are stated. Answering these questions is intended to generate knowledge needed to develop an RCM introduction strategy.

Several organisations experience difficulties when introducing RCM, but the literature on the phenomenon is scarce. In-depth knowledge regarding the management of RCM introduction is a precondition for identifying and understanding factors that affect the introduction. Based on this reasoning, the following research questions have been formulated:

- **What characterises an RCM introduction?**

Another issue of interest is to identify factors that affect the introduction of RCM. Therefore, the following research question has been formulated:

- **What managerial factors affect RCM introduction?**

An RCM introduction is usually in progress for some years. It is therefore of interest to identify when or where managerial factors appear in an RCM introduction, in the form of obstacles and driving forces. Based on this reasoning, the following research question has been formulated:

- **When and where do managerial factors affect an RCM introduction in the form of obstacles and driving forces?**

It is of interest to explore in what way it is possible to reduce factors that lead to obstacles when introducing RCM. It is also of interest to explore in what way it is possible to reinforce factors leading to driving forces. Based on this reasoning, the following research question has been formulated:

- **How can obstacles be reduced and driving forces reinforced?**

1.5 Structure of the thesis

The thesis consists of nine chapters and four appended papers. The thesis can be structured in three main parts, see also Figure 1.1:

- **Part 1:** This part of the thesis comprises the introduction and a description of the research design and process. The theoretical frame of reference comprises issues on RCM and RCM introduction, maintenance management, project management, and change management.
- **Part 2:** This part of the thesis comprises the empirical studies, including analysis and discussion of a longitudinal single-case study and a multiple-case study.
- **Part 3**: This part of the thesis comprises the results of the research project and a general discussion and conclusions.

![Diagram of thesis structure]

*Figure 1.1. The structure of the thesis.*
2 RESEARCH DESIGN AND PROCESS

In this chapter the author will explain and describe the research design and process. The analysis design will also be presented, as well as a discussion of validity and reliability. First, a brief introduction to the background to the research project.

2.1 Background to the research project

The research project described in this thesis is performed within the research activities of the Polhem Laboratory. The Polhem Laboratory is a competence centre that was initiated by NUTEK (The Swedish National Board for Industrial and Technical Development). Member organisations of the Polhem Laboratory include twelve companies, several departments of Luleå University of Technology, four research institutes and VINNOVA (The Swedish Agency for Innovation Systems, previously NUTEK). The main goal of the research within the Polhem Laboratory is to develop technologies for product development and manufacturing through integration of design, manufacturing, materials engineering and maintenance for application in Swedish industry. The research project described in this thesis has been performed within the field of maintenance engineering.

In the beginning of the research project mainly three member organisations were involved. One company belonged to the nuclear industry, ABB Atom, one to the hydropower industry, Vattenfall AB Vattenkraft, and one to the aircraft industry, Volvo Aero Corporation. The author made several visits to the industrial representatives. The aim was to comprehend the present situation considering the maintenance management at the companies. An overall interest of the industrial participants was the integration of risk management and maintenance management, to support effective and efficient maintenance decisions. Volvo Aero Corporation had used RCM for a long time, while the other two companies were going to introduce RCM. As these two companies identified and experienced difficulties in the beginning of their RCM introduction, the phenomenon ‘RCM introduction’ became interesting to study. Later on, the ABB Atom participation in the centre ended, and the research project became mainly focused on the introduction of RCM at Vattenfall AB Vattenkraft.

2.2 Research approach

The choice of research approach has to be based on the type of research questions we set out to illuminate (Merriam, 1988; Yin, 1994; Holme & Solvang, 1997). In this thesis, the research focus is on the management of RCM
introduction, when the aim is to change the overall way of working with maintenance in the organisation. Managerial factors during an RCM introduction may be difficult to distinguish from its context. Therefore, in-depth knowledge is considered necessary to obtain an understanding of why some organisations experience the introduction of RCM cumbersome to manage. Qualitative research is suitable when studying things in their natural settings (Denzin & Lincoln, 2000) and is commonly used in human and social sciences, where there is a need of nearness to the subject studied. It is used to understand a particular situation for an individual, group or organisation (Yin, 1994; Holme & Solvang, 1997).

The main objective of the research is to develop a strategy for RCM introduction. To fulfil the aim, a couple of research questions have been stated. The aim and the research questions in this thesis are of a descriptive nature, where the management issues are related to a social context. According to Merriam (1988), descriptive research is suitable when description and explanation are looked for. However, the second research question, considering factors that affect the introduction in the form of driving forces or obstacles, is of an explorative nature. The last research question, considering how managerial factors leading to obstacles or driving forces can be reduced or reinforced, is of an explanatory nature.

A quantitative approach might be considered an alternative to answering the research questions, by means of, for example, surveys. However, one disadvantage with such an approach would be the difficulties of obtaining a deeper knowledge of the introduction process. According to Merriam (1988) and Patton (1990), quantitative research implies taking apart a phenomenon to examine its components, which become the variables of the study. Since the aim of the research is to develop an introduction strategy based on management studies, qualitative research was judged to be the best alternative. Therefore, the research design chosen in this thesis is based on social, empirical and qualitative science.

In discussions concerning methodology choices, one often distinguishes between induction and deduction, see Figure 2.1.
However, there are some shortcomings with induction and deduction. Induction implies making generalisations from the conclusions derived from a specific case. A weakness is that a general rule is developed from a number of observations. When using deduction, the researcher starts from a general rule and explains a specific case. A weakness here is that the approach does not explain, but rather establishes the rule; see, for example, Molander (1983) and Alvesson & Sköldberg (1994).

According to Alvesson & Sköldberg (1994), abduction is used in most case studies. With this method a single case is interpreted with a kind of overarching hypothetical pattern. The interpretation is corroborated with new observations. In this way abduction can be interpreted as a combination of induction and deduction. During the process the empirical application is developed, and the theory is adjusted. Abduction departs from empirical facts, just like induction, but makes use of a theoretical framework and is closer to deduction, see Figure 2.2. The author has chosen a research approach in accordance with abduction. Such an approach should strengthen the validity of a developed introduction strategy, as both empirical findings and theoretical studies are used.
2.3 Case study designs

A research design describes a set of guidelines that connects theoretical paradigms to strategies of inquiry and methods for collecting empirical material; see Denzin & Lincoln (1994). According to Yin (1994), a research design is an action plan for getting from here to there, describing how empirical data connects to the study’s initial research questions, and to its conclusions. Case study is one way of performing social science research. Other ways are, for example, experiments, surveys, and the analysis of archival information. Each strategy has advantages and disadvantages, mainly depending upon three conditions: (1) the type of research question, (2) the control an investigator has over actual behavioural events, and (3) the focus on contemporary as opposed to historical phenomena; see Yin (1994).

A case study can be considered an intensive and holistic description and analysis of a restricted phenomenon (Merriam, 1988). A case study methodology is suitable when the aim is to better understand complex social phenomena and is an empirical inquiry that investigates a contemporary phenomenon within its real-life context. The methodology is especially useful when the boundaries between phenomenon and context are not clearly evident (Yin, 1994). According to Merriam (1988), case study is preferable when the focus is on the process rather than the result, on the context rather than specific variables, and on discoveries instead of proving causal connections. One important application of the case study methodology is when we want to explore situations in which the intervention being evaluated has no clear, single set of outcomes. A second application is when we want to describe an intervention and the real-life context in which it occurred. The case study strategy may also be used to explain the causal links in real-life interventions that are too complex for survey or experimental strategies (Yin, 1994).

In general, a case study methodology is preferred when solving research questions including ‘how’ or ‘why’, when the investigator has little control over
events, and when the focus is on a contemporary phenomenon within some real-life context. For example, a case study is suitable when studying introduction processes, managerial processes, and organisational changes (Yin, 1994).

Based on the reasoning above, case study methodology was considered to be the most suitable research strategy for answering the research questions in Section 1.4.

### 2.3.1 Single-case versus multiple-case designs

A primary distinction when designing case studies is between single-case and multiple-case designs. Both designs may be further classified as holistic or embedded designs, depending on the defined ‘unit of analysis’ (Yin, 1994).

A single case may be used to study whether a theory’s propositions are in accordance with practice or whether some alternative set of explanations might be more relevant. Other rationales for a single-case study are when the case is rare or unique, or when the investigator has an opportunity to observe and analyse a phenomenon previously inaccessible to scientific investigation (Yin, 1994).

In a multiple-case study, one goal is to build a general explanation that fits each of the individual cases in the study, even though the cases will vary according to different characteristics. With a multiple-case study, there is a better potential for greater explanatory power and better possibilities for generalisations than by using a single-case study (Miles & Huberman, 1994). Any use of a multiple-case study design should follow a replication, not a sampling logic. In a way, the cases should serve a purpose similar to that of multiple experiments. A few cases, two or three, would be literal replications, i.e. predicting similar results. Four to six cases might be designed to pursue two different patterns of theoretical replications, i.e. to produce contrasting results but for predictable reasons (Yin, 1994). An important step in all of these replication procedures is the development of a rich, theoretical framework. The framework needs to state the conditions under which a particular phenomenon is likely to be found, a literal replication, as well as the conditions when it is not likely to be found, a theoretical replication. The theoretical framework later on becomes the vehicle for generalising to new cases, again similar to the role played in cross-experiment designs, where the theories can be practical, and not just academic (Yin, 1994).

When only one unit of analysis is studied, as for example ‘RCM introduction’, the case study is considered to be holistic. However, the same case study may involve more than one unit of analysis. This occurs when, within a single-case,
attention is also given to different sub-units. The design used will then be called an embedded case study design (Yin, 1994).

2.3.2 The choice of a single-case study

An extensive literature study, followed by an in-depth case study, is, according to Yin (1994), an appropriate approach when studying managerial processes. This approach seemed even more suitable considering that previous research on RCM introduction, in general, did not discuss or analyse these kinds of managerial issues in-depth. Therefore, the author decided to perform a longitudinal single-case study to obtain in-depth understanding of the phenomenon ‘RCM introduction’. Such a research design for the studied phenomenon had not been performed earlier, as known to the author.

The opportunity to study a full-scale RCM introduction within an organisation is quite uncommon, particularly in Sweden. When the opportunity to follow the RCM introduction within a Swedish hydropower company appeared, that was seen as an excellent possibility for an in-depth case study. According to Yin (1994), the situation might be compared with a unique case, which put a single-case study design in a favourable position. The overall unit of analysis was chosen as ‘RCM introduction’. In order to scrutinize the main unit as realistically as possible the sub-units studied, chosen by the author, were:

- The customer organisation, Vattenfall Vattenkraft, including the senior manager responsible for the financial means (the sponsor), purchasers of maintenance services, and technical specialists.
- The entrepreneur, Vattenfall Service, including top and middle regional managers.
- The RCM project group, which also includes the facilitators.

The choice of sub-units was made for various reasons. The RCM project group was selected as a sub-unit representing the ones managing the RCM introduction, while the other two sub-units represent the actors involved in the introduction. To avoid too resource demanding a study, the plant groups were not studied. Instead, discussions have been made with the middle managers, assuming they have good insights in their plant groups’ work. The approach was considered suitable considering that both middle managers and employees in the plant groups in general had been working in the organisation for a very long time. The sponsor and the regional top managers were the highest level of senior managers that in practice were involved in the introduction of RCM.

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2 See Chapter 4 for more information about the sub-units and the organisations.
Referring to the given arguments, the chosen case study design therefore became a single-case embedded design.

2.3.3 The choice of a multiple-case study

It was of interest to the author to be able to indicate whether factors identified in the longitudinal case study could be considered general for hydropower organisations. For this purpose, a multiple-case study was also performed. The organisations in the multiple-case study were chosen to show similarities between themselves, and with the single-case study findings, i.e. a literal replication.

However, since performing case studies may be a very time-consuming activity, according to Gummesson (1991) and Yin (1994), less comprehensive studies were chosen in the different organisations. The studies within the multiple-case study were not made with the intention of comprehensively describing and following the chosen organisations’ work with introducing RCM, but of validating the findings from the longitudinal single-case study.

The multiple-case study involved three organisations, which had all begun the introduction of RCM. To reduce the influence of industrial contextual aspects, only hydropower organisations were chosen. No similar comprehensive RCM introduction was going on among the other major hydropower organisations in Sweden at that time. Therefore, three hydropower organisations, one in Norway, one in Canada, and one in Australia, were chosen. The first two organisations were chosen due to their similarity in size and progress in the RCM introduction, compared to the Swedish organisation. The Australian company was smaller, but had progressed further in the introduction. That was of interest when analysing the managing of the earlier introduction efforts, comparing with the experiences of managing the introduction later on. As managerial issues were to be studied, it was important to consider cultural differences when choosing cases in other countries. The countries involved were considered to have cultures quite similar to those in Swedish society.

The overall unit of analysis within the multiple-case study was the ‘RCM introduction’. The sub-unit was the RCM project group, which involved the project manager and other project staff members. The case study design was chosen as a multiple-case study embedded design.

2.4 Information collecting methods

There are several possible ways of collecting the information in a case study, such as reviewing documentation and archival records, interviews, direct
observations and participant observation. According to Yin (1994), the case study’s unique strength is its ability to deal with all these varieties of evidence.

2.4.1 Interviewing

One of the most important sources of case study information is the interviews, because most case studies are about human affairs. The most common type of interview is individual, face-to-face verbal interchange, but it can also take the form of a face-to-face group interview, mailed or self-administered questionnaires, and telephone surveys (Fontana & Frey, 1994). Most commonly, case study interviews are of an open-ended nature, in which you can ask the respondents for the facts of a matter as well as for the respondents’ opinions about events (Yin, 1994). The strength of in-depth interviewing is that the research situation is similar to a common everyday situation and an ordinary conversation, in a flexible and dynamic manner; see, for instance, Taylor & Bogdan (1984), Patton (1990) and Holme & Solvang (1997).

2.4.2 Direct and participation observation

Making a field visit to the case study ‘site’ provides an opportunity for direct observation. Observations may include, for example, observations of meetings and factory work. Observational evidence is often useful in providing additional information about the topic being studied. For example, observations of an organisational unit add new dimensions for understanding of the context of the phenomenon being studied (Yin, 1994).

Participant observation means a special mode of observation in which the researcher is not merely a passive observer. Instead, the researcher may adopt a variety of roles within the case study situation and actually participate in the events being studied. The most distinctive opportunity when using participant observation is that it permits access to people who are involved and to everyday events and activities, which otherwise might be inaccessible to scientific investigation. Another distinctive opportunity is the ability to perceive reality from the viewpoint of someone “inside” the case rather than external to it (Yin, 1994).

According to Patton (1990) and Holme & Solvang (1997) qualitative observations and interviews are the best methods available for studying processes. According to Gummesson (1991) qualitative, informal observations and interviews provide the best opportunities for the traditional study of an organisation. These methods provide opportunities for better understanding the complexities of many situations. One must physically go to the people, in “the field” in order to observe their behaviour in its natural setting (Merriam, 1988).
2.4.3 Action research
Action research is characterised by the researcher participating together with others in finding the solution to the practical problem. Also, the approach implies co-operation in the practical work including both learning and research (Holme & Solvang, 1997). An important element in action research is the ability to both monitor and influence a real process (Wallén, 1996). By using action research, the researcher enters a real-world situation and aims both to improve it and to acquire knowledge; see e.g. Checkland & Holwell (1998).

2.4.4 Reviewing documentation and archival records
For case studies, the most important use of documents is to confirm and strengthen evidence from other sources. Because of their overall value, documents play an explicit role in any collection of qualitative data when doing case studies. This type of information can take many forms, such as agendas and other written reports of events, administrative documents such as progress reports and other internal documents, and also organisational records such as organisational charts and budgets over a period of time (Yin, 1994).

2.4.5 Information collection during the single-case study
For the single-case study, five different information collecting methods were chosen; interviews, documentation collection, direct observation, participant observation and, to some extent, action research. The author considered it a valuable strength to make direct observations, participant observations, and to some extent action research to get primary information. During the pilot study and the beginning of the planning and preparation of the introduction, relatively few people were involved and the activities in the RCM project progressed slowly. Therefore, participant observation and action research were not considered useful. Interviews were also used in the beginning of the planning and preparation work, asking specific questions and to get more personal information about the introduction process. The use of internal documents, such as project reports, also contributed to the information gathering. See Section 4.1, for a more comprehensive description of the research approach during the single-case study.

2.4.6 Information collection during the multiple-case study
For the multiple-case study, two different data collecting methods were chosen; interviews and documentation collection. Telephone interviews were considered a suitable approach for gathering information in this part of the research, partly due to the geographical distances. However, to make the respondents willing to take time for this kind of interview, the author considered it necessary to first
make visits to the organisations. Internal reports about the organisations’ work with introducing RCM were also used, when available.

2.5 Analysis design - strategies and methods

According to Miles & Huberman (1994), analysis of qualitative data consists of three activities: data reduction, data display, and conclusion drawing.

2.5.1 Analysis strategies

Relying on theoretical propositions
The most preferred analytical strategy is following the theoretical propositions that led to the case study. The propositions should shape the data collection plan and thereby give priority to the relevant analytical strategies. Theoretical propositions about causal relations – answers to ‘how’ and ‘‘why’ questions – may be very useful in guiding case study analyses (Yin, 1994).

Developing a case description
A second analytical strategy is to develop a descriptive framework for structuring the case study. This strategy is less preferable than the use of theoretical propositions, but may serve as an alternative when theoretical propositions are absent. At the same time, a case description is valuable when the original purpose of the case study is descriptive (Yin, 1994). The typical mode of data display in qualitative research is narrative text, although narrative text alone is sometimes considered a weak and cumbersome form of display, see Miles & Huberman (1994). On the other hand, Czarniawska (1999) argues in favour of narrative knowledge as an attractive approach for bridging the gap between theory and practice.

2.5.2 Analysis methods

Some useful analysis methods are:

- **Pattern-matching.** For case study analysis, one of the most desirable strategies is to use a pattern-matching logic. Such logic compares an empirically based pattern with a predicted one. If the patterns coincide, the results can help a case study strengthen its internal validity (Yin, 1994).

- **Explanation building.** Explanation building is, in fact, a special type of pattern matching. Here, the goal is to analyse the case study data by building an explanation of the case. The procedure is mainly relevant to explanatory case studies. To “explain” a phenomenon is to stipulate a set of causal links about it (Yin, 1994).

- **Time-series analysis.** To identify important activities in time conducting a time-series analysis may be useful (Miles & Huberman, 1994; Yin, 1994).
- **Programme logic models.** A programme logic model is a combination of pattern-matching and time-series analysis. The pattern being matched is the key cause-effect pattern between independent and dependent variables. However, the analysis deliberately stipulates a complex chain of events (pattern) over time (time series), covering these independent and dependent variables (Yin, 1994).

- **Cross-case analysis.** A fundamental reason for making a cross-case analysis is to enhance the possibilities for generalisations and to deepen understanding and explanation (Miles & Huberman, 1994).

### 2.5.3 Chosen strategies and methods

Strategies and methods considered suitable for describing, exploring and explaining the ‘phenomena’ studied were:

- **Theoretical propositions.** A literature study was made of RCM introduction and application. Based on the study, several theoretical propositions were made as a basis for structuring and analysing the empirical material.

- **Case study description.** A case study description was developed to increase the understanding of the RCM introduction studied, and to be able to evaluate the forthcoming analysis and discussion.

- **Analysis methods.** Methods suitable for analysing the case studies and generating a basis for developing an RCM introduction strategy, were pattern matching, explanation building, a programme logic model, and cross-case analysis.

### 2.6 Reflection on the design and generalisation of results

The choice of any chosen research design involves advantages as well as disadvantages. The most frequent criticism of qualitative methods is that they are inevitably subjective, where objectivity is traditionally considered as the fundamental idea of the scientific method (Patton, 1990). According to Gummesson (1991) and Yin (1994), some researchers claim, for example, that case studies sometimes result in little basis for scientific generalisation, take a long time to complete, lack statistical validity, and can be used to generate hypotheses but not to test them. However, when working with case studies, the analogy to survey research, in which a ‘sample’, if selected correctly, readily generalises to a larger universe, is incorrect. Survey research relies on statistical generalisation, whereas case studies give possibilities for analytic generalisation. In analytical generalisation, the investigator strives to generalise a particular set of results to a broader theory. Therefore, the results from case studies are possible to generalise to theoretical propositions but not to populations or universes. In analytical generalisation a previously developed theory is used as a template with which to compare the empirical results of the case study. If two or
more cases are shown to support the same theory, replication may be claimed. Analytical generalisation may be used independently of whether your case study involves one or several cases (Yin, 1994).

The author has been aware of the long time needed to obtain results from an in-depth case study. Therefore, only one in-depth single-case study was performed. The minor cases studied within the multiple-case study were considered to be an efficient approach for validating findings in the single-case study. The awareness of the criticism should to some extent decrease the subjectivity of the information gathered and analysis performed. The author agrees with Patton (1990), who claims that the ways in which measurements are constructed, for example in questionnaires, are no less open to the intrusion of the evaluator’s biases than making observations in the field or asking questions in interviews.

As many sources of collecting information are preferable, see Sections 2.9.1 and 2.9.2, there are some drawbacks with some of the information collecting methods. Problems related to participant-observation and action research have to do with potential biases and the fact that the approaches may take considerable time. The roles are sometimes to be assumed contrary to the interest of good science practices (Yin, 1994). However, the author considered that the advantages of the information collecting methods were more important for the research than the potential drawbacks.
2.7 The research process

The research process may be viewed as consisting of some main steps, see Figure 2.3.

The steps have not been completed strictly sequentially, but to some extent been worked on in a parallel mode. The performance of the theoretical framework, the single-case study and the multiple-case study will be described below, together with a reflection on the research process. The other steps in the research process will be described in the separate chapters.

2.7.1 A theoretical framework

Empirical regularities initiated the research, when some of the industrial participants in the Polhem Laboratory perceived problems or concerns when introducing RCM in their organisations. From these empirical regularities, the theory of RCM introduction and application was examined. However, the study of literature was performed for a long time in the research process, and was accordingly a parallel activity also during the performed case studies. The analysis of the theory aimed at creating a theoretical platform and propositions, from which the author could proceed in the forthcoming research steps, see Section 3.5. It aimed at identifying the lack of existing theory and at structuring the findings in the case studies. The theoretical framework also was to be used analysing the empirical findings. The literature studies showed a need for managing RCM introduction in a holistic view, including several management areas. Among these areas were, for instance, maintenance management, change management, and project management. The approach of working with literature
studies and empirical observations simultaneously was suitable since working
with case study observations increased the understanding of the literature
findings, and vice versa.

2.7.2 The single-case study
The longitudinal single-case study began in October 1997 and was completed in
February 2003. Information was gathered both from primary sources and some
secondary sources such as direct observations, participant observations,
interviews, and internal company reports.

Until 1999 the author made visits on several occasions to the case company,
including its head office, and the plant where the pilot team worked. This
approach was considered suitable since the RCM project, during this period of
time, mainly involved a minor group of people. The author did not use
standardised interview schemes when meeting personnel during these visits.
However, questions of interest were listed in advance, although they differed
between the respondents, depending on new information and the knowledge
gathered.

In August 2000, planning and preparation started, which was going to involve
many people in the studied organisation. To get better access to the phenomenon
studied, the people involved and everyday events, the author chose to perform
participant observations. Then the author was staying in the company and
followed the work as an independent member of the RCM project group. During
that time, the author attended meetings, with a focus fully, or partly, on RCM
issues. These meetings included project group meetings, information meetings
with managers and employees, project risk analysis sessions, meetings with top
and middle regional managers, meetings with technical personnel and
purchasers of maintenance services, senior management meetings, and
information and education meetings with different categories of employees.

Formal interviews were mainly held in the beginning of the planning and
preparation and included top and middle regional managers. The questions were
mostly of an open-ended nature. During all interviews notes were written, which
were later filed in a qualitative database. The purpose was to obtain a general
picture of the phenomenon and later on have the possibility to follow-up with
specific questions when needed. Information was gathered continuously during
the research process. Analyses, conclusions and hypotheses generated during the
research process affected the shapes of the questions later on. This approach is
in accordance with Taylor & Bogdan (1984) and Merriam (1988) considering
collection of information and analysis as a simultaneous activity in qualitative
research.
2.7.3 The multiple-case study

The information from the three organisations in the multiple-case study was mainly gathered from interviews and to some extent internal reports. The type of interview used was mainly as telephone interviews. It was considered necessary to get into personal contact with the respondents in order to obtain favourable conditions for the follow-up interviews on telephone. Therefore, visits were made to the organisations with the major aim of establishing a personal contact with the respondents. Another aim was to get a first general picture of their experiences of introducing RCM. As the respondents had a lot of regular work assignments to care about, each visit lasted approximately for half a day. The discussions were based on open-ended questions, to be followed up with more specific questions on the coming discussions over telephone, see Appendix. During the company visits, two to four respondents attended the meetings. The telephone interviews were performed with one respondent at a time. However, not all the respondents from the visits were available for telephone interviews due to other work assignments. The discussions via phone were preceded by a document summarising overall aspects of the RCM introduction, based on the earlier visits to the organisations, and on the literature study. The intention was to promote a common understanding of the phenomenon ‘RCM introduction’. The followed interviews were based upon a structured questionnaire, of an opened-ended nature. During all interviews notes were written, which were filed in a qualitative database later on. As the respondents had many regular work assignments to deal with, the time for the telephone interviews was limited. The interviews were made on approximately three occasions for each company, during one hour on each occasion.

2.8 Reflections on the research process

2.8.1 The information collection

During the single-case study, the author perceived the participant-observation approach as suitable, as it was easy to get into contact with respondents and to attend meetings. The direct observations were experienced as very valuable as they promoted objectivity in the findings. For example, during the interviews in the multiple-case study, respondents from the same organisation gave, to some extent, different views on the same matter.

During the multiple-case study it was sometimes difficult to get into contact with the respondents since they were busy with different kinds of work assignments. Therefore, it is the author’s opinion that the personal contacts, gained from the company visits, were of significant importance. If the author had been more anonymous to the respondents, they would probably not have taken so much time for telephone interviews and reviewing the case
descriptions. The rather comprehensive single-case study that was performed implied that there were many questions that the author would like to discuss in the multiple-case study, but it was unfortunately not possible. Therefore, the comparison and validation had to be made on a rather overall level. It could also be difficult to follow a specific order of questions, as the respondents had very much information to share on each specific question and related issues. This also affected the time available for the interview.

Another reflection regarding the interviews is related to the respondents’ skills in change management issues. An important part of the research was about organisational change due to the RCM introduction. As all the respondents were engineers, with technical issues as main interest, their views and interpretations of change issues could sometimes be simplified. That might have implied that the information on change management issues was not sufficiently comprehensive, in relation to the significance of the management perspective in the actual introduction. A larger number of respondents, including middle managers and employees, could probably have revealed a more realistic picture of the organisational change. However, using such an approach, in all the three companies, was considered to be too comprehensive to manage in the research project.

2.8.2 The influence of the author

The research approach used during the single-case study has to some extent been related to action research. During the observations and the interviews, the author was aware of the possibilities of influencing the phenomenon studied. However, the author was not in charge of any kind of activity in the RCM project, in the single-case study, and did not have any direct influence on the final decisions on activities going on. The author mainly had the role of an independent member of the project group, and mainly took part in the discussions when asked to do so. Main activities in which the author supported the introduction were:

- Some information gained during the observations and interviews was passed on to the RCM project group, with the aim of facilitating their work. It should be pointed out that such kind of information could not be traced back to the specific respondent.

- Some information gained during the literature study was also passed on to the RCM project management group, with the aim of facilitating their work.

- The multiple-case study performed by the author was in some way a benchmarking study, which could be used in the RCM project. However, it is the author’s opinion that the information was used mainly as a way of evaluating the status of their own project, than actually using the findings for making improvements.
It is the opinion of the author that these activities, together with interviews and participation in different meetings, have mainly influenced the studied phenomenon regarding information and communication. The respondents have been given a possibility to speak more freely about their views on the project. At the same time they got information about the project during interviews and discussions. The knowledge that the RCM project was studied in a research project might also have influenced the respondents’ interest in the introduction.

It is also the author’s opinion that being actively involved in the project activities was essential in order to get good access to the work in the project group, to other respondents and attending meetings. During such a long study, acting only as an observer would probably have been experienced as annoying by the project group, making them less willing to have a researcher involved. It should also be pointed out that the author was in the middle of a learning process, and did not have the competence and skills needed to give clear advice on how the project group should manage the introduction.

2.8.3 The author’s frame of mind

According to Taylor & Bogdan (1984) the author’s frame of mind is of interest when examining books and dissertations based on participant observation or qualitative interviewing. This procedure implies clarifying the researcher’s assumptions, biases, and theoretical orientation, which increases the internal validity according to the reasoning in Section 2.9.2.

The author looks upon reliability and maintenance management as multidisciplinary engineering sciences, related to areas such as safety, design, statistics, quality, production and management. The author’s educational background is within Maintenance and Material engineering (B.Sc) and Manufacturing engineering (M.Sc). The research studies have been performed in the field of Quality technology and management. These four subject fields studied include both technical and management aspects. It is the author’s belief that this theoretical background established a good basis for the research project performed.

2.9 Validity and reliability

Traditional research argues that the only way to produce valid information is through the application of a rigorous research methodology, that is, one follows a strict set of objective procedures that separate the researcher from those researched (Kincheloe & McLaren, 1994). According to Janesick (1994), validity in qualitative research has to do with description and explanation, and whether or not a given explanation fits a given description. There are four design
tests, most commonly used in empirical social research, for judging the suitability of a research design. These are: construct validity, internal and external validity, and reliability (Yin, 1994).

2.9.1 Construct validity

The construct validity of a research design means establishing correct operational measures for the concepts being studied (Yin, 1994). It is important for the researcher with a case study approach to describe the studied phenomena as correctly as possible. That implies that the researcher’s comprehension and interpretation of the studied phenomena should be in accordance with the real phenomena. According to Merriam (1988), construct validity is increased by the use of multiple sources of information such as questionnaires, interviews, literature review and observations, used in a complementary way, together making up a so-called triangular approach. The establishment of a chain of evidence and a review of the drafted case study report by key informants are also strategies designed to increase the construct validity (Yin, 1994).

During the single-case study several sources of information have been used, both primary and secondary sources; direct and participant observations, interviews and documents. During the multiple-case study, interviews and documents have been used. In both case studies, literature reviews have been used. Reviews of the drafted case study report by key informants have been applied to some extent. Altogether, it is the author’s opinion that the approach is in accordance with the triangular approach, and that reasonable requirements on construct validity are fulfilled.

2.9.2 Internal validity

Internal validity means establishing a causal relationship, whereby certain conditions are shown to other conditions, as distinguished from a spurious relationship (Yin, 1994). Internal validity can be obtained, during the analysis, by doing pattern matching, explanation building and time-series analysis (Yin, 1994). According to Merriam (1988), basic strategies ensuring internal validity are:

- **Triangulation**, i.e. the use of multiple sources of information
- **Member checks**, taking information and interpretations back to the respondents.
- **Long-term observations**, at the research site or repeated observations of the same phenomenon.
- **Peer examination**, asking colleagues to comment on the findings as they emerge.
- Researcher’s biases, clarifying the researcher’s assumptions and theoretical orientation.

Pattern-matching, explanation building and time-series analysis have been used in the analysis of the single-case study. The author has used triangulation, according to the reasoning on construct validity. The respondents did not get the possibility to revise the notes made by the author during the interviews. However, a draft of the single-case study description was made available to all the respondents concerned. The respondents involved in the multiple-case study also got the possibility to review and revise the case study description, valid for their specific organisation. In accordance with Gummesson (1991), the approach letting the respondents review the documents has given additional information. Long-term observations were made during the single-case study. Peer examination, i.e. discussions with colleagues and supervisors, were used continuously during the research process. However, the research study has been very extensive, and laborious in structuring and analysis findings. An even closer contact with colleagues and supervisors would probably have been valuable for performing an even more effective research process. The author’s assumptions and theoretical orientation have been clarified in Section 2.8.3. It is the author’s opinion that the approach used is in a reasonable way fulfils the criteria for internal validity.

2.9.3 External validity

External validity is concerned with the extent to which the findings of a case study can be applied to other situations, i.e. to what extent the findings can be generalised; see Merriam (1988) and Yin (1994). Basic strategies ensuring external validity are comparisons with similar studies (Merriam, 1988) and using replication logic in multiple-case studies (Yin, 1994).

The multiple-case study design was based on the possibility to make a literal replication. If one of the cases in the multiple-case study should be in accordance with the longitudinal single-case study, the case study findings should be of a sufficient number of replications to draw conclusions of a more general phenomenon. Furthermore, the cases were compared with documented experiences of introducing RCM. The single-case study was also compared with documented experiences of introducing Total Quality Management, TQM, and Total Productive Maintenance, TPM\(^3\), i.e. analytic generalisation. Reader, or user generalisability, involves leaving the extent to which a study’s findings apply to other situations up to the people in those situations (Merriam, 1988). That is of importance for the results of this thesis, since the proposed RCM introduction strategy, presented in Chapter 7, has not been tested yet. It is the

\(^{3}\) For further discussions on the introduction of TQM and TPM, see Appended paper no. IV.
author’s opinion that the approach used, sufficiently well corresponds to the requirements for fulfilling external validity.

2.9.4 Reliability

The goal of reliability is to minimize errors and biases in a study. In a case study this means that another investigator should be able to carry out the same study, following the same procedures and arrive at the same findings and conclusions (Yin, 1994). Reliability is usually problematic in social sciences due to the fact that human behaviour is never static. Therefore, in qualitative research, there is no benchmark by which one can take repeated measures and establish reliability in the traditional sense (Merriam, 1988).

A case study protocol is an effective way of dealing with the overall problems of increasing the reliability of case studies. The preparation of the protocol forces the investigator to anticipate several problems, including how the case study reports might be completed. A case study protocol should include an overview of the case study project, field procedures, case study questions, and a guide for the case study report. A formal, presentable database, making it possible for other investigators reviewing the evidence directly, and not be limited to the written reports, markedly increases the reliability of the entire case study (Yin, 1994).

During the single-case study, formal case study reports were not used, but many of the parts to be included in such a report have nevertheless been used. An overview of the case study project was communicated to the company involved in the single-case study, as the company was a participant in the Polhem Laboratory. Before visiting the companies included in the multiple-case study, the research project and its aims were sent to a respondent in each company. Senior managers, with an overall responsibility for the RCM project in the respective company, were informed and had approved the study. The use of field procedures was not seen as necessary in the single-case study, as the participant-observation approach used gave very good access to respondents and events. For example, if a respondent for some reason could not attend a pre-decided time for an interview or discussion, it was easy to find a new time suitable for both parties. During the multiple-case study, contacts were made to secure the meeting during the visit by the author. However, the questionnaire used during the telephone interviews were not formally developed within the different levels of the ‘studied object’ in mind, i.e. the interviewees, the single-case, and the multiple-case. A guide for the case study report, i.e. the design of the final case study report, was not used in the beginning of the study.
The author acknowledges that preparing the case study, according to the principles of a formal case study protocol, would have facilitated the awareness of potential problems that came up and increased the reliability of the study. However, in order to ensure the reliability of the single-case and multiple-case studies, field notes that were taken during observations and interviews have been stored in a qualitative database. Case study descriptions have been made, making it easier for other readers to validate the analysis and conclusions made. The information gathered has also been collected from several different sources, which, according to Patton (1990), increases the reliability of evaluation data.

The theoretical framework, the interview questionnaire, the case study descriptions, and the database would make it possible for other researchers to walk the same path during the information collecting phase. The description of how the data material was analysed also ensures the reliability of this study. However, the author has to some extent been part of the context of the studies. It is therefore impossible to achieve the same result for another person who wants to repeat what the author of this thesis has achieved. But it is the author’s belief that other researchers, going through the same steps within the research process, would come up with quite similar results.
3 THEORETICAL FRAME OF REFERENCE

This chapter includes findings on RCM, RCM introduction and some management perspectives. The theory is to some extent developed with the aim of building up a basis for the structuring and analysis of the case studies in Chapter 5 - 7.

This chapter includes sections on Reliability-Centred Maintenance, RCM, and RCM introduction, based upon a literature study, see Backlund (2003a). Different management perspectives also are presented. In the literary sources, different authors use different concepts, even if the meaning might be quite similar. For example, ‘RCM process’, ‘RCM method’, and ‘RCM technique’ are often used with a similar interpretation. The different views may be confusing for the readers, something that will be discussed in Section 3.1.5. The author prefers the view of RCM as a method of working, which will also be explained in the Section. However, in the thesis, the concept ‘RCM method’ will in general be used.

Some authors use the concept ‘implementation’ to describe the work with planning, preparation, performing analyses and implementing the RCM analysis recommendations in the existing maintenance programme. This interpretation of the concept is used by, for example, Hipkin & Lockett (1995), Harrold (1999) and Hardwick & Winsor (2002). Other authors, for example, Bowler et al. (1995) and Rausand (1998) use the concept ‘implementation’ to describe the specific phase when the analysis recommendations are implemented in a maintenance programme. They use the concept ‘introduction’ to describe all the activities needed to obtain a RCM based maintenance programme, such as planning and preparation. The author prefers the concept ‘RCM introduction’, to avoid misunderstanding of the meaning of ‘implementation’. Introduce or introduction can be defined as “Bringing into use or operation for the first time. For example, the introduction of new manufacturing methods (Hornby, 1989).”

Based on the reasoning above, the concepts ‘RCM method’ and ‘RCM introduction’ will be used further on in the thesis.

3.1 Reliability-Centred Maintenance

F Stanley Nowlan and Howard F. Heap, at the United Airlines under the Department of Defence, in US, established the concept ‘Reliability-Centred Maintenance’, RCM, in 1978. The principles of RCM arose from a rigorous
examination of certain questions that were often taken for granted (Nowlan & Heap, 1978):
- How does a failure occur?
- What are its consequences?
- What good can preventive maintenance do?

A misdirected interest in merely keeping equipment operational neglects functional requirements (Pujadas & Frank, 1996). The primary objective of RCM is to preserve system function (Nowlan & Heap, 1978), not ‘preserve equipment’. That implies knowing what the expected output is supposed to be, and that the primary task is preserving that output or function (Smith, 1993). Failure prevention has more to do with avoiding or reducing the consequences of failure than with preventing the failures themselves (Horton, 1993). In summary, the RCM method can be described in four unique features, see e.g. Smith (1993) and Anderson & Neri (1990):
- Preserve functions.
- Identify failure modes that can defeat the functions.
- Prioritise function need, via the failure modes.
- Select only applicable and effective preventive maintenance tasks.

Moubray (1997) defines RCM in two ways 1) “A process used to determine the maintenance requirements of any physical asset in its operating context”; 2) “A process used to determine what must be done to ensure that any physical asset continues to do whatever its users want it to do in its present operating context”. Another definition is “A systematic approach for identifying effective and efficient preventive maintenance tasks for items in accordance with a specific set of procedures and for establishing intervals between maintenance tasks” (IEC60300-3-11, 1999).

Basically, RCM does not contain any new principles for performing maintenance, it is more a structured way of utilising the best of several methods and disciplines, see e.g. Sandtorv & Rausand (1991) and Sutton (1995). RCM may in many respects be compared with some kind of quality assurance of a maintenance performance, defined as: “All systematic actions required to plan and verify that the efforts spent on preventive maintenance are applicable and cost effective” (Sandtorv & Rausand, 1991). According to Nowlan & Heap (1978), the concept ‘Reliability-Centred Maintenance’ was developed because the method is centred on achieving the inherent safety and reliability capabilities of equipment at minimum cost.
3.1.1 Background

RCM was developed in the USA, in the 1970’s, by the Air Transport Association (ATA), the Aerospace Manufacturers’ Associates (AMA), and the US Federal Aviation Administration (FAA) (Moubray, 1997). The licensing of an aircraft type requires, among other things, that FAA approve the preventive maintenance programme specified for the particular aircraft type. The development of the Boeing 747 civil aircraft involved many technologically advanced systems and structures. As a result, a traditional preventive maintenance approach would make the Boeing 747 so expensive to maintain that no airline could operate it profitably. This situation led the commercial aircraft industry to essentially undertake a complete revaluation of preventive maintenance strategy. A new method for structuring preventive maintenance programmes was defined in the document Maintenance Steering Group, revision 1 (MSG-1) for the 747, and was subsequently approved by the FAA (Smith, 1993). The document was also published under the title “Handbook: Maintenance Evaluation and Programme Development” (Nowlan & Heap, 1978).

Subsequent improvements in the so-called logic decision diagram, see Section 3.1.3, led to a second document, MSG-2: “Airline/Manufacturer Maintenance Programme Planning Document” (Nowlan & Heap, 1978). The MSG-1 and MSG-2 documents revolutionised the procedures followed in developing maintenance programmes for transport aircraft. However, their application for other types of equipment was limited by their brevity and specialised focus. Furthermore, the problem of establishing task intervals was not addressed, the role of hidden function failures was unclear, and the treatment of structural maintenance was inadequate. Solving these problems, ATA published the “Airline/Manufactures Maintenance Planning Document”, MSG-3 (Anderson & Neri, 1990). MSG-3 is still the process used to develop and refine maintenance programmes for all major types of civil aircraft (Moubray, 1997). In 1975 the ideas from MSG-3 were labelled Reliability-Centred Maintenance (RCM) by United Airlines under the Department of Defence (DoD) (Smith, 1993).

3.1.2 Outcomes and benefits of RCM

The RCM method makes it obvious that not all maintenance, not even preventive maintenance, is necessarily good maintenance (Horton, 1992). RCM has been applied with considerable success for more than 20 years; first in the aircraft industry, and later in the military forces, the nuclear power industry, the offshore oil and gas industry, and many other industries (Rausand, 1998). According to Moubray (1997), if RCM is correctly applied, it can reduce the amount of routine maintenance work by 40% to 70%. The cost-benefit payoff with RCM has been dramatic with its impact on commercial aviation, and
potentially offers similar dramatic payoffs in other areas where complex plants and systems are routinely operated (Smith, 1993).

The benefits and advantages of using RCM are several and have an impact on operations, safety, logistics, configuration, and administration (Smith, 1993). Some of the benefits are tangible and others are intangible. According to Bowler & Leonard (1994a), a benefit should not be excluded from an evaluation because it has been labelled ‘intangible’, only if its financial impact is insignificant. In Table 3.1, a number of examples of potential benefits of using RCM are presented, gathered from Anderson & Neri (1990), Ryan (1992), Bowler & Leonard (1994a), Harris & Moss (1994), Rausand & Vatn (1998), Pintelon et al. (1999), and Hardwick & Winsor (2002). For a more comprehensive discussion of benefits and outcomes of RCM, see, for example, Bowler & Leonard (1994a; 1994b), Bowler & Malcolm (1994), and Johnston (2002).

**Table 3.1. Examples of potential benefits of using RCM.**

<table>
<thead>
<tr>
<th>Potential benefits of using RCM</th>
<th>Potential benefits of using RCM</th>
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<tbody>
<tr>
<td>- Cross-discipline utilisation of knowledge</td>
<td>- Identifying hidden failure modes, i.e. unplanned corrective maintenance</td>
</tr>
<tr>
<td>- Traceability of decisions</td>
<td>- More effective requirement of skilled personnel and asset maintenance across the company</td>
</tr>
<tr>
<td>- A broader and more attractive way of working</td>
<td>- Better team working</td>
</tr>
<tr>
<td>- Significant reductions in preventive maintenance costs while maintaining, or even improving, the availability of the systems</td>
<td>- Establish a uniform and consistent approach asset maintenance across the company</td>
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<tr>
<td>- Less corrective maintenance</td>
<td>- Better opportunities to introduce multi-skilled staff</td>
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<tr>
<td>- More condition monitoring</td>
<td>- Cross-discipline utilisation of knowledge</td>
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<tr>
<td>- Reduced maintenance costs</td>
<td>- Design-out-maintenance projects</td>
</tr>
<tr>
<td>- More systematic maintenance</td>
<td>- Improved technical insights</td>
</tr>
<tr>
<td>- Fewer maintenance hours</td>
<td>- On-line information exchange among engineering and maintenance staff, and management</td>
</tr>
<tr>
<td>- Improved operational feedback</td>
<td>- A common language and thought process</td>
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<tr>
<td>- Reduced spare requirements</td>
<td>- Improved understanding between representatives of the operations and maintenance functions.</td>
</tr>
<tr>
<td>- Higher quality maintenance plans</td>
<td>- Improved operating performance</td>
</tr>
<tr>
<td>- Better availability of maintenance history</td>
<td>- Improved plant reliability</td>
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<tr>
<td>- More comprehensive documentation</td>
<td>- Improved availability</td>
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<tr>
<td>- Improved planning and administration systems</td>
<td>- Greater safety</td>
</tr>
<tr>
<td>- Tractability of decision making</td>
<td>- Educational capabilities</td>
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<td>- Better long term budgeting</td>
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<td>- Reduced environmental impact</td>
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<td>- Maintenance optimisation</td>
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<td>- Greater staff motivation</td>
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34
Examination of the RCM benefits listed in the table, and further described in the references, reveals that their effects can be grouped into five categories (Bowler & Leonard, 1994a):

- Reduced maintenance activity.
- Improved maintenance management systems.
- Improved productivity.
- Greater safety and environmental integrity.
- Other benefits.

It should be noted that several of the benefits can belong to more than one category. According to Johnston (2002), benefits of RCM can usually be traced back to two broad categories

- Risk reductions.
- Cost savings.

Full benefit of RCM can only be achieved when we have access to reliability data for the items being analysed, when considering the optimising of preventive maintenance intervals. The operating organisation must be prepared to collect and respond to real data throughout the operating life of the equipment (Nowlan & Heap, 1978; Vatn et al., 1996). Once a system has been through the initial RCM analysis, it produces a base-line definition of the preventive maintenance programme for that system. Therefore, the system needs only periodic updating to account for new information and system changes (Smith, 1993). In the long run, it is also of key importance to have a mutually supportive partnership between the personnel responsible for equipment design and the personnel responsible for equipment maintenance if maximum RCM results are to be achieved (Nowlan & Heap, 1978).

However, the use of RCM is not worthless if no data or very poor data is available in the beginning. The RCM approach will provide useful information for assessing the type of suitable maintenance task (Sandtorv & Rausand, 1991). For example, RCM was developed to help airlines draw up maintenance programmes for new types of aircraft before they entered service. It is an ideal way to develop maintenance programmes for new assets, especially complex equipment, where no historical information is available (Moubray, 1997). As a result of an RCM analysis we know whether (Sandtorv & Rausand, 1991):

- The failure involves a safety hazard to personnel, environment or equipment.
- The failure affects production availability.
- The failure is evident or hidden.
Traditionally, preventive maintenance programmes tend to be “cemented”. After some time one hardly knows on what basis the initial decisions were made and therefore no motive exists for changing existing maintenance tasks. In an RCM based maintenance programme one should go back and see on what basis the initial decisions were taken, and adjust the tasks and intervals based on operating experience. This is especially important for initial decisions based on insufficient data (Sandtorv & Rausand, 1991). If a maintenance programme already exists, the result of an RCM analysis will often be to eliminate inefficient preventive maintenance tasks (Laakso et al., 1995; Rausand, 1998). RCM can also be used to evaluate existing maintenance programmes, see, for example, Simola et al. (1998).

Tangential, or intangible, benefits realised from RCM may well turn out to be a major factor in the economic picture. For example, an RCM analysis at a power generation station showed, to the surprise of the managers, that more than half of the failure modes were hidden for operations personnel. The savings from the findings of hidden failures could exceed the maintenance savings on some entire systems. Without a comprehensive analysis process, these items would not have been discovered (Delzell et al., 1996). RCM can also be used as a way to reduce the isolation between practitioners and researchers by building “bridges” over the gap between the maintenance practitioners, the reliability engineers, and the statisticians and operation researchers working with maintenance optimisation models. By using this bridge, the statisticians and operations researchers may get help to establish more realistic models and methods, and transform these into practical tools for the maintenance practitioners (Rausand, 1998).

3.1.3 The RCM method

The RCM method is exhaustively described in books by, for example, Nowlan & Heap (1978), Smith (1993) and Moubray (1997), the standard on RCM published in IEC60300-3-11 (1999), and articles such as Vatn et al. (1996), Rausand (1998) and Rausand & Vatn (1998). RCM will therefore only be briefly described in this thesis.

In Moubray (1997) the RCM method is described according to seven questions that have to be asked about the asset or system under review as follows:

1. What are the functions and associated performance standards of the asset in its present operating context?
2. In what way does it fail to fulfil its functions?
3. What causes each functional failure?
4. What happens when each failure occurs, i.e. what is the failure effect?
5. In what way does each failure matter, i.e. what is the failure consequence?
6. What can be done to predict or prevent each failure?
7. What should be done if a suitable proactive task cannot be found?

The questions are answered by working through a number of structured steps described below, see also Figure 3.1. These steps are mainly performed by an RCM team under the guidance of a highly trained specialist in RCM, often called a facilitator. The group analyses the context in which the asset is operating, and then completes the RCM information on some kind of worksheet (Moubray, 1997). The team should preferably consist of four to six people with different experiences. However, both maintenance and operation people should be present. See, for example, Smith (1993) and Moubray (1997) for more thorough examples of the structure and skills needed. The order and the number of the steps during the analysis might differ somewhat, due to different authors’ recommendations, but the approach is usually quite similar. According to Smith (1993), satisfactory completion of the steps will provide a basis for preventive maintenance tasks in a system. This will come together with a well-documented record of exactly how those tasks were selected and why they are considered to be the best selections among competing alternatives.

![Figure 3.1. General steps to work through when applying the RCM method.](image)

Below, the different steps are shortly commented upon.

**Defining system functions, performance standards and system boundary definition**
Organisations acquire physical assets for one, possibly two, but seldom more than three main reasons. Primary functions are the reasons why an asset exists at all. Most assets are expected to fulfil one or more functions in addition to their primary functions. These are known as secondary functions. A function...
definition is not complete unless it specifies the level of performance desired by the user. Performance can be defined in two ways (Moubray, 1997):

- Desired performance, i.e. what the user wants the asset to do.
- Built-in capability, i.e. what it can do.

System boundary definition is important, for two major reasons (Smith, 1993):

- There must be a precise knowledge of what has been included in the system so that potentially important functions are not inadvertently neglected, or, conversely, do not overlap with an adjacent system.
- The boundaries will be the determining factor in establishing what comes into the system by way of power, signals, flow, heat, etc, and what leaves the system.

**Determining the ways in which the system functions may fail**
A failure is an unsatisfactory condition. A functional failure is defined as the inability of any asset to fulfil a function to a standard of performance. All the functional failures associated with each function should be recorded (Nowlan & Heap, 1978) and Moubray (1997).

**Determining the significant failure modes**
A failure mode is any event that causes a functional failure. The best way to show the connection and the distinction between functional failures, and the events which could cause them, is to list functional failures first and then to record the failure modes, which could cause each functional failure. When drawing up a list of failure modes it might not be practicable to list every single failure. It is necessary to consider the possibility of its likelihood. However, if the consequences are likely to be very severe, less likely failure possibilities should be listed and subjected to further analysis (Moubray, 1997).

**Assessing the effects and consequences of the failures**
A failure effect is what happens when a failure mode occurs. The failure consequence implies in what way each failure matters (Moubray, 1997). The extent to which each failure matters depends on the operation context of the asset, the performance standards that apply to each function, and the physical effects of each failure mode. This combination of context, standards and effects means that every failure has a specific set of consequences associated with it. This shows that the consequences of failures are more important than their technical characteristics. RCM classifies the consequences in four groups (Nowlan & Heap, 1978; Moubray, 1997):
- **Hidden failure consequences.** Hidden failures have no direct impact, but they expose the organisation to multiple failures with serious, often catastrophic, consequences.

- **Safety and environmental consequences.** A failure has safety consequences if it could hurt or kill someone. It has environmental consequences if it could lead to violations of any corporate, regional, national, or international environmental standard.

- **Operational consequences.** A failure has operational consequences if it affects production.

- **Non-operational consequences.** Evident failures, which fall into this category, affect neither safety nor production, so they involve only the direct cost of repair.

To identify the failure modes and their failure effects, a Failure Mode and Effect Analysis, FMEA, form is usually used. The basic idea in FMEA is to systematically identify the possible failure mechanisms and their effects on the system and list them in tabular form on specially designed worksheets (Laakso et al., 1995). An FMEA becomes a Failure Mode, Effects, and Criticality Analysis, FMECA, if criticalities or priorities are assigned to the failure mode effects (Høyland & Rausand, 1994). When using an FMECA, probabilities may be added to help determine component criticality (Taylor, 1989) and provide a critical item list (Paté-Cornell & Fischbeck, 1993). These critical items are items with significant failure effects on safety, production availability, or maintenance cost, and are usually called Maintenance-Significant Items, MSI (Sandtorv & Rausand, 1991; Laakso et al., 1995), or Functional-Significant Item, FSI (Nowlan & Heap, 1978). Items are also judged to be significant if they contain hidden functions whose failures would expose the organisation to a multiple failure with significant safety, environment or operational consequences (Sandtorv & Rausand, 1991).

**Identifications of maintenance tasks by means of a decision-logic scheme**
The RCM decision-logic scheme is a guide to ensuring consistent decision-making (Horton, 1992). The inputs to the decision logic scheme are the Maintenance Significant Items, MSIs, or Functions Significant Items, FSIs from the FMECA (Rausand, 1998). The decision-logic scheme facilitates the evaluation of the maintenance requirements for each significant item in terms of the failure consequences and selects only those tasks which will satisfy these requirements (Nowlan & Heap, 1978; Taylor, 1989). For items where no applicable and effective task can be found, re-design is recommended if safety is involved, otherwise no scheduled maintenance (Nowlan & Heap, 1978).
Identification of maintenance tasks interval

RCM focuses only on what tasks should be executed and why. When the tasks should be executed is derived from separate analyses that must consider and utilise combinations of company and industry experience to establish initial task frequencies. Statistical tools should be used when data is available (Smith, 1993). For a practical execution of these interval-based maintenance tasks, they should be grouped in maintenance packages (Nowlan & Heap, 1978; Worledge, 1993a).

Auditing, implementation and feedback

Immediately after the review has been completed for each asset by the RCM team, senior managers with overall responsibility for the plant’s equipment must evaluate the decision made by the team, a procedure called auditing. After each review is approved, the recommendations are implemented by incorporating maintenance (Moubray, 1997). Updating of the analysis results is important due to the fact that nothing remains constant (Rausand & Vatn, 1998). Some reasons for continuing the RCM activity to obtain full potential of the process is, according to Smith (1993) and Hollick & Nelson (1995):

- An imperfect system analysis process.
- Increased knowledge, both in terms of understanding how the plant equipment behaves and how new technology can increase availability and reduce operating and maintenance costs.
- Items fail in a way, which was unexpected.
- Items do not fail at all.
- Items fail in an expected way, but tasks are not effective in preventing failures.

3.1.4 Streamlined RCM

Performing RCM as described in the steps above, is in accordance with traditional or classical RCM, which is more comprehensively described by, for example, Nowlan & Heap (1978), Smith (1993) and Moubray (1997). Today, different streamlined models are common, see, for example, Rotton (1994), Heimbach (1995) and August (1997). A specific focus for small and medium sized enterprises, SME:s, is described by, for example, Richet et al. (1995), Sæbø (1999) and O’Reilly (2002). The streamlined models have mainly been developed with the aim of decreasing the great number of resources involved (i.e. time, money, and people) experienced by several companies when using classical RCM. Also the industrial application context seems to influence the RCM model used, where streamlined RCM models are used many times in the nuclear industry (Toomey et al., 1994; August, 1997). The different streamlined approaches are, according to Moubray (2002), characterised by:
- Retroactive approaches, where the use of RCM starts not by defining the functions of the asset, but starts with the existing maintenance tasks.
- Use of generic analyses, i.e. applying an analysis performed on one system to technically identical systems.
- Use of generic lists of failure modes.
- Skipping elements of the process, for example, the definition of functions.
- Analysis only of critical functions or critical failures.

The proponents of streamlined RCM approaches claim that the principal advantage is that streamlined RCM achieves results similar to those of ‘classical RCM’, but with much less time and at much lower costs. However, according to Moubray (2002), these streamlined approaches have some serious drawbacks, for example:

- Streamlined RCM versions, with a retroactive approach, focus on maintenance workload reduction rather than plant performance improvement.
- Assuming that the existing maintenance programme covers just about all the failure modes that are likely to require some sorts of preventive maintenance is simply not valid.
- Technically identical systems often require completely different maintenance programmes if the operating context is different.
- It is necessary to ask whether a loss of function caused by a failure mode will become evident to the operating crew under normal circumstances.

3.1.5 Different views of RCM

RCM is described quite similarly in books and papers, even if the use differs, as in some of the streamlined approaches. However, the opinions about ‘what RCM is’ differ between different authors. RCM is described as a tool, a method, a strategy, a process, a technique, and a philosophy. For example, RCM is a tool according to Geraghty (1996), and a powerful maintenance organisation and measurement tool according to August (1997). The RCM approach is a logical and systematic method or methodology according to Basille et al. (1995), Ben-Daya (2000) and Hipkin & DeCock (2000), and Rajotte & Jolicoeur (2000) describes RCM as a method for continuous improvements. RCM is like a maintenance technique according to Bowler & Malcolm (1994), Rotton (1994) and Page (2001). RCM is described as a process according to Adjaye (1994), Hipkin & Lockett (1995) and Hardwick & Winsor (2001). RCM is a maintenance management strategy according to Briggs (1994) and Harris & Moss (1994). According to Worledge (1993b) RCM is a complete maintenance philosophy based on maintenance engineering. According to Bowler et al. (1995), RCM is one of several philosophies. Some authors even use a mix of different views.
Even if the meanings of the different views might be similar, the many concepts might be confusing for researchers and, not least, practitioners. Another aspect of this issue is that the many different views on RCM probably indicate how people may look upon RCM, i.e. what it can achieve and consequently what the requirements are when introducing it in an organisation.

According to Harris & Moss (1994), RCM is basically a rational ordering of techniques – such as Block Diagram Analysis, Fault Tree Analysis (FTA), Pareto analysis and FMEA – which have been well-established and routine in reliability engineering. That general view is supported by, for example, Smith (1993) and Rausand (1998). According to Organ et al. (1997), RCM is one of the most powerful methods available in the application of maintenance tools. Based on this reasoning, the author of this thesis prefers to view RCM as a method of working, making use of different techniques and tools. This view is quite similar to Akersten & Klefsjö (2001), who views RCM as a way of working within the organisation to reach the goals set by the organisation, as what they call a methodology. The author also prefers the definition used by Nowlan & Heap (1978), who call a maintenance programme developed by means of RCM an RCM programme, defined as “A scheduled maintenance programme consisting of a set of tasks each of which is generated by the RCM analysis.”

3.2 Successful and failed introductions

In the literature, there are few findings of comprehensive descriptions of full-scale RCM introductions (Backlund, 2003a). Therefore, examples of successful or unsuccessful RCM introductions are few. However, according to Moubray (1997), Hipkin (1998) and Rausand (1998), many companies have successfully introduced RCM. Many companies have also experienced serious difficulties and even failed introducing RCM, see, for example, Smith (1993), Worledge (1993a), Worledge (1993b), Bowler & Leonard (1994b), Bowler & Malcolm (1994), Schawn & Khan (1994) and Moubray (1997).

As the descriptions of successful or unsuccessful RCM introduction are few, a justified question is: On what criteria can an RCM introduction be considered successful or unsuccessful? Based on the literature survey, several criteria have been found suitable, exemplified below, see also Figure 3.2:

- **Resources.** The introduction of RCM requires a significant amount of resources, time, and energy to be successful (Schawn & Khan, 1994; Jones, 1995; Moubray, 1997; Latino, 1999). According to Smith (1993) resources for new equipment and operator training, based on RCM
- **Costs.** Companies, which would gain substantial benefits, may delay, or indeed fail, to adopt RCM because of the high initial costs. Underestimating these costs can lead to the withdrawal of management support, if costs should unexpectedly escalate (Bowler et al., 1995). Several nuclear plants have decided not to go ahead with an RCM programme because of the initial costs involved, a serious problem also for other non-nuclear parts of utility operations (Worledge, 1993a).

- **Time.** RCM is usually a long-term goal with a short-term expectation (Latino, 1999) and RCM is many times criticised for being too time-consuming (August, 1997; Hipkin, 1998). Today’s business environment demands tactical solutions with almost immediate payback. A challenge is to adopt the RCM method to achieve a faster economic return (Jones, 1995; Rausand & Vatn, 1998).

- **Commitment.** A broad base of support for RCM is needed to successfully develop and implement maintenance changes (Jones, 1995). Maintenance is all about ensuring that assets continue to function to standards of performance required by their users. The ‘users’ are nearly always production or operations people. If these people are not closely involved in helping to define functions and performance standards, there will be little or no ‘buy-in’ to the maintenance programme on the part of the users (Moubray, 1997).

- **Conditions for continuous improvement.** People have to understand the importance and usefulness of collecting accurate failure data to support future analysis and changes. Conditional failures must be reported in the way in which the causes of all failures are recorded (Hardwick & Winsor, 2002).

Results and benefits as a criterion of a successful or unsuccessful RCM introduction may be looked upon in many different ways:

- **A customer perspective.** It is very important to analyse what expectations internal and external customers have, as well as the maintenance organisation and the production organisation (Srikrishna et al., 1996). Successful RCM ventures are generally those which meet prescribed requirements and in doing so generate satisfactory benefits (Bowler & Malcolm, 1994).

- **A measuring and evaluation perspective.** Many times, there exists an inability to identify and subsequently quantify the anticipated benefits of RCM (Bowler & Malcolm, 1994). Companies which would gain substantial benefits may delay, or indeed fail, to adopt RCM because of the lack of a clear method, or support systems, to evaluate a return on investment (Bowler et al., 1995; Hipkin, 1998; Hipkin & DeCock, 2000).
- An implementation perspective. Reported successes correlate with RCM analytical results implementation, where successful organisations embraced fundamental change in basic maintenance processes (August, 1997; Hardwick & Winsor, 2002). However, there are several examples where analysis recommendation never got implemented (August, 1997; Hipkin & DeCock, 2000).

- A quality perspective. An effective implementation must balance the organisation’s desire for progress with the need for quality in RCM analyses, to achieve bottom-line results. RCM analysts need measures of quality to ensure that the costly effort is being executed effectively (Johnston, 2002).

3.3 Some management perspectives when introducing RCM

According to Moubray (1997) and Schawn & Khan (1994), some of the main reasons why RCM introduction becomes problematic or fails are technical in nature, but the majority are organisational. Therefore, full and painless introduction requires careful management attention to several issues (Worledge, 1993a; Worledge, 1993b).
As mentioned in Section 1.2, there are not so many books or papers that focus on RCM introduction, especially considering introduction on a full-scale basis. However, in the literature on RCM applications, there are usually some discussions or examples of RCM introduction related issues. Based on the literature study, different kinds of managerial factors that affect the introduction of RCM have been identified. Some of these factors are directly related to managing RCM, as the skills in the RCM team or concerning the level of detail in the analysis performance. Other factors have to do with maintenance management issues, such as the shape of the current maintenance programme or support systems as a computerised maintenance management system, CMMS. As the introduction of RCM is many times carried out in the form of a project, some managerial factors are related to project management issues, such as planning of resources and measuring of performance. The introduction of RCM also seems to contribute to organisational change where, for example, managerial factors such as commitment and resistance affect the introduction. In Section 3.3.4 some examples of these managerial factors will be exemplified and briefly described, structured according to their affinity with the four management perspectives:

- RCM management
- Maintenance management
- Project management
- Change management

A brief introduction to the different management perspectives will be presented in Sections 3.3.1 – 3.3.3. RCM management has already been described in this chapter. The management perspectives are in themselves comprehensive and an extensive review of each perspective would reveal several common management issues. However, the division of the managerial factors is made with a view to what may be seen as some main characteristics of each management perspective.

### 3.3.1 Maintenance management

Maintenance management covers issues such as design of maintenance programmes, deployment of tools, and manpower to perform maintenance work (Tsang, 1998). Maintenance management is a part of a complete production system and is directly related to profitability through equipment output and equipment running cost (Knapp & Mahajan, 1998). Therefore, the many changes taking place in the operations field incorporate the maintenance function. This is essentially because of the increasing demands being brought upon physical assets through stricter safety, environmental control, and because of the role maintenance plays in achieving and retaining quality standards. Also, understanding and ensuring functionality has become a central theme of maintenance (Hipkin, 1998). A company may contain a large number of
technical systems which all interact to achieve the pursued business objectives. Therefore, maintenance also becomes more and more part of the integrated business (Waeyenbergh & Pintelon, 2002) and it is vital that maintenance management is integrated with corporate strategy to ensure equipment availability, quality products, and on-time deliveries (Riis et al., 1997). The practice of maintenance management has also come to focus on a systematic view including maintenance and reliability management. These management areas have traditionally been handled as isolated parts (Tsang, 1998). Maintenance management is defined as “All activities of the management that determine the maintenance objectives, strategies, and responsibilities and implement them by means such as maintenance planning, maintenance control and supervision, improvement of methods in the organisation including economical aspects.” (CEN, 2001). According to Hipkin (1998), the term physical asset management is frequently used synonymously with maintenance management, although the former term encompasses an even broader range of activities and applications. However, as asset management is a broad strategy with the potential of encompassing almost everything, it can be too big to be manageable (Organ et al., 1997). This might be one reason why the concept ‘Asset management’ is not defined in the European Standard of maintenance terminology (CEN, 2001).

The above definition of maintenance management indicates that this management perspective includes many different issues. This is also confirmed by the many descriptions of maintenance management in the literature. One description of maintenance management includes formal and informal elements. The formal elements include management systems and methods, organisational structures, information systems, and technology necessary to implement the generic maintenance tasks within an organisation. Informal elements include the individuals that in different ways contribute to the maintenance performance, i.e. technicians, operators, and managers, as well as the influence of the corporate culture (Riis et al., 1997). Another description is presented by Coetzee (1999) who describes a maintenance management process that consists of a strategic process and an operational process. The strategic process includes the overall managerial planning and measurement process that is used by the maintenance management to lead and control the maintenance organisation. The management planning part of this process consists of maintenance policy setting, maintenance procedure definition, objective setting and business planning. The operational process consists of the maintenance plan and the maintenance operation itself (Coetzee, 1999). According to Madu (2000), it is a responsibility of the other departments in the organisation, not only the maintenance department, to ensure that equipments are properly maintained and functional.
Policy, procedures, maintenance plans, maintenance information, operational systems, and maintenance operations, are all examples of parts to be handled in maintenance management (Coetzee, 1999; Madu, 2000). Documentation of maintenance work is essential for appropriate analysis and measures. Therefore, well-designed work order and procedures are a precondition for maintenance management. This is also a precondition for clear communication between all parties involved (Raouf & Ben-Daya, 1995). To implement maintenance tasks and analysis results, existing work orders must be revised and new work orders developed. Work orders should also be ‘packaged’ to be executed effectively. However, packaging of work orders may be a complex and demanding task when optimising maintenance performance (August, 1997).

Effective maintenance and reliability management programmes require, among other matters, data collection, planning and scheduling of maintenance operations (Madu, 2000). However, inappropriate intervals for scheduled maintenance frequently arise because of inadequate history reporting systems (Hipkin, 1998). A necessary condition for planning and controlling maintenance performance is to have a well-developed computerised maintenance management system, CMMS (Jonsson, 1997a; Hipkin, 1998). For example, managing a successful power generating business requires both the achievement of facility targets and making the right choice between operating costs and plant availability. A modern CMMS plays an important role in how best to achieve this balance (Burns, 1999). A CMMS allows better labour and cost control, and the identification of potential improvement areas. Information in a CMMS may, according to Raouf & Ben-Daya (1995), include:

- Information on work order status and estimated time versus actual time.
- Maintenance productivity reports.
- Charts and graphs showing backlog, overtime, emergency work.

The maintenance performance affects equipment performance and consequently final product quality. Therefore, any corporation that uses complex facilities in producing products, realises that preventive maintenance plays a key role in their quality management approach (Smith et al., 1991; Ben-Daya & Duffuaa, 1995). This has led to the development of maintenance methods such as Total Productive Maintenance, TPM, and RCM. TPM and RCM constitute important structures in maintenance management (Hipkin & DeCock, 2000). According to Smith et al. (1991) and Kelly (1992), TPM and RCM provide both effective and efficient maintenance in response to the needs of Total Quality Management, TQM. TPM focuses on integrating operators in maintenance work and on continuous and systematic improvement in order to maximise overall equipment effectiveness. The main goal is robust processes, i.e., processes free from disruption (Nakajima, 1988; Nakajima, 1989; Davis, 1997). However, while
adequate for simple assets, TPM does not work for complicated physical assets. RCM is more directed towards technology and offers a sound basis for assessing maintenance requirements in this context (Geraghty, 1996). When a maintenance programme is introduced, based on, for example, RCM, operational experiences begin to accrue. Documentation and reporting systems, integral to both the maintenance and logistics support functions, should serve as a major source of information for programme revision and product improvement. For example, an Integrated Logistic Support, ILS, programme includes management and technical activities to support requirements based on the reliability and maintainability characteristics of a system (Anderson & Neri, 1990; Rausand, 1998).

Maintenance management involves many different and integrated issues. The rather complex picture makes it sometimes cumbersome to manage these issues in practice. For example, the success of maintenance management interventions has been limited largely because of bad introduction attempts, involving factors such as incorrect planning, and poor measurement (Hipkin, 1998). Except from cumbersome or failed RCM introductions there also are several examples of failed introductions of TPM and TQM in organisations, see Appended paper IV. It may also be troublesome to make support systems work properly in an organisation, such as a CMMS, see, for example, Burns (1999).

### 3.3.2 Project management

Today much of the non-repetitive work in corporations and other organisations is carried out in projects. The goal may be to rapidly commercialise a new product or service, install new equipment, or satisfactorily complete some other time-limited undertaking (Rosenau, 1998). The Project Management Body of Knowledge, PMBOK, was developed by the Project Management Institute, which is the largest professional organisation, dedicated to the project management field (Raz & Michael, 2001). In the PMBOK a project is defined as “a temporary endeavour undertaken to create a unique product or service” (PMI, 2000). According to White & Fortune (2002) project management has become well developed and well accepted as a domain for the exercise of professional expertise and as an area for academic research and discourse.

There are some characteristics of projects that, taken together, distinguish project management from other managerial activities. Projects have a three-dimensional objective, i.e. simultaneous accomplishment of performance specification, time schedule, and cost budget. Projects are also unique, involve resources, and are accomplished within an organisation (Rosenau, 1998). In Chong & Brown (2000) a project is characterised by:

- An objective, i.e. to create or achieve something.
- Some resources, i.e. manpower, management, and physical resources.
- A budget, i.e. the estimate of resources needed.
- A schedule or time-span from identification to achievement of the objective.
- Milestones for monitoring at set stages.
- Success criteria for measuring progress.

The three most common criteria used for judging project success are to compile on time, to budget, and to specification, see, for example, Rosenau (1998) and White & Fortune (2002). In Raz & Michael (2001), emphasis is also put on these criteria, but customer satisfaction is in addition considered as an important success criterion. According to Lock (1998), the objectives of any project may be grouped under three headings, which are closely related to the success criteria:

- **Performance and quality.** The end result of the project must be fit for the purpose for which it was intended. Achieving the quality, performance and reliability objectives must be completed by adequate quality procedures.
- **Budget.** The project must be completed without exceeding the authorised expenditure. For commercial or industrial projects failure to complete work within budgeted costs reduces profits and any expected return on the capital invested.
- **Time for completion.** All significant stages of the project must take place no later than their specified dates, to result in total completion on or before the planned finish date.

The project manager should ensure that the project is given the resources needed for completion (Chong & Brown, 2000). However, the resource allocation by the senior management may be scarce. Therefore, an important decision regarding resource allocation might be to decide whether the schedule is to be resource-limited or time-limited (Lock, 1998). Project management is many times a highly problematical endeavour. A great many projects exceed their budgets, run late or fail to meet other objectives (White & Fortune, 2002). If the planned time-scale is exceeded, the original cost estimates and budgets are almost certain to be exceeded too. If any project task takes longer to perform than its planned duration, there is the obvious risk that the budget man-hours will also be exceeded (Lock, 1998). Control or monitoring processes are essential for projects (Lock, 1998; Chong & Brown, 2000). If the work can be carefully monitored, and managed against a sensible, achievable plan, many of the obstacles to control costs will be reduced (Lock, 1998). No project goes in accordance with your plan, however, planning is a basis for project monitoring activities (Rosenau, 1998).

There are several ways of structuring project management. On an overall level, they are mainly the same, according to stages and phases. For example,
according to Rosenau (1998), project management can in a simplified way be structured as a five-step process:

- **Defining.** Defining the project’s goals.
- **Planning.** Planning how the goals for performance specification, time schedule, and money budget, will be satisfied.
- **Leading.** Providing managerial guidance to human resources, subordinates, and others.
- **Monitoring.** Measuring the project work to find out how progress differs from plan in time to initiate corrective action.
- **Completing.** Making sure that the job that is finally done conforms to the current specifications.

Another way of structuring project management, according to a project life cycle, are described in Chapman & Ward (1999). On an overall level, phases and stages are:

- **Conceptualisation,** i.e. conceive.
- **Planning,** i.e. design, plan, allocate.
- **Execution,** i.e. execute, coordinate and control, monitor progress, modification of targets and milestones, allocation modification, and control evaluation.
- **Termination,** i.e. deliver, review, and support.

The need to manage uncertainty is inherent in most projects, which puts requirements on formal project management (Chapman & Ward, 1999). For example, PRINCE, Projects IN Controlled Environments, is a method that creates structures to handle project management and support the delineations of responsibilities for the project members. PRINCE was originally designed as a complete project management philosophy for information systems and information technology projects, especially in projects for UK government departments and agencies. The three key elements of PRINCE are organisational structure, planning, and control (Lock, 1998).

Other important phases or stages in project management are communication, quality and risk management (PMI, 2000; Raz & Michael, 2001). The use of effective quality management methodologies and tools is important for the development of project management processes and the way projects are conducted. Project quality management includes the processes required to ensure that the project will satisfy the needs for which it was undertaken. There is obviously a close relation between quality management and project management. Quality management and project management might be described in the same way, but each set of management practices has its own language and also sets of methodologies and tools, that separate the two bodies of knowledge.
Quality management has been very successful in cases where repetitive processes are common. Project management, in contrast, is applied to temporary work to create unique systems or services (Orwig & Brennan, 2000). A number of variations of project risk management have been proposed, including risk assessment and risk control. It may be relatively easy to identify risks, but you need a structured process for the more complicated tasks of analysing, tracking and controlling the project risk (Raz & Michael, 2001).

One of the main stresses on a project that can potentially cause it to fail is the element of change management with its strong social factor. Managing people is often the most difficult aspect of managing a project. However, the sometimes fundamental changes that affect people and their work environment are often understated in the engineering view of a project (Rosenau, 1998; Chong & Brown, 2000).

3.3.3 Change management

Most organisations today find themselves undertaking a number of projects as part of their organisational change efforts (Duck, 1993). Organisational change can be defined as: “…an alteration in people, structure or technology” (Robbins et al., 1994). However, getting through the pilot stage of a change programme is a long way from a company-wide scale-up (Pettigrew & Whipp, 1991). Management looks for enthusiasm, acceptance, and commitment among employees but are often unsuccessful. For example, communication breaks down, the planning misses its mark, and results fall short (Strebel, 1996). For any company, it is time-consuming and emotionally wrenching to manage change (Eisenstat, 1993). Unfortunately, failed programmes far outnumber successes (Graneville, 1996). For example, in a study of change programmes related to TQM, a number of companies did not foresee critical events during the change process, which served to impede, hasten or redirect the route to change (Dawson, 1994; Dawson & Palmer, 1995).

Drift in introduction efforts is a reality, but it is usually very difficult to understand what is causing the drift. Action to get the project back on track tends to be counterproductive and have even worse effects. This can partially be attributed to the very complexity of large projects in companies and the fact that drift is not due to one specific cause, but to a multitude of little actions that go wrong. This multitude of events is usually grouped under “resistance to change” (Ballé, 1998). The complex and challenging nature of a change process is important to understand theoretically, as well as practically (Whittington et al., 1994). Changes may be described as incremental, sudden - breakthrough, or holistic - transformative (Schaafsma, 1997). The key to the change effort is not attending to each piece in isolation; it is connecting and balancing all the pieces.
In managing change, the critical task is to understand how pieces balance off one another, how changing one element changes the rest, how sequencing and pace affect the whole structure (Duck, 1993). For example, training programmes may target competence, but rarely do they change a company’s patterns of coordination. Indeed, the excitement engendered in a good corporate training programme frequently leads to increased frustration when employees get back on the job only to see their new skills unused in an organisation in which nothing else has changed. People end up seeing training as a waste of time, which undermines whatever commitment to change a programme, may have roused in the first place (Beer et al., 1990).

A critical prerequisite to successful change is the extent to which management throughout the organisation have the incentive and ability to introduce changes (Martin & Beaumont, 1998). When it comes to change, people believe in a new direction when they are actually seeing behaviour, action, and results that lead them to conclude that an improvement programme works. The first change in behaviour should be that of the top management (Duck, 1993). Visibility and senior management support promotes widespread enthusiasm for employees participating in future change initiatives (Strebel, 1996). However, the inappropriate choice of a credible champion and/or their early departure from the process can lead to extremely negative consequences (Pettigrew, 1985; Tichy & Devanna, 1986). Lack of involvement makes managers and workers feel alienated and devalued, when their concerns and feelings are never considered (Duck, 1993). By helping people develop a shared diagnosis of what is wrong in an organisation and what can and must be improved, a general manager mobilises the initial commitment that is necessary to begin the change process (Beer et al., 1990). Change is too often driven by an exclusive core group who are seen to be the sole or main owners of the problem, and therefore of its solution. Such groups are often insensitive to the history, culture and priorities within sub-parts of the organisation (Pettigrew, 1985; Edmonstone, 1995).

Industrial change usually involves the pressure of increased work throughput (Grieves, 2000a) and competition for resources among the different business units (Strebel, 1996). Stress and anxiety have been increasingly recognised as an organisational issue (Ballé, 1998). For many employees, including middle managers, change is neither sought after nor welcomed. Instead, it is disruptive and intrusive (Strebel, 1996). The decision to adopt and implement any change is a micro-political process that operates through internal and external social networks (Schaafsma, 1997). Employees might favour maintaining the status quo, so resistance to change is embedded in the culture. Senior managers consistently misjudge the effect of this gap on their relationships with subordinates and on the effort required to win acceptance of change. Too often
disaffected employees will undermine their managers’ credibility and well-designed plans (Strebel, 1996). Organisations defend against change not because they are just like insecure individuals, but because they are made up of individuals who are working as they always have worked. Managers must understand that people are naturally scientific, they must see the reasons for change (Martin, 1993). Some people have been through so many change programmes that they are sceptical. Companies today are full of “change survivors,” cynical people who have learned how to live through change programmes without really changing at all. Their reaction is the opposite of commitment. They say things like, “I’ll believe it when I see it” (Duck, 1993). Most of the literature on successful change highlights the importance of early wins for managers through creating “islands of progress” (Beer et al., 1990; Pettigrew, 1998). Frequent success is a powerful motivator for managers and employees. Therefore, large-scale improvement projects should be replaced by short-term, incremental projects that quickly yield tangible results (Schaffer & Thomson, 1992). Also Burnes (1996b) advocates incremental changes which occur over time and which can themselves constitute a major transformation of an organisation.

One of the most common obstacles preventing successful introduction is a breakdown in communication up and down the hierarchy (Eisenstat, 1993). A change effort will most likely fail if not everyone involved is informed. Lack of communication prevents people from understanding the design principles that guided them. Everything a manager says or does not say delivers a message. In fact, communication must be a priority for every manager at every level of the company (Duck, 1993). A continued effort at generating understanding is essential in driving change in an organisation (Pettigrew & Whipp, 1991). Discourse should be considered a critical element in enabling people to change their attitudes and behaviours and in their gaining ownership of the change (Grieves, 2000b), especially since managers and employees usually view change differently (Strebel, 1996). The more leaders clarify the company’s intentions and ground rules, the more people will be able to predict and influence what happens to them. When each side understands the needs, capabilities, and objectives of the other, trust can be built (Duck, 1993). Organisational change must expose its ideological underpinnings by those interests the change serves - shareholders, customers and internal stakeholders (Grieves, 2000b).

Many times, different kinds of “change models” fail to address the complexity of change. This appears to be particularly true as regard change models such as Total Quality Management, TQM, and Business Process Reengineering, BPR. These kinds of models emphasise top-down corporate change or linear instrumentalism programmes that concentrate on short-term gains at the expense of longer-term learning (Grieves, 2000a). In the organisational development
literature, many general change models are developed, see, for example, Dehler & Welsh (1994), Bate (1995) and Burnes (1996a). Below, a change model developed by Beer & Nohria (2000) will be briefly presented, as an example of some typical issues to consider when managing change. The change model is based on two different theories. Theory E is change based on economic value and theory O is change based on organisational capability. Theory strategies of Theory E is a hard approach to change, shareholder value is the only legitimate measure of corporate success. Theory O is the soft approach to change, where the goal is to develop corporate culture and human capability through individual and organisational learning, i.e. containing feedback, reflecting, and making further changes. As the theories E and O are so different it is hard to manage them simultaneously. However, for a company to adapt, survive, and prosper over the years, theory E strategies must somehow combine with theory O strategies. The conflicts of E and O can be resolved along the six main dimensions of change (Beer & Nohria, 2000), see Table 3.2

Table 3.2. Dimensions of change based on theory E and O. From (Beer & Nohria, 2000).

<table>
<thead>
<tr>
<th>Dimensions of change</th>
<th>Theory E</th>
<th>Theory O</th>
<th>Theory E and O combined</th>
</tr>
</thead>
<tbody>
<tr>
<td>Goals</td>
<td>Maximise shareholder value</td>
<td>Develop organisational capabilities</td>
<td>Explicitly embrace the paradox between economic value and organisational capability</td>
</tr>
<tr>
<td>Leadership</td>
<td>Manage change from the top down</td>
<td>Encourage participation from the bottom up</td>
<td>Set direction from the top and engage the people below</td>
</tr>
<tr>
<td>Focus</td>
<td>Emphasise structure and systems</td>
<td>Build up corporate culture employees’ behaviour and attitude</td>
<td>Focus simultaneously on the hard (structures and systems) and the soft (corporate culture)</td>
</tr>
<tr>
<td>Process</td>
<td>Plan and establish programs</td>
<td>Experiments and evolvement</td>
<td>Plan for spontaneously</td>
</tr>
<tr>
<td>Reward system</td>
<td>Motivate through financial incentives</td>
<td>Motivate through commitment – use pay fair exchange</td>
<td>Use incentives to reinforce change but not derive it</td>
</tr>
<tr>
<td>Use of consultants</td>
<td>Consultants analyse problems and shape solutions</td>
<td>Consultants support management in shaping their own solutions</td>
<td>Consultants are expert resources who empower employees</td>
</tr>
</tbody>
</table>

3.3.4 Managerial factors

In Tables 3.3 – 3.6, the managerial factors, identified in the literature study on RCM, are summarised and divided according to their affinity with the four management perspectives:
- RCM management
- Maintenance management
- Project management
- Change management

Some examples of these managerial factors will be exemplified and briefly described. The literature study is based upon searches in different databases, where search words have been ‘Reliability Centred/Centered Maintenance’ and ‘RCM’. Additional literature sources, in the form of books, papers and conference proceedings have also been used. For a more comprehensive description of the databases, literature sources used, and more examples of the managerial factors, see Backlund (2003a). In the Tables 3.3 – 3.6, the number of literature sources, i.e. authors, on a specific managerial factor are also presented, labelled ‘hits’.

Table 3.3. Managerial factors that affect the introduction of RCM, divided according to an RCM management perspective. “Hits” refers to the number of authors on a specific factor.

<table>
<thead>
<tr>
<th>An RCM management perspective</th>
<th>Factors</th>
<th>Hits</th>
<th>Example of aspects</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>RCM team competence</td>
<td>9</td>
<td>- Skills</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>- Experiences</td>
</tr>
<tr>
<td></td>
<td>Analysis performance approach</td>
<td>7</td>
<td>- Preparation activities</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>- Scope</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>- Level of analysis</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>- Templates</td>
</tr>
<tr>
<td></td>
<td>Documentation and information</td>
<td>9</td>
<td></td>
</tr>
<tr>
<td></td>
<td>RCM computer system</td>
<td>2</td>
<td></td>
</tr>
</tbody>
</table>
Table 3.4. Managerial factors that affect the introduction of RCM, divided according to a maintenance management perspective. “Hits” refers to the number of authors on a specific factor.

<table>
<thead>
<tr>
<th>Factors</th>
<th>Hits</th>
<th>Example of aspects</th>
</tr>
</thead>
</table>
| Strategic maintenance management    | 17   | - Asset or maintenance management strategy  
|                                     |      | - Connection between RCM and other methods                                          |
| Maintenance programme and performance | 15   | - Work orders and packaging  
|                                     |      | - Implementation of analysis results  
|                                     |      | - Computerised Maintenance Management System, CMMS                                  |
| Maintenance culture                 | 4    | - Cooperation between professionals  
|                                     |      | - Conservatism                                                                      |

Table 3.5. Managerial factors that affect the introduction of RCM, divided according to a project management perspective. “Hits” refers to the number of authors on a specific factor.

<table>
<thead>
<tr>
<th>Factors</th>
<th>Hits</th>
<th>Example of aspects</th>
</tr>
</thead>
</table>
| Planning                            | 11   | - Focus-Scope-Limitation  
|                                     |      | - Objectives, aims and goals  
|                                     |      | - Economic considerations or suitability                                             |
| Introduction strategy and approach  | 8    | - Short-term versus long-term approach and strategy  
|                                     |      | - Customised approach  
|                                     |      | - Phases and stages                                                                 |
| Control and monitoring              | 3    |                                                                                  |
| Measuring and evaluation            | 15   | - A measurement plan  
|                                     |      | - Evaluation and assessment  
|                                     |      | - Results and benefits                                                              |
| Resources                           | 16   | - Time  
|                                     |      | - People                                                                           
|                                     |      | - Costs                                                                            |
Table 3.6. Managerial factors that affect the introduction of RCM, divided according to a change management perspective. “Hits” refers to the number of authors on a specific factor.

<table>
<thead>
<tr>
<th>Factors</th>
<th>Hits</th>
<th>Aspects</th>
</tr>
</thead>
<tbody>
<tr>
<td>Planning and preparation for managing change</td>
<td>4</td>
<td>- Strategy and approach</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Awareness for change</td>
</tr>
<tr>
<td>Commitment and support</td>
<td>14</td>
<td>- Management commitment and support</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Employee commitment and support</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Union commitment and support</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- An RCM champion</td>
</tr>
<tr>
<td>Work situation</td>
<td>4</td>
<td>- Workload</td>
</tr>
<tr>
<td>Behaviour characteristics</td>
<td>10</td>
<td>- Ownership</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Expectations</td>
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<tr>
<td></td>
<td></td>
<td>- Understanding</td>
</tr>
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<td></td>
<td></td>
<td>- Resistance</td>
</tr>
<tr>
<td>Involvement</td>
<td>10</td>
<td>- Participation</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Buying-in – Selling in</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Empowerment</td>
</tr>
<tr>
<td>Training</td>
<td>12</td>
<td>- New technologies</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Statistic</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- System engineering and configuration management</td>
</tr>
<tr>
<td>Information and communication</td>
<td>13</td>
<td>- Presentation of results</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Transparency of the process</td>
</tr>
</tbody>
</table>

**RCM management factors:**

- **RCM team competence.** The skills and the experience of the personnel are crucial to the near-term and long-term success of RCM (Schawn & Khan, 1994). RCM is criticised for being too time-consuming, which usually has to do with lack of knowledge of the plant and equipment in the RCM team (Hipkin, 1998). The facilitator’s abilities can easily change the group’s rate of progress by a factor of two or more (Horton, 1993). Of all the factors that affect the ultimate quality of the analysis, the skill of the facilitator is the most important (Moubray, 1997).

- **Analysis performance approach.** The main drawback of RCM is the intensive analysis (August, 1997). If the analysis is performed at too low a level, the analysis takes far longer than it should. As a result, people start finding the process tedious and hence lose interest (Moubray, 1997). No effort can be successful if it is too broad either (August, 1997).

- **Documentation and information.** For RCM to work, a major amount of data has to be collected and analysed for each component in each subsystem.
(Latino, 1999). However, one of the major pitfalls of introducing RCM in practice is the lack of information and data (Page, 2001). At the same time, there is also a tendency to place too much emphasis on the importance of data such as mean time between failure, MTBF, and mean time to repair, MTTR (Moubray, 1997).

- **RCM computer system.** The use of appropriate software during the performance of an RCM analysis is also crucial in terms of project cost reduction. However, too much emphasis on a computer means that RCM starts being seen as a mechanistic exercise in populating a database, rather than exploring the real needs of the assets under review (Moubray, 1997). Some software has proved to be cumbersome in an analysis approach, not particularly friendly or easy to use, man-hour intensive to master and difficult in data entry. Other software is technically demanding and not easy to use on a variety of systems (Phillips, 1992).

**Maintenance management factors:**

- **Strategic maintenance management.** Introducing RCM implies a rethinking of other organisational processes that affect or are affected by the maintenance functions (Hipkin & DeCock, 2000). Developing an asset management policy makes the needed of RCM in the organisation clearer to management and employees (Hardwick & Winsor, 2002). RCM needs to be supported by various methods to make it viable (Mokashi et al., 2002), for example, integrated logistic support, ILS (Anderson & Neri, 1990), and Total Productive Maintenance, TPM (Pintelon et al., 1999), and Total Quality Management, TQM, (Smith, 1993).

- **Maintenance programme and performance.** A critical success factor for introducing RCM is a comprehensive preventive maintenance programme. The programme, coupled with predictive maintenance methodologies and the data accumulated with a computerised maintenance management system, CMMS, allows the organisation to introduce RCM (Steibly, 1995). Often an organisation does not have the knowledge of its plant and equipment, or adapting systems and procedures, to support RCM demands (Hipkin & Lockett, 1995). A necessary basis for implementing the results of the RCM analysis is that the organisational and technical maintenance support functions are available (Rausand & Vatn, 1998), for example a CMMS. It is also a challenge for managers to stimulate their staff to use such systems correctly (Hipkin, 1998).

- **Maintenance culture.** The lack of cooperation between operations and maintenance people may doom the condition directed and failure finding tasks and, along with them, the entire RCM programme (Smith, 1993). The step in the process where greatest resistance has come is the selection of maintenance tasks. People are conservative and will, if allowed, include non-effective maintenance tasks (Knowles, 1995).
Project management factors:

- **Planning.** In many cases, it has been shown that the planning of RCM is perhaps the most important part of the RCM introduction (Schawn & Khan, 1994). Since planning and implementation of the recommendations do not form part of the RCM functional analysis and decision process, this vital stage is often neglected (Hipkin & DeCock, 2000). Many utilities have run into difficulties when introducing RCM at their facility due to too extensive scope of the analysis that they attempted to complete. In many cases, organisations become so excited about completing systems analyses that the focus on the overall RCM goal is nearly lost (Schawn & Khan, 1994). Necessary conditions for success are, among other things, setting precise objectives (Hipkin, 1998). As with most projects, it is essential to define clear project aims, to assess the benefits of performing an RCM study, and to understand the costs that will be incurred to justify the investment in time and resources (Thomas, 1994).

- **Introduction strategy and approach.** Faced with no clear long-term RCM introduction strategy, managers may pursue blind and short-term aims in direct response to calls for reductions in maintenance expenditure (Bowler et al., 1995). According to Moubray (1997), RCM can be introduced in one of two ways. The first focuses on assets and processes, with less emphasis on people, the short-term approach. The second takes advantage of the opportunities that RCM offers on the human front as well as on the technological front, the long-term approach. The long-term approach can also be introduced as an intensive campaign or review all the equipment on the site in stages (Moubray, 1997).

- **Control and monitoring.** The analysis programme should be reviewed at intermediate points to keep the analysis on track and respond to any changes in analysis priority (Srikrishna et al., 1996; Hardwick & Winsor, 2002). Some companies experience burnout and give up, which may occur because of insufficient rigours of the work and discipline of the method (Latino, 1999).

- **Measuring and evaluation.** A key part of an introduction is measuring work completion to visualise performance change (August, 1997). There is a general failure to evaluate realistically, prior to committing resources, the economic implications of potential RCM applications (Bowler & Malcolm, 1994). The introduction of RCM is usually a long-term goal with a short-term expectation (August, 1997; Latino, 1999). The main reason for adopting a short-term introduction approach is to achieve the quickest possible return on the investment of time and money needed to carry out an RCM project (Moubray, 1997). There is also an inability to identify and subsequently quantify the anticipated benefits of RCM (Bowler & Malcolm, 1994).
Resources. RCM initiatives involve a large amount of resources, time, and energy that have to be committed by many different managers (Jones, 1995; Latino, 1999). Common to some observed cases where RCM was tried and abandoned was that it demanded much greater resources of time and manpower that originally anticipated (Harris & Moss, 1994).

Change management factors:

- **Planning and preparation for managing change.** A documented key issue of success is the establishment of a strategy to manage change before the RCM introduction (Hardwick & Winsor, 2002). However, many companies studied had not adequately prepared for change (Hipkin & Lockett, 1995). Training directed towards attitudes and behavioural changes is necessary to ensure programme success (Steibly, 1995).

- **Commitment and support.** The importance of the support from senior management cannot be emphasised enough (Hardwick & Winsor, 2002). Do not even bother starting an RCM introduction project unless you have full management support and authority to implement the results (Jones, 1995). Managing an introduction requires a champion whom workers respect (August, 1997). Preferably secure an RCM 'champion' among the management, and have an RCM facilitator with good networking skills who is respected for his/her extensive plant background (Worledge, 1993b). If the RCM ‘champion’ should depart, there is a danger that the introduction will be abandoned (Bowler et al., 1995). RCM introduction requires corporate commitment to initiate strategic change. The workers must be excited about the initiative and must stay enthusiastic (Conlin, 1991; Jones, 1995; August, 1997; Latino, 1999). The best programme in the world will fail if management and staff do not support it (Latino, 1999).

- **Work situation.** Many times, the RCM teams have undertaken the analysis sessions in addition to their normal workloads (Hardwick & Winsor, 2002). If the RCM team members are not released from normal duties during the introduction, the result may be an incomplete maintenance programme, which lacks credibility with the people expected to carry it out (Thomas, 1994).

- **Behaviour characteristics.** A major problem that often arises during the RCM introduction is that it represents a significant change; people are often resistant to the RCM programme, causing the introduction to languish (Johnston, 2002). Without the essential ingredients of acceptance and ownership, it is highly unbelievable that a plant staff will feel motivated and compelled to introduce anything (Smith, 1993). People will recall the inconsistencies between the assumptions that previous interventions espoused and their experiences. They will then compare RCM with these as a means of solving organisational problems, and be reminded of earlier attempts which were managerially conceived and which were largely
unsuccessful. Managers must recognise the irreducible social dimensions and relationships of RCM introduction (Hipkin & DeCock, 2000).

- **Involvement.** Sell the benefits to each group that can affect the success of the initiative. Selling a concept is often a challenge. Know what satisfies each group of participants. Three groups must be committed to the idea: top management, middle management, and the people closest to the work (Latino, 1999; Mokashi et al., 2002).

- **Training.** Too hurried or too superficial application is usually the result of insufficient training and practice. It often results in a set of tasks that are almost the same as they were to begin with (Moubray, 1997). It is also important to provide sufficient training so that managers and employees understand the aims of the RCM introduction, in addition to understanding the RCM process and what is expected of them (Thomas, 1994).

- **Communication and information.** Managers should develop a coherent, plausible and legitimate discourse for RCM that will provide actors at all levels with distinctions, definitions and understanding (Hipkin & DeCock, 2000). It is an imperative that individuals who are spearheading the application of RCM be effective leaders and communicators (Schawn & Khan, 1994).

**Interrelationships**

An awareness of relations and connections between the management perspectives also seems to influence the introduction of RCM. This can be discerned in the examples above considering factors within the management perspectives. For example, the lack of a CMMS (a maintenance management factor), makes it difficult to measure progress (a project management factor), which affects the motivation and support among management and employees (change management factors). Another example is when a single individual performs the RCM analysis (a RCM management factor), which results in lack of ownership among maintenance and operation personnel (a change management factor).

### 3.4 An RCM introduction process

The managerial factors that affect the introduction of RCM may also be structured according to their occurrence in different phases. For example, according to Hipkin & DeCock (2000), some studied companies perform the planning and implementation of RCM analysis recommendations poorly. One main reason was that these kinds of phases did not form a part of the RCM functional analysis and decision process. According to Schawn & Khan (1994), obstacles and driving forces appear at various stages, or phases, when introducing RCM. Phases to be managed when introducing RCM are a planning phase, a second phase that involves the performance of RCM analysis on
selected systems, a third phase that includes the review of technical results generated from the second phase, and a last phase that involves implementation of the technical results into the plant environment (Schawn & Khan, 1994). In Harrold (1999), a three-phased RCM introduction is described by means of progressing through a multi-year, effort of discovery, stabilisation, and breakthrough.

However, based on managerial factors identified in the literature study, some other specific phases when introducing RCM have been identified, exemplified as follows:

- **An initiation phase.** Before introducing RCM the internal arguments should be identified and formulated, where a new asset management policy initiated RCM according to Hardwick & Winsor (2002). It is generally difficult for the plant management to decide, for example, whether RCM is more beneficial than for example TPM (Rausand, 1998). According to Conlin (1991), a study has to be conducted to determine the best method for improving the current preventive maintenance programme at the site.

- **A pilot study phase.** One or several pilot projects should enable an organisation to gain first-hand experience of the managing of RCM, what it achieves, and what resources are needed to achieve it (Moubray, 1997). According to Basille et al. (1995), a two-year pilot project was performed to test and assess the benefits of the application of RCM.

- **A planning and preparation phase.** In many cases, it has been shown that the planning of RCM is perhaps the most important part of an RCM introduction (Schawn & Khan, 1994). Prepare and pre-work the introduction as thoroughly as possible. Provide early planning specifically for the implementation of the analysis recommendations (Worledge, 1993b).

- **An analysis phase.** According to Schawn & Khan (1994), one stage when introducing RCM is the performance of RCM analysis on selected systems. After the analysis process we must take the final and crucial action to realise the fruits of our efforts (Smith, 1993).

- **An implementation phase.** According to Schawn & Khan (1994) the last phase when introducing RCM is implementation of analysis results into the plant environment. Taking the technical results of the analysis and ensuring that these results are effectively implemented in the field is the key element of introducing RCM (Worledge, 1993b).

- **A living programme phase.** The primary objectives of all the planning, training, obtaining resources and management support is to successfully conclude the living RCM programme. That includes making procedure and programme changes based on the analysis results, and providing feedback from the field for incorporation into the preventive maintenance programme as part of a living programme (Schawn & Khan, 1994; Hardwick & Winsor, 2001).
An RCM introduction process, including several phases, is proposed and illustrated in Figure 3.3. The phases could be managed sequentially, as each phase seems to be a precondition for the coming phases. For example, a pilot project should be performed to give experiences used in the planning and preparation phase and the analysis phase. The planning and preparation should be a precondition for effectively implementing the analysis recommendations and for successfully concluding the living programme phase. The living programme phase should be seen as a phase where favourable conditions should be settled for the work with continuous improvements.

![Figure 3.3](image)

**Figure 3.3.** An RCM introduction process, based upon some proposed phases.

### 3.5 Theoretical propositions

Based on the analysis and discussion of the literature study findings on RCM application and introduction, some theoretical propositions are stated below. Different management factors affect an RCM introduction and should be managed according to four management perspectives:

- RCM management
- Maintenance management
- Project management
- Change management

In Tables 3.3 – 3.6, the managerial factors, identified in the literature study on RCM, are divided according to the management perspectives described in Sections 3.1 and 3.3.1 – 3.3.3. To make an RCM introduction more manageable, the managerial factors should be managed according to the sequential phases in the RCM introduction process, illustrated in Figure 3.3.

### 3.5.1 An analysis model – A basis for an RCM introduction strategy

Based on the theoretical propositions an analysis model may be developed. The analysis model, illustrated in Table 3.7, is based upon the managerial factors within the management perspectives and the phases in the introduction process. The analysis model corresponds to the second and the third research questions stated in Section 1.4, considering what managerial factors affect RCM introduction and when, or where, the managerial factors occur in an RCM introduction.
Table 3.7. An analysis model used to explore where managerial factors occur in the different introduction phases.

<table>
<thead>
<tr>
<th>Phases</th>
<th>Perspectives</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>An RCM management perspective</td>
</tr>
<tr>
<td>Initiation</td>
<td></td>
</tr>
<tr>
<td>Pilot study</td>
<td></td>
</tr>
<tr>
<td>Planning and prepare</td>
<td></td>
</tr>
<tr>
<td>RCM analysis process</td>
<td></td>
</tr>
<tr>
<td>Implementation</td>
<td></td>
</tr>
<tr>
<td>Living programme</td>
<td></td>
</tr>
</tbody>
</table>

The managerial factors identified in the literature study are gathered from different industrial sectors, with different aims and scopes. The intention of the analysis model is, by means of empirical studies, to develop an RCM introduction strategy for a specific industrial context. There are several management perspectives and introduction phases to consider when managing an RCM introduction. There also seem to be interrelationships between the management perspectives, and the activities in one phase seem to affect the pre-conditions for the coming phases. Therefore, an RCM introduction strategy should probably be most usable when applied with a holistic view in mind, See figure 3.4.

![Figure 3.4. A holistic view, including four management perspectives, when introducing RCM.](image-url)
4 MANAGING RCM INTRODUCTION – A SINGLE-CASE STUDY

The aim of this chapter is to describe an RCM introduction and thereby contribute to the overall understanding of its complexity. First, the research process used during the case study is presented, followed by a brief presentation of hydropower matters and the companies involved in the study.

4.1 The realisation of the case study

The introduction of RCM at Vattenfall has been studied during a period of almost six years. The studies began in connection with the initiation of a pilot study, in April 1997. The research study ended in the beginning of the company-wide analysis work, in February 2003. According to the current time-schedule for the RCM project RCM will be introduced to all the hydropower plants in 2006. Therefore, it has not been possible to study the complete introduction within the research project. The aim of the in-depth single-case study has been to obtain a comprehensive description of managing RCM introduction. The description has a direct connection to the first research question, in Section 1.4; what characterise an RCM introduction? The case will be analysed in Chapter 5 according to the management perspectives and the factors, which constitute the theoretical propositions in Section 3.5. The case will also be analysed considering when and where these factors occur in the introduction. This procedure corresponds to the second and the third research question in Section 1.4. The case study description, together with the forthcoming analysis, should contribute valuable knowledge to the overall research question considering the development of an RCM introduction strategy.

4.1.1 Information gathering

As was briefly described in Section 2.4.5, five different information collecting methods have been used during the single-case study: interviews, documentation collection, direct observation, participant observation and, to some extent, action research.

During the pilot study, and the beginning of the planning and preparation of the full-scale introduction, studies were based on several field visits, i.e. direct observations. The author participated in RCM project group meetings, and also visited the pilot RCM team several times. The author also participated in a two-day course that was offered the RCM pilot team, the project manager, and union representatives. On these occasions, notes were made. As a complement to these information sources, the author has had complete access to internal project
reports, such as project specifications and progress reports. Relatively few people were involved during the pilot study, and the beginning of the planning and preparation. During the pilot study, and the beginning of the planning and preparation, activities in the project progressed relatively slowly. However, later on in the planning and preparation, more people became involved in the RCM introduction. During that time, September 2000, the author made use of participant observation in the form of an independent member of the RCM project group. Until the beginning of the company-wide analysis work, the author attended most of the meetings in the project group, including project risk analysis sessions. Five project managers were involved during the introduction, which further on will be labelled (A) to (E). During the time as an independent member of the project group, mainly two project managers, (C) and (E), were involved in managing the project. The author had several discussions with these project managers and followed them during visits to the two pilot groups. Together with the project manager (E), visits were also made to all regions during informal meetings with the top and middle regional managers. In addition, the author has performed formal interviews with all top and middle regional managers, mainly in the beginning of the planning and preparation of the company-wide introduction.

The author has been stationed, organisationally, within Vattenfall AB Vattenkraft, more specifically, at the plant unit, see Section 4.4.2. This made it natural to discuss RCM matters several times with the technical manager, technical personnel and purchasers of maintenance services. The author also attended several meetings in the plant unit, where the RCM project usually was on the agenda. The author also had formal interviews with the sponsor and some of the purchasers of maintenance services in the beginning of the planning and preparation. The author attended several meetings where the senior managers at Vattenfall AB Vattenkraft and the maintenance contractor discussed the RCM project.

It is the author’s opinion that participant-observation generated favourable opportunities to meet personnel in their natural environment. The many formal and informal meetings made it possible to observe and ask questions, which limited the need for formal interviews. In addition to meetings and informal discussions, internal project reports have been used to gather information. To avoid a too time-consuming study, the plant groups have not been studied specifically. Instead, discussions have been made with the middle managers, assuming that they have good insights in their plant groups’ work. This approach was considered suitable, as both middle managers and employees in general had worked in the organisation for a long time.
The case description is based on the author’s interpretation of observations, discussions, interviews and internal reports. This material has been summarised in a narrative text with the aim of facilitating the reader’s comprehension of the introduction at Vattenfall. The use of participant observation makes it difficult to point out, more precisely, when and where a certain kind of information has been received. However, the author has not brought personal analysis or valuations into the summarised text. Different actors involved in the introduction have reviewed the case description. The case description has been reviewed by the project manager (E) and to some extent project manager (C). The technical manager, also sponsor of the project, and other members of the project group have made a review. The regional managers have had the case description available for review.

4.2 About Hydropower

A brief introduction of the hydropower sector and the companies involved in the study will be presented. The aim is to facilitate for the reader to apprehend the case description. The current information about hydropower was mainly obtained from different home pages on the Internet.

World-wide, about 20 percent of all electricity is generated by hydropower. Hydropower does not produce greenhouse gasses or other air pollution, and in addition, it produces no solid or liquid wastes. Hydropower is a leading source of renewable energy. It provides more than 97 percent of all electricity generated by renewable sources. Other sources, including solar, geothermal, wind, and biomass, account for less than three percent of renewable electricity production. The top ten hydropower-generating countries are presented in Figure 4.1.

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Figure 4.1. Top ten hydropower-generating countries. From http://www.wvic.com/hydro-facts.htm.

There is potential energy stored in a water reservoir behind a dam. It is converted to kinetic energy when the water starts flowing down the penstock from the dam. The falling water strikes a series of blades attached around a shaft, which converts kinetic energy to mechanical energy, and causes a turbine to rotate. The shaft is attached to a generator, so that when the turbine turns, the generator is driven. The generator converts the turbine's mechanical energy into electric energy. Voltage is the pressure that makes electricity flow. Generators usually produce electricity with a low voltage. In order for the transmission lines to carry the electricity efficiently over long distances, the low generator voltage is increased to a higher transmission voltage by a step-up transformer. Grid transmission lines, usually supported by tall metal towers, carry the high voltage electricity over long distances. Terminal stations control the power flow on the grid transmission lines. The major sub systems in a hydropower plant are illustrated in Figure 4.2.
Figure 4.2. An illustration of major sub systems within and near a hydropower plant.

4.3 The Swedish power market

The current information about the Swedish power market was mainly obtained from different home pages on the Internet\(^5\).

4.3.1 Major changes in the Swedish power market

Before 1992, the power generation and transmission in Sweden was state-owned and business was performed on a monopoly market. In order to adapt to a competitive power market a first major reform was taken in 1991, with the decision to separate transmission from generation. The state-owned Svenska Kraftnät (Swedish National Grid) was launched on January 1, 1992 to manage Sweden's power network and foreign interconnectors. This was the first major step towards a deregulated and competitive electricity market. A fully deregulated Swedish power market was established on January 1, 1996. Sweden is today a part of the Nordic market, a market comprising approximately 19 million people.

### 4.3.2 Power plants

The Swedish electricity system is largely based on hydropower and nuclear power. Other power plants are mainly municipal heating networks, industrial gas turbines and condensing power plants. Table 4.1 presents different power plants and their production capacity, in Sweden and in the Nordic countries.

**Table 4.1. Power plants, and their production capacity, in Sweden and in the Nordic countries 2001, and the energy produced in Sweden 2001. From Konkurrenserverket (2002).**

<table>
<thead>
<tr>
<th>Type of power plant</th>
<th>Nordic (MW)</th>
<th>%</th>
<th>Sweden (MW)</th>
<th>%</th>
<th>Sweden (TWh)</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydropower</td>
<td>46769</td>
<td>52,6</td>
<td>16239</td>
<td>51,2</td>
<td>67,8</td>
<td>48,8</td>
</tr>
<tr>
<td>Nuclear power</td>
<td>12076</td>
<td>13,6</td>
<td>9436</td>
<td>29,7</td>
<td>60,3</td>
<td>43,4</td>
</tr>
<tr>
<td>Wind power</td>
<td>2835</td>
<td>3,2</td>
<td>293</td>
<td>0,9</td>
<td>0,5</td>
<td>-</td>
</tr>
<tr>
<td>Municipal heating networks</td>
<td>15339</td>
<td>17,3</td>
<td>2340</td>
<td>7,4</td>
<td>5,5</td>
<td>3,9</td>
</tr>
<tr>
<td>Gas turbines</td>
<td>2644</td>
<td>3,0</td>
<td>1461</td>
<td>4,6</td>
<td>0,2</td>
<td>-</td>
</tr>
<tr>
<td>Condensing power plants</td>
<td>5008</td>
<td>5,6</td>
<td>1023</td>
<td>3,2</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

Most Swedish large-scale hydropower plants were built during the 1970s. Thermal power stations were built exclusively in order to secure the power supply in dry years and to cope with peak loads. In 1965 it was decided to supplement hydropower with nuclear power, to avoid the uncertainties of oil prices and increase the security of supply. The policy was reinforced by the oil crisis of the early 1970s, at a time when Sweden depended on oil for about one fifth of its electrical power consumption. The first nuclear power was generated in 1972. Six reactors entered commercial service in the 1970s and six in the 1980s. The introduction of nuclear power has meant that electricity has outdistanced other forms of energy production in Sweden, particularly fossil fuels such as coal and oil.

### 4.4 Vattenfall AB Vattenkraft

The current information about Vattenfall, and Vattenfall AB Vattenkraft was mainly obtained from the Internet6.

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6 Information from http://www.vattenfall.com
4.4.1 Vattenfall AB

Vattenfall AB Vattenkraft is the largest hydropower company in Sweden, belonging to the Vattenfall Group, i.e. Vattenfall AB. Vattenfall AB was founded more than 90 years ago, and was transformed from a public utility into a Swedish government-owned company in 1992. Today, Vattenfall operates in a deregulated, dynamic and competitive Swedish market, but is also active in Finland, Germany and Poland. Vattenfall had approximately 33,900 employees in March 2002 and generates and supplies power and energy solutions to millions of customers across Europe and the Nordic region. Industries and energy companies are Vattenfall's biggest customers.

Vattenfall operates power plants and grids and is the major power producer and network operator in Sweden. Vattenfall operates electricity generation plants comprising 54 large and 75 small hydropower plants (< 5 MW) together with three nuclear power plants (totally 8 units) in Forsmark, Ringhals and Barsebäck, see Table 4.2.

Table 4.2. Power plants operated by Vattenfall.

<table>
<thead>
<tr>
<th>Power source</th>
<th>Amount</th>
<th>Production capacity (MW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wind power</td>
<td>39 (Number of sites)</td>
<td>23</td>
</tr>
<tr>
<td>Thermal power (oil-fuelled)/standby power</td>
<td>7</td>
<td>312</td>
</tr>
<tr>
<td>Hydropower (large plants)</td>
<td>54</td>
<td>7936</td>
</tr>
<tr>
<td>Nuclear</td>
<td>3</td>
<td>7234</td>
</tr>
</tbody>
</table>

4.4.2 The organisational structure

The organisational structure of Vattenfall AB Vattenkraft valid during the case study consisted of a production unit and a plant unit. The production unit was in charge of plant production management and monitoring, and included three regional dispatch centres. The plant unit was in charge of reinvestments and strategic maintenance management of the plants and the dams. The plant unit included three sub units, all managed by the technical manager. One of these sub units consisted of purchasers of maintenance services, one sub unit of technical specialists, a maintenance engineer, and administrators, and one sub unit of dam specialists. The plant unit could be considered as a flat organisational structure with relatively few employees, approximately 25 persons.

A reorganisation was realised in January 2003, where small-scale hydropower and wind power became two additional units in the organisation, together with a technical unit.
4.4.3 The hydropower plants

Vattenfall AB Vattenkraft owns and maintains 54 larger hydropower plants, located at eight rivers, and maintained within four regions, see Table 4.3.

Table 4.3. Regions, rivers, amount of plants and the installed capacity at each river.

<table>
<thead>
<tr>
<th>Regions</th>
<th>Rivers</th>
<th>Amount of plants</th>
<th>Production capacity (MW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>North</td>
<td>Lule älv</td>
<td>16</td>
<td>4,340</td>
</tr>
<tr>
<td>North-Centre (“Mellan-övre”)</td>
<td>Ume älv, Skellefte älv</td>
<td>10, 3</td>
<td>1,186, 1,245</td>
</tr>
<tr>
<td>South-Centre (“Mellan-nedre”)</td>
<td>Ångermanälven, Indalsälven</td>
<td>8, 8</td>
<td>980, 788</td>
</tr>
<tr>
<td>South</td>
<td>Dalälven, Göta älv, Gimän</td>
<td>3, 4, 2</td>
<td>160, 363, 119</td>
</tr>
</tbody>
</table>

The main hydropower plants are all located in the Luleå River: Harsprånget (945 MW), Porjus (530 MW), and Letsi (450 MW).

The hydropower plants were constructed over a long time span, from 1920 to 1980. During this time, different suppliers have been involved, and different technical solutions have been used. As a consequence, the plants are many times unique, and are seen as ‘individuals’. Plant personnel consist mainly of machinists, performing so-called ‘light’ routine maintenance, and mechanics involved in planned and unplanned corrective maintenance, and overhauls. Electricians and personnel with instrumentation and control and (I&C) skills assist the plant personnel when needed, but are not placed in a plant group.
4.5 The structure of the case study

The case study description is mainly structured according to stages according to a project management model used in the RCM project, see Section 4.9.1. The structure of the chapter is illustrated in Figure 4.3.

![Figure 4.3. The structure of the case study description.]

4.6 Maintenance management in general

4.6.1 A historical perspective

Vattenfall was for a long time a public utility responsible for supplying Swedish society with electricity. The business was not profitability driven, due to the monopoly situation, and mainly focused on high availability performance with a high plant condition.

Maintenance management issues were handled within the four regions, which were mainly self-governed. There were a larger number of people available in the organisation, working mainly “hands on”, and there was no need for a more systematic maintenance performance or sophisticated maintenance systems. There was in general little control of the maintenance performed, where maintenance plans were lacking. In general, the people working with maintenance had their backgrounds within electric or construction engineering, as they had earlier been involved in plant construction. Routine maintenance work, such as inspections and overhauls, was performed in time-based-intervals, based on usage and custom. The approach was reinforced by the organisational structure of the plant groups, in which a supervisor gave detailed orders for what to do. In the plant personnel, machinists were the ones performing routine maintenance while mechanics were the ones that fixed planned and unplanned corrective maintenance, and were involved during major overhauls.
The deregulation of the Swedish electricity market in 1996 led to an increased competition between power producers and, consequently, a reduction in price. The competitive environment that appeared put a focus on controlling and decreasing maintenance costs. It became necessary to find a common way of working with plant maintenance, among the regions, to obtain an effective maintenance performance. The new conditions entailed increased demands on documentation to fulfil environmental regulations and quality requirements. While the plant maintenance characteristics before the deregulation to a great extent still existed, changes now began in strategic maintenance thinking.

4.6.2 An outsourcing situation

In 1996, the CEO of Vattenfall AB Vattenkraft decided that the maintenance on an operational level, i.e. the routine maintenance performed at the plants, should be a task for entrepreneurs. As a first step in that direction, the organisation was divided in 1998 into a customer organisation, i.e. Vattenfall AB Vattenkraft, and an entrepreneur organisation, then called Vattenfall Generation Service Hydro Sweden (VGS HS). The entrepreneur organisation was later on divided into two separate companies, called Vattenfall Service Nord, which included the three northern regions, and Vattenfall Service Syd, which included the region in the south.

The partition into a customer organisation and an entrepreneur could be seen as an outsourcing of maintenance at an operational level, i.e. routine maintenance measures. As both companies belonged to the Vattenfall Group, and collaborated on the basis of a five-year routine maintenance agreement, it could also be interpreted as a partnership agreement. However, the intention was that Vattenfall AB Vattenkraft, in the long run, should promote competition among several entrepreneurs.

4.6.3 Vattenfall AB Vattenkraft

After the reorganisation in 1998 Vattenfall AB Vattenkraft (from now on abbreviated VV) worked mainly with strategic maintenance management issues, focusing on ways of decreasing maintenance costs and managing risks. The main goals for the VV organisation were decreasing maintenance costs, optimisation, i.e. extended length of plant life, and safer plants. A major project was to develop an asset management process. VV also needed better documentation and follow-up of the maintenance performance, as a basis for contracting out maintenance. The maintenance contracting was intended, in a long-term perspective, to be more focused on functional maintenance contracts. The current contracting involved mainly routine maintenance according to the routine maintenance agreement.
4.6.4 Vattenfall Service

Vattenfall Service (from now on abbreviated VS) was to get less paid for routine maintenance during the years to come, as their main customer, VV, put requirements on decreasing the maintenance costs. For the managers in the VS organisation, it became a main task to get the plant personnel use to their new role as entrepreneurs. The plant personnel had to comprehend and understand that maintenance on an operational level had to be performed more cost-effectively. That was not easy as the plant groups, in general, wanted to maintain the plants more than VV gave them means for. To some extent, the plant groups considered themselves as the “owners” of the plants and felt responsible for the plants’ conditions. The organisational structure was changed several times so as to set an effective entrepreneur organisation.

There were also other issues in the VS organisation that had to be dealt with making the personnel become professional entrepreneurs. Regions were viewed as “companies in the corporate company”, where superior level decisions often did not reach all personnel in the regions. Strong plant group cultures existed within almost every region, especially at the plants in the periphery, where changes in maintenance performance were not easily accepted. In some regions, there existed factions of different groups of professionals, for example, machinists, mechanics and electricians. This prevented collaboration between professional categories, when carrying out maintenance performance. The maintenance management knowledge was mainly within the skills and experiences of the employees. The CEO at VS considered this a major obstacle, since the company was too dependent on individuals. The CEO considered that a greater part of the knowledge should be within the method of working, documentation and routines.

Over time, the main part of the plant groups began to adapt to their role as entrepreneurs, i.e. to maintain plant systems based on the resources specified by VV. VS introduced a project management model to obtain a similar way of working between the units and groups. During 2002, VS started to develop an asset management process. As entrepreneurs, VS began to work with maintenance contracts with other kinds of industrial environments, and also strove to work in accordance with tactical, or functional, maintenance contracts.

4.6.5 Collaboration and communication between VV and VS

Since VV and VS had earlier belonged to the same company, and still belonged to the same group of companies, close cooperation was natural. However, the collaboration was experienced as cumberson some extent, which is exemplified below.
Major maintenance management projects were going on in the VV organisation. Several of these had an affect on the entrepreneur’s way of working. But several regional managers at VS experienced that they were not involved sufficiently enough. One example was the development of the asset management process at VV. Senior and middle managers at VS also felt that too many internal projects were going on in the VV organisation. This situation was felt to make it difficult to communicate and collaborate between VV and VS during daily work tasks. The purchasers of maintenance services were also felt to interpret and apply the routine maintenance agreement differently in the regions.

Some people within the plant unit at VV considered that the entrepreneur was focusing too much on managing projects than on managing routine maintenance tasks at the plants. Some of the purchasers complained about the lack of analyses and proposals in the maintenance performance reports. They were doubtful that the entrepreneur would be able to manage maintenance at a tactical level in the future.

Personnel at both VV and VS experienced that informal paths for information exchange and communication many times were better than formal paths, and that areas of responsibility were unclear considering whom to contact in a specific matter. The purchasers experienced that the plant groups within the entrepreneur organisation worked differently with maintenance. This made it difficult to foresee the results of maintenance tasks ordered. At the same time, the plant personnel sometimes experienced that it was difficult to explain to the purchasers why maintenance should be performed in a certain way.

4.7 The initiation of RCM

4.7.1 A maintenance development programme

As a response to the deregulation in 1996 an asset management plan was established in the “old” Vattenfall Vattenkraft organisation, i.e. before the division into a customer and an entrepreneur organisation. The overall aims were to increase maintenance efficiency and map out plant risks and personal risks. A project was realised in 1997 based on the asset management planning, and sub goals to be fulfilled during the time period 1998 – 1999 were:

- To identify the risk profile at the plants considering personal risks, plant risks and environmental risks.
- To identify and develop a new maintenance method, where maintenance efforts should be based on different needs for different plants, based on functional requirements, failure modes and failure consequences.
- To identify drivers for maintenance costs within corrective maintenance, preventive maintenance, and condition-based maintenance. Maintenance indicators should also be developed.
- To identify new maintenance technologies, considering, for example, condition-based maintenance.
- To perform quality assurance of the maintenance performance according to ISO 9000, or correspondingly.
- To develop a common maintenance terminology and philosophy.

Expected results of the project were:

- An increased awareness of maintenance costs, failure functions and risks at the plants as a basis for decreasing maintenance costs, and improving personal and environmental safety.
- A systematic and effective maintenance programme, which was to support a new way of working with maintenance.
- Extended life for expensive plant systems.
- Improved documentation.
- Improved co-operation between operation people, maintenance people, and technical people, as well as improved co-operation with suppliers and entrepreneurs.
- Increased communication and motivation among personnel.
- A basis for discussions with insurance companies with the aim of decreasing insurance fees.

Nine working groups were included in the project, working with different project tasks, for example, the maintenance method, a new way of working according to the maintenance method, and a common terminology.

The initiator of RCM as a new maintenance method in Vattenfall Vattenkraft was a senior manager mainly involved with environmental issues, but he was also a visionary. He had some pre-knowledge of RCM as a maintenance method, inspired by the use of RCM in the Norwegian industry. For example, Statkraft, the biggest hydropower organisation in Norway, had started up RCM some years earlier. RCM was judged to be suitable considering the requirements settled in the asset management plan.

4.8 The Prestudy stage

To evaluate if RCM was a suitable maintenance method a pilot study was initiated in April 1997, as a part of the maintenance development programme. A plant in the Skellefteå River was chosen, as the plant management and personnel showed interest in working within a ‘development project’.
During this pilot study no formal project organisation was used. The project manager (labelled ‘A’, like several different project managers became involved further on in the project) was a technical manager in the southern region. He was also responsible for progress in the other work groups.

The aim of the pilot study was to demonstrate how operation and routine maintenance costs could decrease by 20 – 40 percent compared with the outcome in 1996. This percentage was based on experiences, documented in books on RCM. Later on, a more realistic estimation was considered to be 10 – 20 percent. RCM should be applied to all plants during 1999.

The pilot RCM team mainly involved plant personnel. None of the participants of the pilot study had any previous experiences of RCM. No facilitator, more experience of RCM, was used in this study either. A two-day RCM course was performed. Other people were also participating, for example, union representatives. It was difficult to find people in Sweden who could teach RCM. Therefore, two persons from Norway managed the two-day course. One of these had been working as a facilitator in an RCM pilot study at Statkraft. The other person had been involved in RCM issues at SINTEF, the Foundation for Scientific and Industrial Research at the Norwegian Institute of Technology, in Trondheim. For some of the participants the training was difficult to comprehend, mainly due to language differences. As Statkraft had been working with RCM for some years, it was the project manager’s (A) intention to make a benchmarking study there, but this never took place.

Parallel to the RCM pilot study other initiatives, with higher priority, were going on in the organisation. Senior managers were heavily involved in the major division into an owner and an entrepreneur organisation that was taking part, and a restructuring of the dispatch centres. Later on in the introduction, the initiator of RCM considered that the senior management had not really had time for managing the RCM pilot study. The unions had been involved from the beginning and they found the potential benefits of the RCM project appealing. They saw it as something good for their members and were to some extent pushing for introducing RCM.

During the work at the hydropower plant, a RCM team was established, consisting of three persons. An additional person from the plant personnel was also participating, but was changed every second week. The team leader was trained in RCM at the same level as the other team members. He had a management position at the plant and his participation in the work with RCM was limited. Due to this situation, it became difficult for him to control the work within the RCM team. The other team members had their daily work to do besides the work with the RCM introduction. The situation resulted in
difficulties in gathering the group, which led to individual work instead of teamwork. Due to these obstacles, the work within the RCM team went slowly. The analysis work also became cumbersome due to the scarcity of training and education. A simple RCM computer system was developed, based on Excel, to support the analysis work.

Other problems were that no clear approach was stated regarding which part of the system the analysis should start with. Another difficulty was the risk assessment performance, where the consequences of a failure mode had to be determined. Acceptance criteria to evaluate the risks were not stated by the senior management. The situation implied that the risk evaluation could not be completed and was instead based on intuition. During the RCM analysis, the documentation and information needed was poor, and insufficiently updated. Therefore, the RCM team experienced the gathering of documentation as one of the most time-consuming tasks.

During the pilot study the senior management questioned the amount of time and resources required. Furthermore, stated aims of the RCM introduction were considered as ambiguous among the plant personnel. These conditions resulted in decreased enthusiasm in the RCM pilot team, and later on, also among other personnel at the plant. The pilot study started at the same time as a reduction of personnel was announced within the organisation. The feeling among plant personnel was that RCM was aimed to make maintenance work more efficient, and that this would in turn most likely result in less demand for maintenance personnel. This situation affected the personnel’s attitude in a negative way towards the use of RCM. Facing the problems, senior management later on proclaimed that nobody would lose their jobs due to the introduction of RCM.

The pilot study generated overarching results that were difficult to evaluate in the form of decreased risks and more efficient maintenance tasks. The analysis recommendations were not implemented. The lack of concrete results made the senior management question the benefits of RCM. However, the pilot study also indicated a potential for major decrease in routine maintenance. Therefore, the senior management decided to put more resources into the project to scrutinise the potentials of RCM further.
4.9 The Feasibility study stage

4.9.1 A project management model

In 1998, the work with introducing RCM was managed by means of a model for project management, recently introduced in VV, called PROPS\(^7\). The project management model was to be used in all major projects performed at VV and was based upon the following number of stages and decision points, so called tollgates (TG);

- The Prestudy stage was followed by TG1. The purpose of the Prestudy stage was to assess feasibility from the technical and commercial viewpoints, based on external and internal customers’ expressed and unexpressed requirements and needs.
- The Feasibility study stage was followed by TG2. The purpose of the Feasibility study stage was to form a good basis for the future project, and to prepare for a successful project execution.
- The Execution stage was followed by TG3 – TG5. The purpose of the Execution stage was to execute the project as planned with respect to time, cost and characteristics, in order to attain the project’s goals and thus meet the customer’s requirements.
- The Conclusion stage. The purpose of the Conclusion stage was to break up the project organisation, to compile a record of all experiences made, and to see to it that all outstanding matters were taken care of.

Main roles in the project management model were a sponsor, a steering group, and a project manager. The project sponsor was the orderer of the project and in charge of the financial means. Before going to a new stage, a tollgate decision should be made. The procedure implied that the sponsor, usually together with the steering group, decided if the work in the current stage could be a basis for the next stage. Independent scrutiny should also be used to improve the basis for TG decisions.

The previous pilot study was viewed as a Prestudy stage, corresponding to the first stage in PROPS. The Feasibility study stage began in September 1999 and was completed in July 2000 when TG2 was passed. During the Feasibility study stage a minor pilot study was initiated at a plant in the Luleå River.

\(^7\) In the company internal handbook PROPS is described as a general project management model that can be used to control and manage different kinds of projects.
4.9.2 The project organisation

A new project manager (B) was appointed during the Feasibility study stage, employed at a corporate research company within the Vattenfall Group. Project sponsor was the technical manager at VV. A steering group supported the sponsor, including the head of the purchasers of maintenance services at VV, a region top manager, a manager of one of the dispatch centres, and the CEO of the former VGS HS. To assist the sponsor, a so-called sponsor representative was appointed. That was a person with project management skills and experiences, and he belonged to the entrepreneur organisation.

The project included three sub projects with the aims to:

- Develop a profile of requirements at the plants, which was managed by a maintenance engineer from the VV organisation.
- Develop the RCM model, based on the two pilot studies. A consultant from an internal consultant company in the Vattenfall Group was in charge of this sub project.
- Identify the change process and change management issues needed to introduce RCM in the organisation. A person from the Jokkmokk training centre, belonging to the Vattenfall Group, was in charge of this sub project.

The consultant was working as a facilitator in the second RCM pilot team, but was rather inexperienced in RCM. She had some experiences from performing RCM analysis to a system within the nuclear sector, as a part of a Master’s thesis. The person in charge of the change process was mainly skilled in technical issues.

4.9.3 Aims and goals

Aims and goals of the Feasibility study stage were to:

- Further develop the RCM model that was developed in the Prestudy stage, and then test and evaluate it in another plant.
- Plan the RCM introduction on a full scale, i.e. a project specification for the Execution stage.
- Develop a common maintenance terminology within the organisation, scrutinising the terminology used in the first pilot study.
- Develop a measurement and evaluation plan, as the meaning of ‘introduction’ was somewhat unclear.
- Propose changes in maintenance intervals and routines based on RCM analyses
- Develop educational packages.
- Identify requirement specifications for a future computerised maintenance management support, CMMS, considering the connections to RCM.

Due to the reorganisation in 1998, some additional requirements on the RCM model, compared to those in the initiation of the project, was stated by the sponsor:

- Make it possible to follow-up maintenance performance.
- Provide a basis for purchasing maintenance contracts.
- Promote clear responsibilities and communications between VV and VS.
- Promote long-term control of maintenance in accordance with VV’s needs, which could be changed over time.
- Facilitate the maintenance planning for the entrepreneur.

RCM analysis should only be performed on the systems that the owner considered especially important, which later on became seven so-called standard systems for each plant, see Section 4.10.5. Dams were also to be included in the project.

4.9.4 Approach

Commitment of personnel to the project should be achieved by early involvement of the people needed. The project manager was not responsible for reporting or informing about the project’s progress to managers and employees outside the project. However, the intention was that the project should be visible in internal newsletters in the VV and VS organisations. The project group was trained in RCM and general maintenance management issues during one day. The new pilot study team was given one day of additional training.

The analysis approaches differed between the two RCM pilot teams. The second team claimed that the first team had analysed too much in detail. There were many discussions in the project group to decide what level of analysis should be chosen. Some members of the first pilot team claimed that the analysis of the second pilot study was too superficial, more like documentation activities than “analysis to learn from”. Members of the second team claimed that it would be difficult to find a suitable level of analysis if the approach included too much detail in the beginning.

During the Prestudy stage personnel, managers and employees in the organisation experienced that very little information was sent out regarding the pilot projects’ progress. However, personnel at the pilot plants got informal information from the pilot team members.
4.9.5 Deliveries
The work in the Feasibility study stage resulted in a further developed RCM model. An evaluation of the model indicated that it should contribute to faster analysis performance and quality assurance of the maintenance. The model should also decrease the risk for differences in analysis approach between different RCM teams during the company-wide analysis work. Based on the two pilot studies new maintenance activities were proposed. These were used to estimate cost and profits for the full-scale introduction.

A project specification draft for the Execution stage was compiled. However, an introduction strategy, with focus on change management, had not been prioritised as intended. The main reason for this was the sponsor decision that the VS organisation should be in charge of the RCM model development. VS should also be in charge of managing the introduction of RCM in the organisations. During the work, several benefits using RCM were observed:

- RCM generated significant reductions in routine maintenance when the demand for plant availability was low, as for the plant involved in the first pilot study.
- Routine maintenance tasks would not necessarily be decreased in a total perspective, but instead be reallocated. For example, one kind of turbine type needed more maintenance while another type needed less. This should be seen as a benefit in itself. If current maintenance performance should be retained, some systems would be maintained too much, while others too little.
- A complete documentation of a plant’s systems and maintenance routines, which contributed to quality assurance of the maintenance performance.
- Using RCM should facilitate the change of current maintenance performance, as the old ways of doing things would be analysed and discussed during the RCM analysis.
- Improved conditions for maintenance optimisations and spare parts optimisation.
- Improved communication between VV and VS.
- Different kinds of plant risks became visible.
- Improved understanding of performing maintenance, for example, why and how collecting reliability data and performing analysis.

4.9.6 Recommendations for the full-scale introduction
The project group became aware of several risks and issues that had to be handled before starting up a full-scale introduction:

- There were many projects going on at the same time and an obvious risk was that these projects should compete about the resources needed.
An improved RCM computer system was needed, to effectively handle the great amount of information involved in the RCM analyses. Some commercial computer systems had been identified, but were considered difficult to adjust to Vattenkraft’s RCM model. RCM computer system had not been developed at this stage. The project group considered it to be better to first complete the RCM model.

The decision paths in the organisations had to be identified. Routines needed to establish were, for example, how measures based on analysis recommendations should be communicated and decided on, how new maintenance plans should be established, how cost effectiveness should be calculated, and what maintenance measures to use when waiting for decisions on major design changes.

A compilation of similarities and differences between different units was needed as a basis for template development, which should make the application of RCM more effective.

A very skilled educator in RCM should educate and train the facilitators.

The top management’s maintenance vision and strategy had to be clear and visible. This was considered a precondition for attaining the motivation necessary to make the employees achieve the change of introducing RCM. Leadership was also considered a key issue during an introduction.

To manage continuous improvements, communication of failure and disruption reports had to be working. A clear information flow also had to be developed between the failure report system, the condition monitoring systems and the plant register.

A CMMS was also a precondition for working with continuous improvements of RCM, adjusting maintenance plans and following up failures reported. The maintenance plans that were provided from the RCM analysis should be integrated in the CMMS, making it possible to optimise and package maintenance measures. The traceability in the analyses had to be improved, i.e. understanding what grounds the maintenance measure is based on according to RCM analysis.

An organisation for managing the living RCM programme had to be established, with clear responsibilities. Among other matters, an RCM User Group including people from both organisations should be established.

The project group stated that most of these tasks had to be handled by VV and VS even if RCM was not going to be introduced. Therefore, dealing with these issues, according to a structured method, was seen as a major benefit.
4.9.7 An independent scrutiny

In September 2000 a person from VGS Hydro International performed, together with a former regional manager, an independent scrutiny. The main conclusions were that:

- To have RCM introduced on all plants before the end of 2001 was considered too optimistic.
- VV should be more actively involved in the RCM project, since the organisation had not supported the project with necessary resources, for example, during the review procedure.
- An estimated maintenance cost reduction, due to RCM, was approximately 10%, which implied that the RCM project should pay back in one year. The estimate was mainly qualitative and a more accurate measuring and evaluation was desired.
- An RCM computer system, and other support systems, should be developed as quickly as possible. Otherwise there was a major risk that the project should be delayed.
- The work of introducing RCM in the organisations was considered to become very extensive. The future work had to be given higher status by the top management, who had to show visible engagement and support.

The reviewers recommended that the project proceed to the next stage. The sponsor agreed and TG2 was passed.

4.10 The Execution stage – period 1 and 2

The Feasibility study stage mainly included planning issues performed by the project group. The project manager was not responsible for reporting or giving feedback to the line organisation. However, the Execution stage included a lot of planning and preparation activities, where the personnel of the organisations were more involved, for example considering information and training activities.

A TG3 decision was going to be made in May 2001, i.e. about starting up the company-wide analysis work. However, the sponsor and the steering group were not satisfied with the previous results of the Execution stage. Therefore, it was decided that more efforts on planning and preparation should be performed. A decision on TG3 was made in December 2001. These periods of time are in this chapter structured as period 1 and 2. As the activities within these periods are mainly the same, one summary is made of the work and experiences.

4.10.1 The project organisation - period 1

The project manager of the Feasibility study stage (B) did not continue managing the project. From December 2000 a new project manager (C) was
appointed, employed in the entrepreneur organisation. He had earlier worked as a machinist, but at the time for the RCM project, he worked mainly with environmental and work environmental management issues. He had not been responsible for such a large project before, but was supported by the sponsor representative.

The consultant also became involved during this stage. She was mainly in charge of further development of the RCM model, and planning of the full-scale introduction. The new model version was tested on the second pilot plant. The maintenance engineer, who represented VV in the project group, was managing the work with routines and consequence matrices. Another task was maintenance planning based on the RCM analysis recommendations. This was managed by the machinist involved in the first pilot study.

The sponsor considered that an important factor for project success was to have the same project manager and sub project managers in the RCM project group. This was further emphasised due to the frequent changes of project managers. Therefore, the previous project manager, from the Feasibility study stage, became a member of the steering group. At the same time, the CEO of VGS HS left the steering group.

The members of the steering group were all skilled in maintenance management issues. However, none of the members, except for the former project manager, were educated or trained in RCM. They got their knowledge of RCM mainly from the meetings with the project group. The sponsor had no formal training in RCM, but had some pre-knowledge and understanding of the method from working some years in Norway. He had also discussed the method with the RCM initiator.

4.10.2 Scope, aims and goals

The scope of the RCM introduction was that all plant groups should be involved. Some particularly critical systems, so called standard systems, were to be focused on. RCM analysis and implementation should be completed in all standard systems within four plant groups, one in each region. Due to limitations of resource allocation, the project scope could not include analysis and implementation in all plants’ standard systems. The regional managers, and their middle managers, did not comprehend this. They questioned the purpose of introducing RCM when only a few plants would be analysed in all main

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8 The plants were valued according to a Valuation model, based on the plant’s importance for production. The information from this model was input to the risk matrices, see Section 4.10.7.
systems. However, the goal was not changed or commented on much by the sponsor or the CEO at VS. Aims and goals during this stage were:

- To test the standardised model on the second pilot plant’s remaining units, using a new RCM team.
- A cost and benefit analysis should be performed.
- To educate and train four facilitators.
- To develop remedial maintenance measures including activities and interval estimations
- To introduce and test routines for decision-making, i.e. communication between the purchasers and the entrepreneur.

RCM analysis of the dams, the development of a CMMS, or updating drawings were not tasks to be included in this project stage. During period 2, the following goals should be attained:

- Two standard analyses per plant group, where the plant groups should start working according to the remedial maintenance measures.
- Terminology should be settled and decided on.
- The RCM computer system should be in operation.
- The plant register should be connected to the computer support.
- Technical system descriptions should be completed.
- An organisation managing the living RCM programme should be established.
- 81 standard analyses should be completed.

The new date for TG 4 was set to May 2003.

4.10.3 An introduction approach

During period 1 the project group recommended an approach where the introduction efforts should be focused on some plants or one region. However, the sponsor and the steering group decided that a ‘broad’ introduction approach should be used involving all regions at the same time. That was considered the best way of realising a new way of working, including all regions. One reason why the steering group, and the sponsor, advocated a broad approach was the earlier bad experiences of introducing different kinds of CMMSs, focusing at one region at a time. These introduction attempts had failed to make one CMMS commonly used in all regions.

Many different actors involved in the project had difficulties comprehending the complete introduction ‘loop’. The transparency of the introduction work, and how RCM should be managed in the line organisation further on were unclear. Regional managers and middle managers asked for such an introduction strategy on several occasions. However, a comprehensive and detailed introduction
strategy was not developed. The project group mainly specified tasks in project specifications for each stage, according to the project management model.

4.10.4 A project risk analysis during period 1

According to the guidelines in the project management model, a project risk analysis should precede every new stage. The project risk analysis could be performed more or less comprehensively. Based on the sponsor representative’s earlier project experiences, a less comprehensive approach was used to identify risks.

A project risk management analysis was performed during one day in January 2001. All the members of the project group were involved during the risk analysis, which was performed as a brainstorming session. Identified risks were estimated considering their consequences and the probability of occurring. The risks were gathered in groups based on affinity. The most serious risks identified, which were those to be handled, are presented in Table 4.4.
Table 4.4. The most serious risks identified during project risk analysis in January 2001.

<table>
<thead>
<tr>
<th>Resources</th>
<th>Review</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Difficult to find appropriate facilitators</td>
<td>- Wrong introduction strategy</td>
</tr>
<tr>
<td>- Other projects require similar resources as the RCM project</td>
<td>- Difficult to manage and control the RCM model</td>
</tr>
<tr>
<td>- Project manager or sub project managers leave the project</td>
<td>- Review comments are not cared about</td>
</tr>
<tr>
<td><strong>Communication</strong></td>
<td><strong>Planning</strong></td>
</tr>
<tr>
<td>- The communication within the project group is not working</td>
<td>- The project budget will be extended</td>
</tr>
<tr>
<td>- Too high expectations among managers and employees in both organisations</td>
<td>- Lack of training for managers and employees</td>
</tr>
<tr>
<td>- The purchasers of maintenance services can not understand the full potential of RCM</td>
<td>- Problems identified will not be managed</td>
</tr>
<tr>
<td>- Lack of acceptance for method and results</td>
<td>- The time schedule will be extended</td>
</tr>
<tr>
<td>- Lack of co-ordination with other projects.</td>
<td></td>
</tr>
<tr>
<td><strong>External influences</strong></td>
<td><strong>Other</strong></td>
</tr>
<tr>
<td>- The work with an asset management process at VV takes too many resources</td>
<td>- Analysis results differ between RCM teams</td>
</tr>
<tr>
<td>- Lack of documentation</td>
<td>- The RCM model is not working</td>
</tr>
<tr>
<td></td>
<td>- Lack of guidelines for prioritising</td>
</tr>
</tbody>
</table>

In May 2001, the previous initiator of RCM and the former regional manager, who was involved during the first scrutiny, performed an independent scrutiny. Some comments from the reviewers were:

- The RCM computer system was still not available. This was considered a very high risk since the RCM computer system was considered central for the next stage.
- The engagement and involvement from the VV organisation had to be clearer.
- The senior management, at both VS and VV, had to be more engaged and involved.
- A plan for communication was needed.
- Connections between the RCM project and the work with an asset management process at VV should be clearer. There was an obvious risk of competition of resources.
- The hard work of introducing RCM in the organisation had to be given the highest priority in both organisations.
- More planning and preparation were needed before a TG3 decision could be made.

4.10.5 The project organisation - period 2

Based on the recommendations made by the reviewers in the independent scrutiny, the sponsor and steering group decided that more planning and preparation had to be made before starting up the company-wide analysis work. A project specification of full-scale introduction was to be set up.

The project manager © had to leave for personal reasons and a new project manager (D) was appointed to work in period 2. He left the project very soon after the appointment when he was offered a new job. To obtain some degree of continuity in the project, it was decided that the sponsor representative should be the new project manager (E).

The project manager (E) was skilled in project management and change management, but not skilled in plant technology and systems, and not experienced in plant maintenance issues. To his help, the person in charge of the analysis work in the first pilot study became responsible for the “technology issues”, such as analysis application and development.

The middle managers were to be those responsible for the continuous work with RCM, after the project had come to an end. Therefore, one middle manager from each region was involved as sub project manager for their specific region. Their main tasks were to coach the RCM teams and make resources available. Five sub projects were established. Four of these consisted of a region middle manager, a facilitator, and RCM team members. The maintenance engineer was in charge of the additional sub project, which included four purchasers and technical specialists. Another consultant, with reliability engineering skills, became involved in 2002, supporting the maintenance engineer and the facilitators considering the analysis work.

4.10.6 Project risk analysis - period 2

A project risk analysis was performed in the project management group during two days in February 2002. The most serious risks identified are presented in Table 4.5.
Table 4.5. The most serious risks identified during the project risk analysis in February 2002

<table>
<thead>
<tr>
<th>Resources</th>
<th>Follow-up</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Lack of personnel in the review procedure</td>
<td>- The meaning of ‘a common way of working, became unclear</td>
</tr>
<tr>
<td>- The educator leaves the project*</td>
<td>- Wrong level of analysis performance</td>
</tr>
<tr>
<td>- Low priority of the project among region middle managers</td>
<td>- Standard analyses take too much time to complete</td>
</tr>
<tr>
<td>- Facilitators leave the project</td>
<td>- Insufficient information and data</td>
</tr>
<tr>
<td>- Facilitators have too much to do with regular work tasks</td>
<td>- Lack of a plant register</td>
</tr>
<tr>
<td>- Lack of competence among the analysis teams</td>
<td><strong>Commitment</strong></td>
</tr>
<tr>
<td>- Difficult for facilitators to meet and discuss during the analysis work</td>
<td>- “Two groups” – facilitators and the others</td>
</tr>
<tr>
<td>- Too little information and training</td>
<td>- Lack of support from senior management at VS, and a strong and involved project management group and steering group.</td>
</tr>
<tr>
<td><strong>Living programme</strong></td>
<td><strong>The computer support</strong></td>
</tr>
<tr>
<td>- Cannot be handled by the organisation</td>
<td>- The RCM computer system will not be available or is not fulfilling requirements</td>
</tr>
<tr>
<td>- A CMMS is lacking</td>
<td></td>
</tr>
<tr>
<td><strong>Results</strong></td>
<td></td>
</tr>
<tr>
<td>- Analysis recommendations will not be implemented</td>
<td></td>
</tr>
</tbody>
</table>

* During the analysis work the consultant had already left the project.

4.10.7 A summary of the activities during periods 1 and 2

As the work assignments were mainly the same during the two periods, they are summarised together.

**Benchmarking**

The idea of performing a benchmarking study was initiated by the project manager (D), but as he left the project, nothing happened. During the autumn of 2002 a visit was made during one day to a refinery using RCM.
Roles in the analysis work
During the company-wide analysis work four RCM teams, one team in each region, were to perform analyses simultaneously. Each team was to include personnel from a specific plant group. When an RCM team had performed analyses of three or four systems, a new plant group was to take over the role of RCM team. Each RCM team was to be led by a facilitator and include one mechanic, and two machinists. A person with control and instrumentation (I&C) competence was to be involved when needed, as I&C personnel had a comprehensive knowledge of plant systems.

One machinist from each region assumed the role of facilitator. The RCM project manager (C), and the sponsor representative, were aware that a facilitator needed to master many special skills. For example, it was important to have a person who could make “awkward” decisions, to prevent subjectivity influencing too much of the analysis work. Therefore, in the beginning of period 1, the RCM project manager (C) and the sponsor representative, were going to develop a competence profile for the facilitators. For different reasons a competence profile was not used. It was also considered by the RCM management group that the facilitators that joined the project should be interested of the task and attend voluntarily. That became possible to achieve by means of the top and middle regional managers. Later on, the facilitators considered a key factor to be that the team members had a great deal of experience and were skilled in plant maintenance and systems. Another important factor was that the team members were motivated.

The review procedure was shared between VV and VS. A “local” review was to be performed by reviewers in the VS organisation, to identify differences in the analysis made between the RCM teams. The remedial maintenance measures, based on the approved analysis recommendations, were to be developed together with the maintenance planner in each region.

The remedial maintenance measures were to be reviewed by a purchaser of maintenance services. If the analysis recommendations were approved, they were to be implemented in the current maintenance programme. Four purchasers, each active in one of the four regions, were involved in the project as reviewers. They had assistance by the maintenance engineer, the reliability consultant, and other technical specialists when needed. The specialists were to mainly identify if the RCM teams “forgot” some failure mode, if new maintenance technologies had been thought of, and if the probability estimations were reasonable. The local review and the customer review were to promote a common way of performing maintenance within and between the organisations.
Training and education

Training, education and information were provided to the different groups in the organisation, see Table 4.6.

Table 4.6. Information to and training of different actors within the RCM introduction.

<table>
<thead>
<tr>
<th>Category</th>
<th>Number of participants (approximately)</th>
<th>Days of information and training</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Facilitators</td>
<td>4</td>
<td>20</td>
</tr>
<tr>
<td>- Regional middle managers</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>- Senior management (VS and VV)</td>
<td>25</td>
<td>1</td>
</tr>
<tr>
<td>- RCM team members</td>
<td>66</td>
<td>2</td>
</tr>
<tr>
<td>- Reviewers (VS)</td>
<td>21</td>
<td>3</td>
</tr>
<tr>
<td>- Reviewers (VV)</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>- Maintenance planners</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td>- Users of the RCM programme</td>
<td>200</td>
<td>1</td>
</tr>
<tr>
<td>- Purchasers of maintenance services</td>
<td>5</td>
<td>1</td>
</tr>
<tr>
<td>- Union</td>
<td>20</td>
<td>1</td>
</tr>
</tbody>
</table>

The consultant, who had mainly planned and taught the training packages, considered it very important to provide training and education as close as possible to the actual time for analysis. However, as the start of the company-wide analysis work was delayed several times some people had been replaced or simply forgotten what they had learnt. This involved hard work informing and training them again. Some of the training and education packages were led by the facilitators. For personal reasons the consultant left the project in the middle of the training and education sessions. A new trainer, also a consultant, then became involved, with support from the project manager (E).

Resource allocation

The project group had estimated the resources needed to introduce RCM to all plant groups. However, the sponsor and CEO of VV did not approve the request. In the end the project got approximately half of the money applied for. As a consequence, the overall goal of the RCM project changed, and RCM was to be introduced fully at only four plant groups.

Many projects were going on in both organisations. It was already recognised that it might be hard to involve the purchasers in the review procedure. The regional managers had to plan carefully in advance to be able to put aside the
major personnel resources involved in the RCM project. The middle managers in the regions called attention to the fact that RCM team members also had to be involved with regular work assignments during some specific time periods, something that had to be planned for. The involvement of many people in the project, while the work situation in the companies in general was stressful, was seen as a severe obstacle by the project group.

**RCM model**
The RCM model developed in the project was a customised version of a classic RCM model, in this case RCM II, see Section 3.1.4, for further discussion of different RCM models.

The plants were evaluated differently due to criteria such as capacity and number of aggregates. These criteria were inserted into an evaluation model used by VV to rank the importance of the various plants. The model made it possible to convert calculated risk-taking to become measured in downtime, or availability, i.e., loss of production in relation to availability hours. The amount of time a plant or some of its units could be unavailable could vary considerably, so maintenance efforts had to be in proportion to the need. The evaluation model supported the owner’s possibility of controlling maintenance.

To control availability requirements, consequence and risk matrices were used, see Figures 4.4 and 4.5. In the consequence matrix, the consequences of each failure mode were evaluated based on requirements from VV, i.e., acceptability criteria for safety, the environment, availability and efficiency. Since each plant was unique and evaluated differently, a consequence matrix was developed for each plant. The criteria for safety, environmental protection and efficiency were the same for all plants, only the requirements for availability (downtime) varied.
Figure 4.4. An example of a consequence matrix. Not that this is a hypothetical example, not used in the introduction project. From Backlund & Jonforsen (2002)

<table>
<thead>
<tr>
<th></th>
<th>MINOR CONSEQUENCE</th>
<th>MEDIUM CONSEQUENCE</th>
<th>MAJOR CONSEQUENCE</th>
</tr>
</thead>
<tbody>
<tr>
<td>SAFETY</td>
<td>No injury</td>
<td>Injury</td>
<td>Fatal injury</td>
</tr>
<tr>
<td>ENVIRONMENT</td>
<td>No emissions</td>
<td>Emissions below required limits</td>
<td>Emissions exceeding required limits</td>
</tr>
<tr>
<td>UNAVAILABILITY (Downtime)</td>
<td>&lt;2 h</td>
<td>2 - 10 h</td>
<td>&gt;10 h</td>
</tr>
<tr>
<td>EFFICIENCY</td>
<td>No effect</td>
<td></td>
<td>Large effects</td>
</tr>
</tbody>
</table>

Figure 4.5. An example of a risk matrix. Note that this is a hypothetical example, not used in the introduction project. From Backlund & Jonforsen (2002)

In the risk matrix the estimated consequences were combined with an estimate of the frequency at which a failure would occur. VV decided how often failures could be tolerated, and consequently the risk that was acceptable. The combination of the consequence and frequency estimates generated a weighted number between 0 and 5. For a risk with a weighted number of two or less, the cost of preventive and reactive maintenance was compared, and the most cost-effective solution chosen. Risks ranked three or higher were to be further
analysed, using decision logic, to choose the most effective preventive maintenance measures.

Sensitivity analyses were made of the matrices. These showed that changing the estimated frequency of a failure greatly affected the analyses. On the other hand, changing the availability requirement in the consequence matrix by only a few hours had little, if any, effect on analysis results. When describing failure effects there was always the problem of deciding how many details to include. If the effects could be distinguished as either normal or worst-case effects, with different probabilities of occurrence, this problem was to some extent eliminated. Thus two risk evaluations had to be made, one for normal and one for worst-case effects.

There were no major reactions from plant personnel considering the evaluations of the plants. The project manager (D) did however consider it important to discuss and communicate the evaluation of the plants, and the risk matrix, with the regional managers, to make them accept the procedure.

RCM was aimed at being introduced in to 54 plants, several of which have more than one hydropower unit (a common name for a turbine completed with a generator). The plants were built over a long period of time and are virtually all different, though subsystems could be similar. The many different systems and subsystems made a complete analysis of all the systems too resource demanding. The project group recognised that some kind of templates should be used, as was recommended at the Feasibility study stage. The group started work identifying similarities between different plant sub systems. Seven standard systems were identified; shaft, turbine, generator, transformer, cooling water, intake and spillway, see Figure 4.2. These systems were evaluated considering criteria such as manufacturer and year of manufacture. Finally, based on the standard systems, 81 system types were identified, representing the 1200 plant sub systems. Individual analysis of each system was considered to take two to three weeks on average, while using the system types as templates, called standard analyses, a system analysis would approximately take two to three days. The use of standard analyses would also promote a more common way of performing maintenance among the different groups.

However, the RCM model was experienced as too complicated by several members of the project group. According to the project manager there was a risk that the plant personnel would not experience the RCM model as user-friendly. Therefore, an important issue was to make the RCM model easier to understand for the personnel. The project group members had had difficulties determining what the RCM model really implied. For example, if it included support systems and/or methodology steps. In the Prestudy stage the project group had used the
concept ‘maintenance model’, but it was difficult to agree on whether the RCM was, for example, a model, a strategy, or a method.

**The analysis approach**
Some of the project group members wanted to implement the analysis results from the pilot projects in reality, before starting up the analysis work on a full scale. That action would imply a break in project progress, something that neither the sponsor nor the project manager approved. Changing the overall way of working was prioritised. The sponsor pointed out that it would probably be easier to improve analyses later on than to interrupt and start the change initiative over again. It was the sponsor’s opinion, as well as the CEO of at VV, that too much work on “perfect” initial analyses should be avoided. They advocated an approach where maintenance plans, based on RCM analysis of some systems, with minor adjustments could be applied to similar standard systems.

The RCM teams needed information and documentation about the different systems, something that in general was lacking. At most of the plants, system descriptions, drawings and historical operational data were lacking or insufficient. The system descriptions were important for traceability, facilitating the review work. According to the reliability consultant, the RCM team members had to comprehend how a system was built up, for example by means of a block diagram. This could initially take time, but would make the work more effective further on.

The 81 system types were to be analysed by 22 plant groups, which meant approximately three to four analyses per group. The facilitator was to support one RCM team at a time. To keep up interest and skills, the plant groups were to continue with the cooling water system by themselves. The analysis work was to start by gathering the four facilitators for eight weeks. Together they were to perform analyses of four systems in one region. This approach was intended to contribute to a common view of how to perform the analyses. Another aspect to handle was an equivalent review procedure among the reviewers, both at VS and VV, to make them take similar kinds of decisions. It became a task for the maintenance engineer and the reliability consultant to manage how a suitable review organisation should look like to effectively manage the remedial maintenance measures.

**A computerised maintenance management system**
No common computerised maintenance management system, CMMS, was available in the organisations, but local CMMS existed in some of the regions. VV had recently introduced a business software system, where a CMMS module was available. However, several people within VV questioned the usability of
that module to support the maintenance performance. There were considerations to purchase another CMMS, but decision on how to proceed was not made during the Execution stage.

A condition monitoring system, named Conwide, was used at all plants. It was also possible to make analyses in that system, but the plant groups did not use that function in general. Conwide was accepted by the plant personnel and by the purchasers. As a common CMMS was missing, remedial maintenance measures, generated from the RCM analyses, were to be implemented in the Conwide system. However, the project group considered that a CMMS was necessary for optimisation of the initial RCM analyses, especially considering a common database for all the regions.

An RCM computer system
The requirement specification when purchasing an RCM computer system became a cumbersome task to manage, where both costs and time frames increased several times. Among other matters, there were disagreements on the connection to other technical support systems, as a CMMS and Conwide.

Both at the Prestudy stage and the Feasibility study stage the significance of RCM computer system had been noticed. For different reasons, the issue was not sufficiently comprehended during the Execution stage, period 1, and concrete actions were not taken. However, some project members had warned of the relatively long time frames to purchase (offer, order, test, approve) and apply RCM computer system. Another company within the Vattenfall Group, with available IT-competence, assisted the project considering specifications, evaluation of purchasers, and quality assurance issues. After an evaluation process, a company that developed RCM computer system for some of the Swedish nuclear plants was chosen. However, the development process took time. The time for the facilitators to test and to become familiar with the computer support, before the analysis work started up, became very short.

According to the Feasibility study stage RCM computer system should have been available during the autumn of 2000, which later on was changed to December 2000. According to the Execution stage period 1 a RCM computer system would be available in March 2001. However, the RCM computer system was still under development in September 2002.

A plant register
The project group considered that a plant register was needed. Such a system would facilitate the communication between the different support systems. By means of a plant register it would be possible to use a common structure in the technical support systems, i.e. a logical structure description of systems, sub
systems and components. The development of a plant system structure had begun during the Prestudy stage. The structure was revised on the initiative of the sponsor, who did not find it sufficiently well performed. The need of a plant register was identified relatively late and the project group regarded the work as “stealing time and resources” from the already limited time frames and resources. However, the plant register turned out to be so important that there was no sense in starting with the analysis work before the plant register was developed. The sponsor was informed that it could delay the project for several months.

**Communication and information**

The geographical spread of regions and groups made it difficult for the project group managing communication and information. Plant personnel, as well as VV personnel, complained about too little information from the project and about its slow progress. However, personnel that had been working close to the pilot projects had informally got information and knowledge about RCM. As plant personnel complained about too little information, many also experienced an overflow of information from the many different initiatives going on. As a consequence, regional managers experienced information tiredness among their employees. Even the sponsor and the steering group had some difficulty comprehending and evaluating all the information received in RCM project reports, documents, and presentations during meetings.

The deficient project marketing and information resulted in negative rumours among the plant personnel. In many plant groups RCM was known as a way of performing major reductions of personnel. The aim of a 40% reduction of maintenance costs, as was speculated in the beginning of the Prestudy stage, was also considered a common ‘truth’ among many plant groups.

Discussions were made early in the project group of the importance of general information available to people in the organisations. Inquiries concerning this issue had been made but sufficient information was not available. Documentation from the project management, i.e. project specifications and other documents, were stored on an intranet site. Not all personnel in the organisation had access to the documents. The project group members also found the information on the Intranet unstructured and difficult to find desired information on.

To facilitate a better information flow in the organisations, a hierarchical structure was applied. The regional managers and other managers were to spread information received to their subordinates. According to the project manager (E) the approach was used to make employees experience that the information was something that their managers stood behind. The project group also saw a good
opportunity to spread information about RCM by means of union representatives, as they had well-established contacts with the plant groups. Two meetings were held with union representatives, with the aim of giving information and improving communication. The project management group experienced these meetings as successful.

The project manager (E) put a lot of efforts on informal meetings with the top and middle regional managers and other personnel involved in the RCM project. The project manager was of the opinion that the regional top managers and middle managers had to make their own insights and understanding of RCM. This way of promoting communication in a personal way was to improve buy-in of the employees.

The project group considered that a common maintenance terminology was a precondition for avoiding misunderstanding in communication during the work with RCM. The issue was worked on already during the Prestudy stage, but for some reasons not followed up. The terminology used differed considerably between different categories of professionals, plant groups, and regions. It was decided by the sponsor that the development of a common terminology had to be harmonised with the project, developing an asset management process, and the terminology in the quality management systems, both managed in the VV organisation. The determination of a common maintenance terminology took a while, as several projects were involved, but it finally became based on the Swedish/European standard SS-EN (CEN, 2001).

**Previous projects**

Many of the employees at Vattenfall had been working in the company for 15 to 30 years. In the “old” Vattenfall organisation they had experienced several improvement projects that had failed or faded away during the years. The project manager (E) pointed out that “we must have history with us”, indicating that people might be negative to introducing RCM based on the earlier experiences of failed projects.

A purchaser of maintenance services concluded that “knowledge of the managing of introduction was missing in general, where driving forces and obstacles were not identified, or handled, sufficiently”. A regional manager experienced that a common problem in the old organisation was that the introduction of a technology, or method, became too complex to manage, i.e. too many activities were included. Several people in both VV and VS experienced that earlier projects had mainly been initiated and controlled by top management, with little involvement by and information to the employees. For example, five CMMSs had been introduced in the old organisation but had been abandoned. Many managers and employees considered that the major reason
was lack of organisational commitment. The introduction was usually controlled from the top and pushed down in the organisation, with little communication and information about changes going on. However, managers and employees considered that the introduction and application of Conwide had been successful. The main reason was employee involvement in the development and introduction. Conwide was however not considered as a complete CMMS.

A major project aiming at making the old organisation ‘managed by objectives’ was started up in 1996, when the current RCM project manager (E) had been project manager. After two years, the senior management considered that an organisation managed by objectives was achieved, and that further efforts should be made in the regions. Instead, the efforts faded away. Another problem experienced by the project manager during the project was that top managers were only formally committed, but not in practice. He considered the procedure to be a general culture problem in the old organisation, where people did agree at meetings, but were not committed in practice. Examples of other introduction efforts that had failed in the old organisation were the work related to the criteria of the Swedish Quality Award, and the European Quality Award. According to the project manager, due to the division of the old organisation in VV and VS 1998, the efforts faded away.

Several people involved in the RCM project pointed out the significance of successfully introducing RCM, since so many previous projects had failed. They considered that a failed RCM project would make it almost impossible to succeed with future improvement projects. According to regional managers, union representatives, and employees, there was a general mistrust of the top management in the plant groups. Many people had been discharged during the reorganisation in 1996. That episode damaged the trust of the top management because of the many failed improvement projects. As a consequence, when the top management announced that no one would lose their jobs due to more systematic and effective maintenance, introducing RCM, few really believed that.

4.10.8 Work situation

Another aspect influencing employee commitment to the RCM project was the many other initiatives and projects going on at the same time. The purchasers of maintenance services were very busily involved in other projects, for example, the project introducing an asset management process. Several purchasers experienced that they hardly had time to visit the plant groups and that all the improvement projects going on were a heavy burden. The purchasers were also in the process of changing their way of working, getting used to the role of sponsors of projects, instead of being more involved as project managers.
According to one of the purchasers, the changeover implied many times that the purchasers were too involved in many projects. Other employees in the VV organisation also experienced a stressful work situation. At least five major initiatives were going on at the same time as the RCM project. Some of these projects also had higher priority according to the CEO of VV.

Both the purchasers of maintenance services and the technical specialists had a hard working situation and had little time reviewing the remedial maintenance measures. The project group considered it to be a major risk that the decision during the review procedure would take too much time. As the communication between purchasers and the technical specialists had to be working smoothly, it was also important that technical specialists got feedback on their part in the review. A tedious review procedure could negatively affect the motivation and interest among the RCM teams, and other personnel, as concrete results would not be realised fast enough.

The personnel in the entrepreneur organisation were also involved in many other projects. They were introducing a project management model named PIVO, which was a part of the reorganisation, and change, going on to become professional entrepreneurs. Some middle managers considered that the “thinking as entrepreneurs” was spread among their subordinates, but not yet established at all the plant groups. The managers in the northern region experienced major difficulties making people used to the role of entrepreneurs. The managers in the southern region did not have the same experiences. The managers in the southern region considered a main reason was that their region was relatively small, with few employees compared with the other regions.

The general stressful working situation, in both organisations, indirectly generated obstacles to the introduction of RCM. According to one of the RCM project group members “this is as it always has been, nobody has time to follow up and be involved sufficiently.” According to the regional managers, the employees were in general willing to accept changes, but with too many projects going on at the same time interest and motivation disappeared.

Some regional managers considered that the introduction of PIVO and the new organisational structure should have been realised before the RCM project began. Also some middle managers complained about the situation, as they found it difficult to allocate resources to the RCM project during an organisational change. The middle managers were also very busy. Some technical personnel considered that the initiators of major projects, in general, did not realise that the employees had to work with many regular work assignments at the same time. The persons involved in the project group were
also busy with other tasks and experienced that it was difficult to find time for the project.

**Sponsor and steering group commitment**
The RCM project had become more complex and resource demanding than the sponsor and steering group expected. They considered that the efforts and requirements needed to introduce RCM in the organisation had been partly underestimated. They recognised that this had a lot to do with activities and tasks that should have been dealt with in the current maintenance management practices. The sponsor had also begun to view RCM as a method of working instead of only as a ‘model’.

**Management commitment**
The regional managers’ commitment to RCM was ambiguous. They could see many advantages with RCM, but also questioned the expected benefits and savings from introducing RCM, compared with the major resources involved. Some regional managers’ commitments were mainly based upon the customer VV requiring RCM to be introduced. Not all were familiar with the RCM principles and could not judge if RCM was something that VS really needed. Some managers also expressed some fear about using RCM, as the structured documentation could be used by VV to negotiate with competitors of VS. The unions pointed out the lack of regional managers’ commitment as a major risk for the project. Some unions’ representatives made parallels with the introduction of PIVO, where they experienced that some regional managers ignored the introduction efforts.

Within some regions, the middle managers experienced that their plant groups had too much to do, and that the many remedial maintenance measures took a lot of time. These middle managers supported the introduction of RCM, as it was a way of decreasing routine maintenance activities, and of taking more effective measures. RCM was also seen as an objective way of demonstrating ‘defects’ in the current maintenance performance; something they considered would facilitate employee commitment to introducing RCM. The managers also apprehended that the requirements from VV would be clearer by means of RCM, which was a precondition for controlling maintenance. They were also pleased that, as they saw it, the risk taking moved from the entrepreneur to their customer.

As the repayment from the routine maintenance performance contract was decreasing, some of the middle managers had difficulties finding job assignments for their personnel, which made their commitment to RCM ambiguous. Some regional managers also believed that RCM was too complex and that it would never pay back. They also feared that the risk taking involved
in the RCM principles would go too far, i.e. when failures occurred the entrepreneur would get blamed. Many middle managers also saw a risk in too high expectations on RCM in the organisations, for example on quick economical results. Some regional managers emphasised the importance of senior managers, and employees, in both organisations having to understand why results could take a great deal of time to be realised.

**Employee commitment**

The regional managers and middle managers were in general familiar with their plant groups and knew about their employees’ commitment to the introduction of RCM. The managers also had some recommendations for how to manage employee commitment. Based on the regional top managers’ and middle managers’ experiences, examples of employee commitment issues are described below.

There were the plant groups that were to carry out the analyses and the new maintenance tasks. Therefore, the managers considered that a key factor was that plant personnel apprehended and grasped RCM, and understood how important it was for the organisation. Many employees did not understand the shortages in the current maintenance performance and consequently did not understand why RCM should be used. Many had also heard that RCM would reduce maintenance costs by 30-40% and feared for major personnel reductions.

Managers pointed out that the usefulness of RCM had to be visualised at all levels in the organisation, and that personal benefits with RCM had to be focused on. Both top and middle managers considered that it was very important that the RCM teams had time to work with the analyses. Creditable analysis recommendations were a precondition for making other personnel willing to make changes in the current maintenance programme. Therefore, realistic time plans for carrying through the project were important. But the managers considered it also important to acknowledge that many of the plant personnel were not fond of analysis work, as they did not usually work with documentation routines. The employees would probably be more positive if they could work more in practice, between the analysis assignments. There was also a major culture barrier to deal with. The maintenance personnel had earlier taken care of the plant system and equipment meticulously, while RCM guidelines in some way violated these fixed beliefs. The issue was not only about how to maintain the assets, it also affected professional pride, which was very strong, especially among the older personnel.

However, it was also the opinion of several regional managers, and middle managers, that many employees desired to do something new and work less with routine maintenance tasks. More analysis tasks could inspire some people. The
new situation as entrepreneurs should also motivate a new way of maintaining the assets according to RCM.

The project had been going on for a long time. Middle managers experienced that and interest and motivation among some plant groups already had decreased. Several managers pointed out the major risk in letting the RCM project take too much time. As many previous projects had failed, delays in the RCM project could be interpreted as another failed project. The analyses had to be applied as soon as possible to generate feedback and thereby increase motivation. Several top and middle managers saw a risk with long decision paths. It was also considered important to secure more support, interest and involvement from the VV personnel.

Several managers also pointed out that the motivation for change was influenced by specific group cultures. These cultural aspects differed a lot among the plant groups. Plant groups operating far off tended to be less motivated for changes. The high average age among people who had been working in the organisation for 25 to 30 years, also affected the culture and motivation for change. For many years Vattenfall was a state-owned organisation with a stable working environment and with many personal benefits for the employees. Against that background, the managers found it difficult to make the VS personnel get used to an entrepreneur organisation. According to regional managers and middle managers, the cultural aspects would most likely affect the introduction of RCM. They thought that even if actions were taken to facilitate employee commitment, RCM would probably not be accepted in some groups. According to the project manager (D), the VS organisation was not really mature for introducing RCM during the first few years of the RCM introduction, due to the issues discussed above.

It also became an important task for the project group to make the purchasers of maintenance services, and the technical personnel, involved and committed to the RCM work. However, the importance of the review procedure, and the handling of the different aspects turning up, was managed relatively late in the planning and preparation work. The main part of the information, training and education packages was focused on the VS organisation. As a consequence, the project group find it difficult to involve VV personnel in the project.

**Unions’ commitment**

The unions required that it should be clearly stated, in an agreement, that the use of RCM should not generate rationalisations among the plant groups. This was considered a precondition for project success. Some union representatives feared that VV in the future would use the documented RCM analyses as a basis for offers to other entrepreneurs, i.e. competitors. A more systematic maintenance
programme, based on RCM, was also seen as a risk in itself. It would make it easier for other entrepreneurs to take over the responsibility for some parts of the maintenance work.

During one of the meetings between the project management and the union representatives, the CEO of VS emphasised the importance of having the unions’ support for the RCM introduction and acknowledgement of the possibilities; “We cannot just stop the RCM introduction and look at it as a threat, we must see it as a way to be competitive”. The union representatives were in general positive to the RCM introduction.

Managing commitment
The project group members were aware of the importance of managing commitment, based on experiences from previous improvement projects in the organisations. Introduction and change management issues had been focused on slightly in the Feasibility study stage, but no comprehensive approach or strategy had yet been developed during the project time. The project management group was also aware of the importance of informing employees and managers why the RCM project would be successful, compared with earlier failed improvement projects. To obtain acceptance for the standard analyses, these had to be preceded by information why these were better than the current procedures. The senior and middle managers in the regions also had to be committed to RCM. If the management was not committed, their employees would not be either. Involvement was considered a key factor in order to secure the necessary resources, due to the many people needed in the RCM introduction.

Even within the project group some people questioned the introduction, as many major obstacles were turning up. Some wanted to take a break, to rethink the introduction efforts, while others believed that things would be solved later on. Information and educational efforts were the main activities used to attain commitment among the steering group, regional managers, and employees. The project manager (E) deliberately involved few consultants in the project, so as to make the personnel feel that they were the ones actually introducing RCM in the organisation.

Both managers and employees in the organisations were negative to the frequent changes of project managers. Some made parallels to earlier failed projects and interpreted the many changes as a sign that the project managers really did not believe in RCM. Regional managers and middle managers found it cumbersome, since new project managers usually introduced new directions, aims and goals. A change of project manager could imply changes in earlier fixed agreements, which was experienced as disturbing in such a big project.
Benefits identified during the progress of the project

Managers and employees discussed, on many different occasions, the benefits of using RCM. However, the main parts of these benefits were not incorporated in the project as concrete aims or goals. Some of these were of interest to both VV and VS, and some were more beneficial to one of the organisations. In general, what could be considered a benefit for the entrepreneur’s working with maintenance management was also a benefit for their customer VV. Benefits identified were, listed randomly:

- *Speeding up cultural change.* The introduction of RCM was seen as a catalyst for speeding up the ongoing cultural change in the organisations, especially for the employees in the VS organisation. The systematic and effective principles within RCM promoted the employees in VS to become entrepreneurs.

- *Maintenance optimisation.* To be able to work with maintenance optimisation reliability data are required and RCM could give guidelines where to measure, i.e. apply monitoring devices.

- *Controlling maintenance.* RCM made it possible to control maintenance, which in general was lacking.

- *More condition monitoring and analysis.* Applying RCM implied more focus on analyses and condition monitoring, which would result in fewer interruptions for maintenance measures.

- *Recommended design modifications.* List of recommendations for design modifications would reduce serious risks.

- *Basis for decision-making.* The purchasers of maintenance services would obtain a much better basis for decision-making by means of the systematic and comprehensive documentation.

- *Measuring and controlling maintenance.* VV lacked a suitable approach to controlling and evaluating the maintenance performed by the entrepreneur. The RCM method included steps, which would make it possible to control maintenance performance.

- *”Right” availability.* VV strove to obtain the “right” availability, while many other organisations focused mainly on increased availability. By means of RCM it became possible to differentiate the maintenance efforts between the plants.

- *Maintenance plans.* There were no maintenance plans available in the organisations. The documented measures by means of RCM would make it possible.

- *Competence and understanding.* The RCM introduction provided an opportunity to increase competence and to understand how the organisation would work with maintenance management. The RCM steps could also be a trigger for people in the organisation to start thinking of what they were doing and why, and how it affected maintenance
performance, and the consequences of not doing things. Working with RCM would promote function and risk awareness and not only generate lists and maintenance plans. The personnel involved in the analyses obtained good system knowledge and a fundamental basis for performing suitable maintenance actions.

- **Clear customer requirements.** The consequence and risk matrices would generate more precise requirements on, for example, downtimes, something that had not been experienced before.

- **Objective decisions.** RCM provided an opportunity to make objective and ‘inconvenient’ decisions on reduction of maintenance tasks.

- **A common way of working.** Working according to RCM would support a structured common way of working with maintenance among the different regions and groups.

- **Making maintenance work interesting.** Working with RCM would make it more interesting for the personnel to work with maintenance. The way of working with analyses and optimisation would promote professional pride and motivated personnel. It would also promote a higher status for maintenance work.

- **A maintenance ‘product’.** Introducing RCM provided VS with a maintenance method that they could use when working with other customers. The skills in RCM could be an advantage in the competition for obtaining new contracts.

- **Basis for measures taken.** The plant personnel sometimes experienced it difficult to explain to the purchasers of maintenance services why maintenance should be performed in a certain way. The RCM analysis would support the communication about maintenance measures advocated by the plant personnel.

- **Capture knowledge.** There were many people with long experiences in the organisation, and with comprehensive knowledge. It would be important to make RCM analyses while these people still were in the organisation to capture knowledge. That would facilitate for new employees to understand how to work with maintenance.

- **Maintenance on a tactical level.** VS strove for managing maintenance issues on a tactical level, and not just on an operational level. RCM could support them with a way of working that made that possible.

**Measuring Results and benefits**

At the end of the Execution stage, period 2, there were still many preparation issues that remained to be completed, for example, the plant register, a CMMS, and the RCM computer system. However, the project manager (E) considered the preparation sufficiently worked through to start up the company-wide analysis stage.
The project group found it was necessary to evaluate the current maintenance performance to be able to measure and evaluate the coming results from the RCM introduction. However, documentation of maintenance performance was not available, which made an evaluation demanding and difficult. That was a main reason why evaluation of the current maintenance performance did not take part during the planning and preparation of the full-scale introduction.

Some project members emphasised that an evaluation of the results of the RCM introduction had to include the identification of hidden failure modes and design modifications. The focus mainly on routine maintenance was not considered adequate. The project group experienced that the main focus on decreasing routine maintenance costs indicated that the senior management of VV did not see maintenance as an investment. A cost-benefit analysis was made by a consultant company, which showed a major reduction of routine maintenance. The study showed, among other matters, that ‘light’ maintenance inspections could be decreased by approximately 50%. The potential saving should be visible two years after the analysis recommendations had been implemented at all plants. However, the reliability consultant and the maintenance engineer considered that the project in general had too little focus on plant utilisation, i.e. how the maintenance cost rationalisation affected the production in the form of losses and unplanned stoppages.

**Deliveries during the Execution stage - periods 1 and 2**

According to previous project specifications, RCM computer system should have been developed during this project stage, in period 1. However, the project management group merely stated that the time and work had been underestimated. The test of the analyses according to the RCM model showed many design modification and condition monitoring potentials, and that inspection and maintenance intervals may be extended. The testing of the RCM model showed a potential to save time facilitated by standardised formulations of functions, function failures and failure modes.

During a steering group meeting in December 2001 the Tollgate 3 was considered completed by the steering group. The sponsor approved the purchase of an RCM computer system, which had become four times more expensive than originally expected. The main project goal was defined as ‘A common way of working will be applied in the complete organisation in April 2004’. The sponsor and the steering group encouraged the project group to actively look for approaches to apply the results on more than the four plant groups.
Considerations of the implementation of analysis recommendations
The planning and preparation had mainly been focused on the analysis work. Some ideas in the project group came up, described below, considering the following implementation.

The outcomes of a RCM analysis would be remedial maintenance measures, including lists of light routine maintenance, periodic maintenance measures, and modification proposals. The remedial maintenance measures would be used to develop maintenance plans, including, for instance, unplanned and planned corrective maintenance, spare parts, and modifications. The maintenance plans were significant when working with continuous improvements. While remedial maintenance measures were valid for one specific plant’s system, maintenance plans could include one or several plants. The maintenance plans would be updated if failure with unacceptable consequences should occur in the plant or in another plant with a similar system. Updates would also be performed if changes were made to the consequence matrix, and if new, more effective, maintenance technology was to become available. As a CMMS was lacking, the changed maintenance measures would be implemented in the Conwide system.

To actually apply an RCM programme to a plant, the analysis recommendations had to be implemented in all the plant systems, i.e. the standard systems. It was a task for the regional middle managers and the plant groups to have the recommendations implemented. The project group considered that changes in current periodical maintenance could be difficult to achieve in practice. Changing peoples’ minds about current routines for inspections and overhauls, where traditions and professional pride were involved, would most likely be a cumbersome task. To manage the implementation of the recommendations effectively, the tasks would be handled by different groups of professionals. For example, mechanics were to take responsibility for minor maintenance tasks. An approach was needed to facilitate the managing of the implementation of analysis recommendations, but was not developed. The RCM consultant also pointed out the usefulness of complementing RCM with TPM, Total Productive Maintenance. TPM was seen as a method more suitable for basic maintenance measures, see Section 3.3.1 for further discussion of this matter.

The living programme
During a project risk analysis session, a plan for execution of the living programme was considered very important, in order to, at an early stage, identify and settle the necessary conditions. However, no plan or strategy for facilitating the managing of the living programme was developed. There were, however, a lot of discussions in the project group considering the administration and maintenance of the analyses, routines, and support systems. Who would be
responsible for continuous improvements of the RCM programme? What should the RCM maintenance programme look like in the long run? How would it be used? Who would manage and control? An overall process description of the work with RCM analysis was developed during the planning and preparation, which included the complete loop of initial to continuous improvements of the analysis.

There were also discussions of how to manage and continually adjust the RCM model. Since there were two organisations involved, the issue became more difficult to handle. The project group proposed the establishment of an RCM User-group, where representatives from VV and VS could collaborate and communicate, to secure continuous improvements of the RCM programme.

An important issue was how to secure that plant personnel did not return to old ways of performing maintenance. Other issues were what input information would generate changes in the RCM programme and how to make the entrepreneur take initiatives for improving analyses. The project manager (E) saw a major risk that RCM should fade away in the VS organisation, as routines for the living programme were lacking. However, a maintenance management strategy, or process, was to be developed in the VS organisation, which would support continuous improvement of RCM.

In February 2003 a group of people from both VV and VS started looking at how the living programme should be managed. However, the organisation for working with the living programme should not be appointed until 2004.

4.10.9 Company-wide analysis work

The analysis company-wide analysis work started in February 2002 when the four facilitators gathered to analyse four plant sub systems, for eight weeks, in one of the regions. The approach was to promote discussion and contribute to a common view on performing analyses among the facilitators.

Analysis approach and performance
In April 2002 the facilitators started analysis work in each region, where they managed only one RCM team, i.e. people from one plant group, at the same time. However, many obstacles observed in the end of the planning and preparation continued during the analysis work. The facilitators interpreted the RCM model differently, even if they had worked together for eight weeks. There was also a lack of traceability in the analyses made, which made it difficult for reviewers to understand the analyses. As a consequence, the reviewers did not approve of the first systems analysed. The technical specialists had, during this time, involved consultants, and also technical specialists, to assist them in the
work, as they had little time to be involved. It was difficult to review the analyses mainly due to an unclear system structure. One reason for the difficulties was the unavailability of people with control and instrumentation (I&C) skills, as they had very good system knowledge. The I&C personnel had in general a very busy work situation. It was also difficult to make the purchasers of maintenance services sufficiently involved in the review work. They did not fully comprehend the RCM model used, and their reviews differed in detail. As a consequence, the system reviews were delayed.

The development of the RCM computer system was going on, with additional delays. Therefore, manual analysis had to be performed in the beginning of the analysis work, to be implemented in the computer system when ready. Testing of the computer system was performed in connection with the facilitators’ joint analysis work. The draft version was considered good by the facilitators, and improved the comprehension of the RCM model. But the RCM model was still considered too complicated by several members of the project group. If the plant personnel did not experience the RCM model as user-friendly, the project group saw a major risk that it would not be used correctly.

People at the plants knew that analysis teams were working in the regions, but several experienced that very little information about their progress came out. The facilitators lacked a common routine for information and presentation of the project and the introduction. They experienced that the lack of such information created general confusion among the plant personnel.

A halt in the work progress
The many obstacles occurring during the analysis work too made it too cumbersome to complete. The project group recommended a ‘halt’ in the introduction, to manage the obstacles that occurred. The sponsor approved the stop provided that the project completion should not be further delayed. The ongoing analysis work was therefore stopped in November 2002 and was to be taken up again in February 2003. Issues to deal with during the stop were:

- Developing a general plant system structure.
- Complete system descriptions at the plants, needed for the analysis work.
- Adjustments of the RCM computer system.
- Modifying the RCM model as regards better traceability, where more text would be used to describe the steps taken.
- Securing the routines in the review procedure.
- Offering additional education and training of reviewers and facilitators.
- Securing the resource need of I&C people and reviewers.
- Adjusting time schedules.
According to the project manager (E), the system structure should be adjusted to the need for the RCM analysis, and to elucidating the RCM model. This would increase the traceability in the analyses. These measures, together with a better review procedure, would contribute to a rapid analysis work that would fulfil the requirements on quality and at the same time keep up with the time schedule. The RCM computer system was finally tested during September 2002.

The work with system descriptions was difficult to complete, as it was difficult to find people that were suitable for the job and that also were available. There were, for example, still problems getting I&C personnel involved in the analysis work.

The measures during the halt were considered not to affect the project time schedule, and TG 4 would be passed in May 2003 and TG 5 in the middle of 2004. At the same time, the project group knew that the halt could be interpreted negatively in the organisation. Some people in the organisation had in fact already interpreted the temporary discontinuing of the project as the project having been closed down permanently.

4.11 An analysis of the present situation

In September 2002 two students became involved in the project. As a part of a master thesis they were going to evaluate the introduction of RCM. The main aim was to perform an analysis of the present situation concerning the organisational commitment. 40 persons were interviewed between November 2002 and January 2003, divided into four groups:

- Sponsor, managers and purchasers of maintenance services, in the VV organisation.
- Middle managers in the VS organisation.
- Senior managers in the VS organisation.
- Plant personnel, including the four facilitators.

A brief summary of the information received from the interviews, and some conclusions made by the students, will be described below. For more details, see Edelman & Johansson (2003).

4.11.1 Managers and personnel at VV

In general, the knowledge of RCM and awareness of the project were good in this group of interviewees. However, the purchasers had not sufficient knowledge of RCM, which already had created problems in the review procedure. The majority of the respondents were of the opinion that the project should be seen in a long-term perspective. Direct financial results
should probably take time before realised, but also be difficult to measure. Main risks in the project, stated by this group, were:

- Too cumbersome to manage and administrate such a large and complex project.
- Lack of resources to complete the project, where the increase in costs for the introduction might be too high to be accepted by top management. Future reorganisations could also make the work with RCM not sufficiently prioritised.
- Relative few personnel were directly involved in the project. The situation could prevent necessary commitment among personnel to carry out the RCM-based maintenance tasks.

4.11.2 Senior managers at VS

A one-day seminar on RCM had been offered the managers one year ago, but not everyone had participated. Likewise, all the managers were of the opinion that they had adequate knowledge of the RCM method and project. However, none of them had any idea about the organisation’s future role and approach working with RCM. During the project the majority of the managers had experienced shortcomings in communication. However, some were also impressed by how well things had been working during the project. Some of the managers considered that too few technical specialists from the VV organisation had been involved in the project, so as to support and contribute to the development of the project. The managers considered that the main objective of introducing RCM was to obtain a common way of working with maintenance in the organisation. Risks in the project, from the managers’ point of view, were:

- The lack of a maintenance management strategy, or process, could generate obstacles for the future implementation of the analysis recommendations and continuous improvements.
- Decrease in maintenance activities due to RCM could result in fewer jobs, making personnel at some regions unwilling to accept the method.
- The high costs involved in the project could make the top management abandon future efforts on RCM.
- The long time introducing RCM could have a negative influence on the interest and motivation among managers and employees, generating insufficient organisational commitment to fully carry out the project.
- Based on previous experiences of improvement projects, there was a risk that RCM only became a formality, and not used in practice.
- Lack of competent employees could make the efforts of introducing RCM fade away.
The managers considered that a vision, mission and strategic plan had to be established to ensure that RCM really should contribute to a common way of working in the organisation.

4.11.3 Middle managers at VS

The content of the RCM method was well known to all the managers in this group. The managers had participated during one or two days of training. All managers considered that they had had enough training, but emphasised the need of continuous education to maintain the RCM knowledge. The managers experienced that the RCM project to some extent interfered with the planning of regular work tasks, especially as they had not been sufficiently informed of the time frames and resources needed in the project. According to the managers, the communication and information during the project had not been satisfactory. For example, project information had not reached out to all the people in the organisation. The managers also found it difficult to obtain information on the Intranet.

The managers experienced that there was a lack of involvement among many of the employees. Some managers got the impression that most of their employees believed that the RCM project should be completed in 2004. However, according to the managers, that was really just the beginning of working with RCM. In order to make the introduction transparent to all employees of the organisation, future objectives and the action plan had to be known to all. This had to come along with senior management communicating the overall objective and mission of the company.

The managers saw the loss of one or more facilitators as a major risk in the project, as there was no one to replace them. They also perceived a risk with RCM as it involved documentation of the corporate knowledge in VS, something that could be used by competitors. However, according to the interviewers, this group of respondents was the most positive to the introduction of RCM.

4.11.4 Plant personnel

Some of the interviewed plant personnel had participated in one day of training, and some claimed that they had not participated in any training at all. Likewise, it was the interviewers’ opinion that all the respondents in this group had a fairly good knowledge and understanding of RCM. However, the majority of the respondents did not know how RCM should fit in the long-term goals of VS. In general, the vision and the mission of the organisation were not well known in the plant groups. Almost every one of the respondents desired more information about the project, of the project status and project progress. The information
available on the Intranet was not experienced as user-friendly, where, for example, updated documents were difficult to find. A majority considered also that the communication did not work satisfactorily. For example, one of the respondents actually believed that the RCM project had been closed down.

A common way of working among the regions and the plant groups was seen as the main reason to introduce RCM. Other reasons were to retain knowledge and experiences among the employees, increased planned maintenance, and decreased unplanned maintenance. This group also considered that by means of RCM an effective and efficient maintenance performance should be achieved, as an opposite to the current maintenance performance mainly based on tradition, usage and custom. However, the respondents were also concerned about some risks of introducing RCM, which could have an affect on the VS organisation. The introduction of RCM could be a way to rationalise the employees. For example, if unplanned maintenance drastically decreased, there would be less work for the planning personnel, which could lead to fewer people being needed in the organisation. The structured maintenance programme and performance based on RCM could also make it easier for competitors, i.e. other entrepreneurs, to purchase contracts from VV. Some employees actually looked upon the introduction of RCM as “digging one’s own grave”. The main risks for the project completion, according to the respondents, were:

- That the complete introduction of RCM to all plants would take too much time, which would have a negative affect on employees’ motivation and involvement. Only a few of the respondents thought that the introduction would be completed on time.
- That some of the facilitators would leave the company for some reason, as no one could really take over their responsibility in this phase.
- Lack of an organisation working with the living programme was seen as a severe risk that could make the previous efforts fade away.

The respondents also commented on the cumbersome reviewing procedure, where the feedback from the reviewers took considerable time. Several of the respondents found it frustrating that no feedback or action followed the analyses made, especially since many of the RCM teams had been working hard to perform the analyses on time. Some plant personnel also questioned why they should perform analyses of systems that were going to be changed in the near future, in connection with major plant reinvestments, as the system design could be completely different.
5 CASE STUDY ANALYSIS, DISCUSSION AND CONCLUSIONS

This chapter contains an analysis, a discussion and conclusions of the single-case study described in the previous chapter.

5.1 An analysis model

In Chapter 3 literature findings concerning RCM introduction and application were presented. Based on these findings, several theoretical propositions were made. One such proposition was that managerial factors affecting an RCM introduction can be managed within four specific management perspectives. Another theoretical proposition was that managerial factors can also be managed in accordance with an introduction process consisting of several phases. According to Yin (1994) a programme logic model is a combination of pattern-matching and time-series analysis, which can be used as an analysis model. The management perspectives and the introduction phases have been combined to form an introductory matrix, i.e. a form of programme logic model, see Table 5.1. The management perspectives will be used to structure managerial factors identified in the case study. The analysis model will be used to analyse when or where different obstacles and driving forces, based on the managerial factors, occur during the introduction.

Table 5.1. An analysis model used to explore when or where managerial factors, affecting the introduction of RCM in form of obstacles and driving forces, occur in the different introduction phases.

<table>
<thead>
<tr>
<th>Phases</th>
<th>Perspectives</th>
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<td></td>
<td>An RCM management perspective</td>
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<td></td>
<td>A maintenance management perspective</td>
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<td>A project management perspective</td>
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<td>A change management perspective</td>
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<tr>
<td>Initiation</td>
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<td>Pilot study</td>
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<td>Planning and prepare</td>
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<td>RCM analysis process</td>
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<tr>
<td>Implementation</td>
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<td>Living programme</td>
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</table>
5.2 Managerial factors identified during the case study

The case study description gave a picture of a rather cumbersome RCM introduction and it is part of the scope of this study to find out why. In the following section, managerial factors that influenced the introduction of RCM will be presented. The four management perspectives, and the managerial factors identified in the literature, see Section 3.3.4, are used as a basis for structuring the factors identified in the case study. However, as will be seen, some additional factors have been identified in the case study, which are italicised, see Table 5.2. In this section, in general no particular consideration is taken of when, or for how long, a factor affected the introduction. As discussed in Section 3.3, the management perspectives and the factors are to some extent overlapping.

Table 5.2. A summary of managerial factors affecting the introduction of RCM, based on the findings from the literature study. Additional factors, identified in the case study are italicised.

<table>
<thead>
<tr>
<th>Factors affecting RCM introduction</th>
<th>RCM management</th>
<th>Maintenance management</th>
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<tbody>
<tr>
<td>RCM team competence</td>
<td>Strategic maintenance management</td>
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<tr>
<td>Analysis performance approach</td>
<td>Maintenance programme and performance</td>
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<tr>
<td>Documentation and information</td>
<td>Maintenance culture</td>
<td></td>
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<tr>
<td>RCM computer system</td>
<td>Outsourcing of maintenance</td>
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<tr>
<td><strong>Project management</strong></td>
<td><strong>Change management</strong></td>
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<tr>
<td>Planning</td>
<td>Planning and preparation for managing change</td>
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<tr>
<td>Introduction strategy and approach</td>
<td>Commitment and support</td>
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<tr>
<td>Control and monitoring</td>
<td>Work situation</td>
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<tr>
<td>Measuring and evaluation</td>
<td>Behaviour characteristics</td>
<td></td>
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<tr>
<td>Resources</td>
<td>Involvement</td>
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<tr>
<td>Project risk management</td>
<td>Training</td>
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<tr>
<td>Benchmarking studies</td>
<td>Information and communication</td>
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<td><em>Project group competence</em></td>
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5.2.1 RCM management

From an RCM management perspective, several of the factors affecting the introduction of RCM are listed and motivated below.
**RCM team competence**
During the Prestudy stage, machinists and mechanics were involved in the RCM team. They started the analysis work based on two days of training. The analysis performance became troublesome and took a lot of time, mainly because of lack of competence and experience of applying RCM. The analysis performance was also characterised by individual work rather than teamwork. During the analysis work in the Feasibility stage, a facilitator became involved. However, this facilitator did not have a great deal of experience and skills in RCM and reliability issues. Also, the prevailing maintenance management culture was, to some extent, characterised by lack of maintenance and reliability engineering competence. During the analyses to come it was also difficult to involve Instrument and Control (I&C) personnel in the RCM teams. During the analysis work, members in the teams were also sometimes forced to work with regular work tasks. During the company-wide analysis work, the lack of instrumentation and control (I&C) personnel resulted in shortages of system knowledge in the RCM teams. This made it difficult for the teams to clearly identify interactions between subsystems, and clearly describe system functions. Consequently, the RCM teams made different assessments of what to include in the analyses, something that became very confusing for the reviewers.

**Analysis performance approach**
The RCM pilot teams had difficulties finding a suitable level of analysis. The choice of level was important since it influenced the identification of causes, and thereby the actions taken. The analyses could not be performed on an overly general level, but at the same time not too deep, as that would lead to excessively resource-demanding analyses. Acceptance criteria for evaluating the risks were not stated by the senior management during the pilot study. The situation implied that the risk evaluation could not be completed and was instead based on intuition. The project group, the facilitators, and the other people involved in the company-wide analysis work experienced the RCM model as being too complex. For example, the RCM model was interpreted differently among the facilitators, which resulted in divergent analysis approaches. Also, the reviewers, mainly purchasers of maintenance services, found the RCM model difficult to understand. As a consequence the review procedure did not work as intended. For example, the analysis recommendations were not implemented, i.e. changes in the current maintenance programme were not realised. Since the RCM teams felt that their hard work, performing analysis on time, did not show up in concrete changes in the maintenance programme, their motivation and interest decreased.
The personnel considered the plants as ‘individuals’ as the plants were built during a long period of years, of different manufacturers using different system designs. Performing analysis to all systems would be a very resource demanding tasks. The uses of standard analyses make the analysis work more effective and should at the same time promote a common way of performing the analyses.

**Documentation and information**

Documentation, in the form of system descriptions for specific plants and historic reliability data, was in general not available or updated. Descriptions of the general plant structure and plant systems were preconditions for the RCM teams to understand the systems and their interactions. Since such descriptions were not available, some analyses became incorrect and failure effects and consequences were interpreted erroneously. Since historic reliability data were missing, it also became difficult to make reasonable probability estimations. The preparation of the analysis work, for example, in order to develop a system description, became a time-consuming task both in the pilot study and in the company-wide analysis work. During the latter, the situation became so severe that the analysis work had to be stopped for several months.

**RCM computer system**

A simple RCM computer system was developed already during the Prestudy stage. The need of a more sophisticated computer system was recognised during the Feasibility study stage. However, the project group ignored the importance of having a computer system available early in the project. There were a number of commercial computer systems available on the market, but the decision taken by the project group was to develop a customised computer system, as a customised RCM model had been developed. The development and purchase of an RCM computer system became a resource-consuming task, where time frames and costs successively increased. The total cost became four times higher than originally anticipated. Without a computer system available, the analysis work became ineffective and strenuous. As a consequence of the delays, the analysis work in the regions started before the facilitators had a chance to test the computer system properly. When an RCM computer system finally became available, it facilitated the understanding of the analyses made and the analysis work became more effective.

**5.2.2 Maintenance management**

From a maintenance management perspective, several of the factors affecting the introduction of RCM are listed and motivated below.
**Strategic maintenance management**
No comprehensive and structured maintenance management strategy was found at the beginning of the case study, neither in VS nor in VV. VV initiated the development of an asset management process during the planning and preparation of the RCM introduction. RCM was a part of that process. The asset management process was to be introduced in the organisation in the middle of 2003. VS was going to develop a maintenance management process, but had just started with the task during 2002. The major reorganisation going on within VS was one reason why they had not begun the work on a maintenance management process earlier. The lack of a maintenance management strategy made it unclear how RCM should fit in the organisations’ work with maintenance management, which made it difficult for managers and employees to clearly understand why RCM should be introduced. Also, the lack of a maintenance management strategy made it difficult to plan for systems and routines needed during the continuous improvement of the RCM programme.

**Maintenance programme and performance**
No comprehensive and structured maintenance programme was available at the beginning of the case study. Very little documentation, measurement and analysis of the previous and current maintenance performance were available. Maintenance was mainly performed ‘hands-on’, seldom based on methodical analysis, and often carried out differently in different plant groups. A computerised maintenance management system, CMMS, was not available. A condition monitoring system, applied at most of the plants, was to some extent used as a CMMS. However, several attempts were made to introduce a CMMS in the old organisation, but for different reasons they all failed. The main reason for the lack of a common CMMS could be traced back to the old maintenance organisation, which included a lot of people working hands on with little focus on analysis work. Since a CMMS had been missing for a long time there was no analysis of current maintenance performance available at the time of the study. Without a CMMS, it also became difficult to effectively measure, follow up and evaluate RCM progress. A comparison of maintenance performance before, during, and after the RCM introduction was needed to promote commitment among managers and employees for the purpose of measuring effects of the RCM introduction. Without a CMMS, it also would become difficult to manage the analysis recommendations, and implemented tasks, for example, obtaining maintenance plans and packaging work orders.

A uniform company-wide maintenance terminology did not exist, but as many people, from different organisations, regions and groups, were involved in the RCM introduction, an adequate terminology was necessary in order to avoid misunderstanding and communication difficulties. Also, there was no plant register available at the beginning of the RCM introduction. A plant register
includes a structure of systems, apparatus and components. Therefore, a plant register turned out to be a precondition for the development of a useful RCM computer system, and also for effective communication between the RCM computer system and other technical support systems, such as a CMMS. However, in the beginning a plant register was lacking. An RCM computer system and a CMMS had to be connected in order to effectively handle the analyses made. Due to the poor maintenance programme, important support systems and routines, such as a CMMS, a plant register, systems descriptions, and a uniform company-wide maintenance terminology, were all lacking. These were major tasks to manage and became ‘projects in the project’, requiring relative large work efforts.

**Maintenance culture**
Before the deregulation of the power market, the plant groups were used to keeping the plants in an excellent shape. The approach and attitude could be traced back to the old organisation, where major resources were available, and where the personnel felt a strong responsibility for the condition of the plants. These conditions were mainly valid for the current maintenance culture, which involved, among other matters, a lot of routine maintenance based on custom and usage. However, at the same time, as many of the maintenance people had their professional background and skills in plant construction, there was in general little interest in, and experience of, analysis work. Therefore, in the beginning of the preparation of the organisation, plant personnel were generally not enthusiastic about introducing RCM with its focus on analysis and optimisation.

In general, different professional categories at the plants were not interested in integrating work tasks between different professions. In some regions there were clear ‘walls’ between, for example, machinists and mechanics. However, in order to efficiently handle the maintenance measures generated by the RCM analysis, tasks were to be managed as integrated work tasks by different groups of professionals, for example by machinists and mechanics. This was seen as an important precondition for improving the conditions of the RCM programme, where resistance among professional categories could otherwise generate problems.

**Outsourcing of maintenance**
The outsourcing of routine maintenance was by many managers seen as an advantage, promoting plant personnel’s understanding and acceptance of the importance of introducing a more effective way of working with maintenance. Obstacles due to the outsourcing situation were mainly the obscurity in resource allocation as regards fully introducing RCM to all plant groups, and that the contractor had a busy situation making people grow in their roles as
entrepreneurs. The outsourcing situation made the maintenance management processes in both organisations, of managing the coming living programme especially important. Matters such as responsibility and discharge issues of systems and routines had to be very clear.

5.2.3 Project management

From a project management perspective, several of the factors affecting the introduction of RCM are listed and motivated below.

**Planning**

The focus of the RCM introduction changed over time. In the beginning the primary focus was on maintenance cost reductions, while at the end of the planning and preparation the focus was on changing the way of working with maintenance in the organisation. The division of the old organisation into an entrepreneur and an owner created additional aims for the project, such as providing a basis for purchasing maintenance contract and promote long-term control of maintenance in accordance with VV’s needs. The change of RCM introduction aims and goals made it difficult to know what to measure and evaluate, and to visualise progress. There was no comprehensive review made on potential advantages and benefits of RCM. During the project, managers and employees discussed several potential benefits of using RCM, as documentation of knowledge, identifying design modifications, and increasing competence. However, these were not used as concrete and measurable goals in the project specifications that preceded each project stage.

The overall goal of the project was to apply RCM on all standard systems within four specific plant groups. In the other plant groups only some standard systems were to be analysed and implemented. This overall project goal was, to some extent, confusing and was questioned by many regional top and middle managers. This affected their commitment to the introduction of RCM and also made them question the commitment of the top management. Many people in the organisations were unsure of the aims and purposes of RCM, and some employees also questioned in what ways the introduction of RCM would benefit them personally.

The aims and goals of the RCM introduction were mainly in accordance with senior management desires. Benefits more appealing to other groups of employees, for example plant personnel, such as more interesting work tasks or a safer work environment, were not directly in focus. On the contrary, for many of the managers and employees in the VS organisation, RCM was just a demand from their customer, i.e. they had to do it.
Introduction strategy and approach
Based on a steering group recommendation a broad introduction approach was used, where all regions were involved at the same time. An introduction strategy was briefly presented in the project specifications. However, the lack of a well thought-out and comprehensive strategy made the introduction difficult to manage. The project specifications were focused on what to do rather than how and when to do it, mainly supporting the management of specific tasks, such as the establishment of an RCM computer system or the unification of a maintenance terminology.

Control and monitoring
The project management model facilitated the introduction as project organisational structure and roles become clear, aiding communication and decision-making. The project management was also facilitated by clear stages and steps.

Measuring and evaluation
The pilot study generated overarching results that were difficult to evaluate in the form of decreased risks and more efficient maintenance tasks. The analysis recommendations were not implemented and the lack of concrete results made the senior management question the benefits of RCM. During the introduction several estimations were made considering the profits of using RCM. These were based on experiences from the pilot projects, and a ‘cost-profit’-analysis. No plan for measuring and evaluating the RCM introduction progress, its benefits and appropriate performance indicators, was developed. The lack of a plan or practice for follow-up, measurement and evaluation resulted in little control of the RCM progress and organisational commitment. Also, as it was difficult to show early results and progress, interest and motivation decreased within the organisations involved. Measurement of intangible aspects, such as improved knowledge and a common way of working in the organisation, were not developed. However, two students made, from October 2002 to March 2003, an evaluation of the organisational commitment in VS and VV, in the form of a master’s thesis, See Section 4.11.

Resources
The RCM project started up in the old organisational structure, but after the reorganisation in 1998, VV became the sponsor of it. People in the VV organisation initiated RCM, but the entrepreneur became the one mainly in charge of realising the remaining work of introducing RCM. This specific situation contributed to uncertainty about the further resource allocation, considering whether VV or VS should provide the resources needed for analysing all plants and having the recommendations implemented.
The activities of the RCM project became comprehensive and extended in time, and consequently the need for resources increased. For example, the purchase and development of different support systems and documentation, such as an RCM computer system, a plant register, and system descriptions, all required more resources than anticipated. However, the main part of the major costs for the project was connected to all the people involved. The continuous increase of resource needs and delay times negatively affected senior management and middle management commitment. Several managers questioned the resources spent and the calculated pay-off time. At the same time, other projects were going on in the organisations parallel to the RCM introduction. In addition, regular work tasks also needed major resources. These projects and work tasks were sometimes more prioritised than the RCM project.

Some categories of people, such as purchasers of maintenance services, instrumentation and control (I&C) people, and even project managers, were difficult to find for the project. For example, the purchasers of maintenance services, and the technical personnel, had little time for the review procedure, which delayed the implementation of analysis recommendations. As the project managers were frequently changed, it became difficult to have a smooth progress in the project. For example, it became difficult to follow up and comprehend ideas made up by previous project managers and members. Many people in the organisations were of the opinion that the small number of facilitators was a major risk for the project, since if some of them had to leave the project, there was no one in the organisations that could replace them.

**Project risk management**
During the Feasibility study stage several risks in the project were identified. In accordance with the project management model, the Execution stage was preceded by project risk analyses, one in each period. Based on earlier experiences, the project managers considered so-called mini risk analyses sufficient for identifying risks in the project. These were mainly performed during one day, as brainstorming sessions, involving the project group. The project risk management approach affected the RCM introduction since many severe risks were identified. However, many risks were not eliminated or sufficiently reduced.

**Benchmarking studies**
Before the RCM project started, contacts were established between VV and another hydropower company in Canada concerning various collaboration and benchmarking projects. The Canadian company was, among other things, working with introducing RCM. Some of the project managers had thoughts on performing benchmarking studies of others RCM introduction processes. However, the contact with the Canadian hydropower company was not used for
that purpose. A minor benchmarking study was made of a refinery in 2002, but this was more a comparison on an overall level. The lack of benchmarking studies affected the RCM introduction indirectly. As the introduction process became complex to manage, and also resource demanding, a benchmarking study should probably have been valuable, learning from others experiences regarding obstacles and driving forces.

**Project group competence**

As the project group members, and especially the project managers, changed during the time of the project, the group competence varied. The project managers involved were mainly skilled and experienced in project management. This, together with the use of a project management model, made it possible for the work to be clearly followed in its different stages and steps during the project. Most of the project group members were skilled in maintenance and maintenance management issues, which facilitated the understanding of the requirements on a living RCM based maintenance programme. When the project manager (E) joined the project, one of the group members, skilled in RCM and plant maintenance, was put in charge of the more technical issues.

The RCM knowledge in the project group increased over time, but was limited in the beginning of the project, as none of the members were experienced in RCM application or full-scale introduction. For example, for a long time the project group members were not clear about the contents of the ‘RCM model’ or whether RCM could be considered as a tool, a model, a strategy, or a method of working. The unclear RCM model created misunderstandings within the project group and unclear guidelines on how to proceed with the model development. When even the project group members found it difficult to comprehend the contents of the RCM model, it became difficult to communicate the model with managers and employees. Also, the uncleasrness of the RCM model was a major reason why the need for support systems was not focused on until late in the introduction process. For example, the ignorance of the need for an RCM computer system was partly influenced by the difficulties of clearly visualising the RCM model. The shortages in RCM application and introduction were probably a main reason for the delayed and cumbersome work during the Prestudy stage, and the following planning and preparation of the full-scale introduction.

The importance of change management was ignored for a long time since change management skills were lacking in the group. Both in the Feasibility stage and in the Execution stage period 1, one group member was responsible for working out guidelines concerning change during the introduction. However, on both occasions, the persons had no competence in change management.
Change management skills were not available for the project group until the time when project manager (E) became involved.

5.2.4 Change management

From a change management perspective, several of the factors affecting the introduction of RCM are listed and motivated below.

Planning and preparation for managing change

Managing change was mainly promoted by the project group in the form of information and communication. During the Feasibility study stage an introduction strategy, with a focus on the organisational change, was to be developed. Due to new directions for the project’s execution during that time, the introduction strategy was never completed. The lack of a strategy for managing change was probably a main reason why it became difficult to create organisational commitment.

Commitment and support

During the Prestudy stage analysis recommendations were never implemented, which prevented access to useful experiences for the planning of the implementation and the continuous improvements of the initial analyses. One reason for not implementing the recommendations from the RCM analysis was the limited interest shown by the top management. Among them, other activities and projects were prioritised during that time. The initiator of RCM was not involved in the ongoing project work more than as a member in the independent scrutiny of the project, which was performed before each Tollgate decision. The technical manager was also busy with many other tasks and other senior managers were not so much involved in the introduction, and the project managers had been frequently changed. Regional top and middle managers were not sufficiently committed, as not enough I&C personnel were available for the project; the same was true of the purchasers as well. Many RCM team members also had to be involved in regular work tasks parallel to their analysis work. However, one of the regional top managers, who was also a member of the steering group, was by many in that region considered a RCM champion. The busy situation among managers led to no real RCM champion being available in the project, neither as senior manager nor as project manager. The lack of an RCM champion contributed to obstacles in the RCM introduction process concerning leadership and clear directions.

The overall project goal to apply RCM only to four specific plant groups was questioned by many regional top and middle managers, as it indicated lack of commitment from the top management at VV and VS. The lack of commitment was aggregated due to doubts about the benefits of RCM. Many regional top and
middle managers saw the RCM introduction as too resource demanding compared to the benefits anticipated. The top management’s ambiguity on the resource allocation for RCM introduction to all plants had a negative influence on regional top and middle management commitment, which in turn influenced employees’ commitment. For example, as long as the sponsor showed no visible and clear commitment, the other management levels took little concrete action. But when the decision was finally made to initiate the company-wide analysis and implementation work, regional top and middle managers became more involved. A general resistance towards RCM could also be traced back to the geographical spread of regions and plant groups. The regions and groups had been rather autonomous for a long time, and many people within the organisation still thought of the regions as “companies within the company”. According to the analysis of the present situation, see section 4.11, the middle managers were the group of people most positive to the introduction of RCM.

**Work situation**
At the same time as the RCM project was initiated, many other projects were going on in both organisations, including major reorganisations. The RCM project had not as high priority as some of the other projects, based on their top managers’ directions. As many regular work tasks were going on parallely, the work situation made it difficult for people in both organisations to participate and devote time and efforts to the introduction of RCM. This affected, among other matters, the review procedure. The work situation was also a problem during the pilot study, where the members in the RCM pilot team were very much occupied with regular work tasks. All members of the RCM project group were also involved in many other issues in the organisations. This was probably a reason why many of the risks identified in the project risk analysis sessions were not managed properly. The many projects and reorganisations that were going on simultaneously had a negative influence on the general willingness to change.

**Behaviour characteristics**
Many people in the organisations had a negative view of improvement projects in general. One reason for this was the many experiences of previously failed projects, for example the many attempts at introducing a CMMS. The geographical distances in the hydropower organisation, where the plants are located along different rivers, make plant groups and regions more or less self-governed, which contribute to different kinds of subcultures. Therefore, resistance and unwillingness to change differed between plant groups. The average age at the plant groups is high, and some people have been working in the organisation for more than 20 years. For a long time the work tasks have been the same, which creates traditions and less need for changes. The introduction of RCM involved changes in work tasks and was by many regarded
as leading to people losing their jobs. This issue was reinforced by rumours about a 30 to 40 percent reduction of maintenance costs in the beginning of the planning and preparation. As the introduction of RCM became a cumbersome and long-term project, several employees made parallels to earlier failed improvement projects. A general resistance to the RCM introduction was also caused by people’s fear of losing their jobs. This phenomenon was especially visible at remote plant groups in the regions.

**Involvement**
A large number of employees were involved in the RCM introduction. From the VV organisation purchasers of maintenance services and technical specialists were involved, mainly as actors in the review procedure. In the beginning of the Execution stage, the project was to be managed mainly by the VS’s personnel, on recommendations from the sponsor. As a consequence, the direction led to limited involvement of VV-personnel, which created problems in the review procedure. Also, interested and involved purchasers were seen as an important factor for promoting motivation among the plant personnel working with RCM. However, a substantial part of the plant personnel stated that the purchasers were neither interested in nor supporting the RCM introduction within VS. Involvement of the sponsor, the steering group and other senior managers was to some extent also lacking as regards training, as they did not really comprehend the RCM principles or why it should be introduced. Another difficulty was how to make all personnel committed to the way of performing maintenance according to RCM, as several of the personnel were actually not involved in the analysis work.

**Training**
The pilot team started the RCM work on the basis of a two-day training course, held at the beginning of the Prestudy stage. Considering that none of the participants in the pilot team had any engineering or reliability background, a two-day training course in RCM was insufficient. During the coming project stages, where more people became involved, additional training was performed and new information packages were developed. However, the relatively superficial training of top managers, the short training of project managers, and the prolonged time between training and practice, together affected peoples’ understanding of the method. Furthermore, it generated little interest in being involved in the introduction, for example, in the review procedure. For a long time in the project, some regional top managers had too little understanding and knowledge of RCM. This had a negative influence on their commitment to the RCM introduction, as they did not really know what it was about or what it was supposed to achieve. Neither the project managers nor the senior and middle managers were well experienced or skilled in RCM. Therefore, they did not
become dedicated to the RCM introduction, especially in the beginning of the preparation of the organisation.

**Information and communication**

For a long time, many of the plant personnel did not understand what was wrong with the current maintenance performance, why the maintenance procedures had to change and become more efficient, and why RCM was a better way of performing maintenance. As long as the personnel did not understand why the previous maintenance procedures had to be changed, and did not accept the principles of RCM, it was difficult to obtain employee and management commitment to the RCM introduction. Some employees complained that there was too little information available regarding the RCM project. Insufficient information regarding the RCM project promoted the development of rumours, for example, that the introduction of RCM would lead to major job rationalisations, or that the project had failed during the halt in the company-wide analysis work. This situation negatively affected the work of strengthening organisational commitment. On the other hand, since many different projects were going on within VS and VV alongside the RCM introduction, many people experienced a heavy information flow. The information flow resulted in information fatigue among many employees, which affected their involvement and interest in the RCM project. Some senior managers experienced that the large amount of information from the RCM project was difficult to comprehend and that this, to some extent, had contributed to bad decisions earlier.

The communication and distribution of information was difficult to control due to the geographical spread of regions and plant groups. For example, many people were not reached by the information given by the project group. The difficulties hindered RCM from becoming a uniform way of working within the whole company. The project manager (E) used, as a complement to the formal meetings, a more personal way of communicating and spreading information, by making several visits to the plants and regions. The approach was based on experiences from previous projects in the organisation, where management commitment mainly lasted during formal meetings, but where old ways prevailed shortly afterwards. The use of informal communication made the regional top and middle managers more easily committed, due to the fact, for example, that during the informal meetings they could speak and ask questions more freely.

**5.2.5 An analysis of the management perspectives and the factors**

The factors identified have been suitable to structure according to the four management perspectives. However, the contents of each factor, i.e. in what ways a factor affects the introduction, are sometimes closely related to other
factors. For example, the lack of a CMMS, a part of the factor ‘maintenance programme and performance’, affected the possibilities for measuring and evaluating RCM introduction progress. However, ‘Measuring and evaluation’ is also a factor within the project management perspective. Therefore, the ‘boundaries’ between the different factors, and in what way they affect the introduction of RCM, is not always evident. The factors identified are mainly the same as were identified in the Chapter 3. However, some factors are different, as well the contents of some factors. This will be discussed below.

The factors identified in the literature study and the case study, related to RCM management, are the same. The contents of the factors are also quite similar.

The factors related to maintenance management in the literature also have been identified in the case study. The factor ‘maintenance culture’ seems to be more emphasised in the case study than in the literature study. One reason might be that the hydropower organisations studied over a long time have acted on a monopoly market. Other specific conditions are the geographical spread of plant groups and regions. These conditions, and others mentioned in Chapter 4, contribute to a strong maintenance culture that might more significantly influence the introduction of RCM than in other types of industry sectors. However, the maintenance culture is also related to factors within the change management perspective. The connection between RCM and other methods, such as TQM, TPM and ILS have been discussed in quite a few papers according to the findings in the literature, but very little in the case study. One reason might be that an overall maintenance management strategy was lacking, where such kinds of connection should be natural. Another explanation might be the resource consuming and cumbersome work on introducing RCM, where it was probably not convenient to start, or time to think about, additional initiatives in the organisations.

The factors related to project management in the literature have also been identified in the case study. However, additional factors identified in the case study are ‘project risk management’, ‘benchmarking studies’ and ‘project group competence’. Why these factors have not been identified in the literature study is difficult to find a clear explanation of. However, one reason might be that the findings in the literature are not so much focused on full-scale introduction. In more limited RCM introductions, a project organisation, comprehensive benchmarking studies and project risk analyses are probably not considered to be needed in the same way. The factor ‘project group competence’, concerning the project manager, is to some extent discussed from a change management perspective.
The factors identified in the literature study and the case study, related to change management, are the same. The contents of the factors seem also to be quite similar.

5.3 An introduction process

A theoretical proposition, Section 3.5, was that the introduction of RCM could be viewed and managed in accordance with an introduction process, see Figure 5.1. Below, a comparison will be made between RCM introduction characteristics, described in Chapter 4, and the phases, with the aim of validating the proposed introduction process.

![Diagram of an RCM introduction process]

Figure 5.1. A proposal for an RCM introduction process

Examples of introduction characteristics related to process phases:

- **Initiation.** In Section 4.7, the initiation of RCM is described. The need for a more effective and efficient way of working with maintenance initiated an asset management plan where, among other things, a maintenance method was to be developed. Inspired by the use of RCM in Norway, RCM was judged to be suitable in view of the requirements established in the asset management plan. This implies that the initiation of RCM could be viewed as a phase in the introduction.

- **Pilot study.** In Section 4.8, the RCM method was tested on one plant in the form of a pilot study. The aim was to evaluate if RCM was a suitable maintenance method and to demonstrate, in practice, how and to what extent routine maintenance costs could be reduced compared to earlier outcomes. This implies that a pilot study could be a phase in the introduction, where the ideas in the initiation phase should be tested in practice, to give information for further planning and preparation.

- **Planning and preparation.** During the Feasibility study stage, see Section 4.9, and during the Execution Stage, see Section 4.10, planning and preparation of the full-scale introduction occurred more or less parallel. For example, how to identify plant systems to be analysed and how to measure progress were issues handled in parallel with training, development of the RCM computer system and the maintenance terminology.

- **Analysis.** As described in Section 4.10.9, the planning and preparation phase was followed up by company-wide analysis work in all the four regions. Therefore, the company-wide analysis work could be seen as a new phase in the introduction.
– **Implementation.** The case study described in Chapter 4 was completed in the beginning of the analysis phase. However, the project group was discussing how the analysis recommendations should be implemented, i.e. how to realise recommended changes in the current maintenance programme. Some thoughts about managing the implementation are described in Section 4.10.8. As the implementation work realises the changes desired, the implementation work could be seen as a phase in the introduction.

– **Living programme.** The project group was also aware of the importance of continuously improving the initial analyses and implementations. In Section 4.10.8, several thoughts and considerations about the management of a so-called living programme are presented. Therefore, the work of obtaining favourable conditions for handling continuous improvements could be seen as a phase in the introduction of RCM.

### 5.3.1 An analysis of the introduction process

When studying the many activities taking place during the introduction, described in chapter 4, the proposed introduction process, with its different phases, seems to be valid. An initiation phase implies that the initiation of RCM could be viewed as a phase in the introduction, with the aim of identifying, already at a conceptual stage, the potentials of and needs for applying RCM. In a pilot study phase the ideas in the initiation phase should be tested in practice, to give information for further planning and preparation. Planning and preparation are activities that aim at developing favourable conditions for the further work on a company-wide basis. As these activities are completely integrated, it may be suitable to view them in one phase. The company-wide work on performing analyses and implementing the analysis recommendations seems to be major task and should preferably be viewed in two different phases. When initial analysis recommendations have been implemented, both analyses and implemented tasks have to be continuously improved. A living programme phase seems to be suitable, with the aim of creating favourable conditions for working with continuous improvements.

### 5.4 Obstacles and driving forces in the introduction process

In what ways a factor affects the introduction of RCM may be viewed as driving forces or/and obstacles, which depends on the criteria mentioned in Section 3.2. For example, if a factor affects resources, costs, time frames, results or commitment, positively or negatively. Below, driving forces and obstacles, based on the managerial factors, will be structured according to what phase they appear in the introduction process, listed randomly within each management
perspective. It has not been possible to study the complete introduction process in the case study. However, potential obstacles and driving forces identified, which may influence the introduction process later on, are also presented. However, there are most likely obstacles and driving forces that will appear that it has not been possible to identify in the case study.

5.4.1 The initiation phase

A maintenance management perspective

- Identification of company needs. An asset management plan pointed out the need for a maintenance method. Even if a clear connection between the company’s needs and the potentials of the RCM method was missing, it was a basis for looking more into RCM by means of a pilot project.

5.4.2 The pilot study phase

An RCM management perspective

- Analysis work. Shortcomings in the competence and experiences of RCM, partly due to little training, resulted in troublesome and time-consuming analysis work during the pilot study.
- Risk evaluation. Acceptance criteria for evaluating the risks were not stated by the senior management. The situation entailed that the risk evaluation could not be completed and was instead based on intuition.
- Preparation. During the RCM analysis, the documentation and information needed were poor, and insufficiently updated. Therefore, the RCM pilot team experienced the gathering of documentation as a very time-consuming task.
- Introduction experiences in practice. During the Prestudy stage analysis recommendations were never implemented, which prevented access to useful experiences for the planning and preparation of the implementation and the continuous improvements.

A project management perspective

- Results. The pilot study generated overarching results that were difficult to evaluate in the form of decreased risks and more efficient maintenance tasks. Also, the analysis recommendations were not implemented. The lack of concrete results made the senior management question the benefits of RCM.
- Resource needs. During the pilot study the senior management questioned the large amount of resources required, which also indicates a decrease in commitment.
- Aims of introducing RCM. The stated aims of the RCM introduction were considered ambiguous among the plant personnel. These conditions resulted in decreased enthusiasm in the RCM pilot team, and later on, also among other personnel at the plant.
A change management perspective

- *Time for analysis work.* The RCM pilot team members had their daily work to do besides the work with the RCM introduction. The situation resulted in difficulties in gathering the group, which led to individual work instead of teamwork.

- *Management involvement.* One reason for not implementing the recommendations from the RCM analysis was the limited involvement by the top management.

5.4.3 The planning and preparation phase

A maintenance management perspective

- *Connections between RCM and maintenance management.* The lack of a maintenance management strategy made it unclear how RCM would fit in with the organisations’ work on maintenance management, which made it difficult for managers and employees to clearly understand why RCM should be introduced.

- *‘Projects in the project’.* Due to a poor maintenance programme important support systems and routines were lacking, for example, a CMMS, a uniform maintenance terminology, and a plant register. These were all major tasks to manage and became ‘projects in the project’, also requiring large resources and work efforts. A plant register turned out to be a precondition for the development of a useful RCM computer system, and also for effective communication between the RCM computer system and other technical support systems, such as a CMMS.

- *Measuring and evaluating RCM progress.* Without a CMMS, it was difficult to effectively measure, follow up and evaluate RCM progress. Since a CMMS had been missing for a long time there was also no analysis of current maintenance performance available at the time of the study.

- *Interest in analysis work.* In the beginning of the planning and preparation phase many of the plant personnel were generally not enthusiastic about introducing RCM with its focus on analysis and optimisation.

- *Planning and preparation for the living programme.* As a maintenance management strategy was lacking it became difficult to plan for systems and routines needed for continuous improvement of the RCM programme.

A project management perspective

- *Resource needs.* The many people involved made the project very costly. Also, the development and purchase of an RCM computer system became a resource-consuming task, where time frames and costs successively increased. Other projects, going on in the organisations in parallel with the
RCM introduction, as well regular work tasks, also needed major resources. These projects and tasks were sometimes more prioritised and affected the resource allocation for the RCM project. The continuous increase of resource needs and delays affected senior management and middle management commitment negatively. Several managers questioned the resources spent and the calculated pay-off time. The top management’s ambiguity about the resource allocation considering RCM introduction to all plants also had a negative influence on regional top and middle management commitment, which in turn influenced employees’ commitment.

- **Introduction focus.** Different aims and goals were defined over time, something that made it difficult to visualise progress and to stay in focus.

- **Scope, aims and purposes.** Many people in the organisations were unsure of the aims, the scope, and the purposes of RCM. This affected their commitment to the introduction of RCM.

- **Internal customers’ needs.** The aims and goals of the RCM introduction were mainly in accordance with senior management desires. Benefits more appealing to other groups of employees were not directly in focus.

- **Introduction strategy.** Lack of a comprehensive introduction strategy made the introduction difficult to manage. The project specifications did not support a holistic management view of the introduction process.

- **Measuring and evaluation.** The lack of maintenance performance documentation made it difficult to compare maintenance performance before, during, and after the RCM introduction. The change of aims and goals during the introduction also made it difficult to know what to measure and evaluate. The lack of a plan or practice for follow-up, measurement and evaluation resulted in low control over the RCM progress and organisational commitment.

- **Project management.** As the project managers were frequently changed, it became difficult to have a smooth progress in the project.

- **Project risk management.** By means of project risk analysis several risks were identified. However, the risk management approach affected the RCM introduction, since many severe risks not were eliminated or sufficiently reduced in time.

- **Benchmarking studies.** As the introduction process became very complex to manage, and also resource demanding, a benchmarking study would probably have been valuable, learning from others’ experiences of obstacles and driving forces.

- **Change management.** The importance of change management was ignored for a long time, since change management skills were lacking in the project group.

- **RCM competence.** The unclear RCM model created misunderstandings within the project group and unclear guidelines for how to proceed with the model development. This affected the analysis work later on and also
became an obstacle to communicating the model with managers and employees.

- **Organisational structure and stages in the project.** A project management model facilitated the introduction as project organisational structure and roles become clear, aiding communication and decision-making. The project managers involved were mainly skilled in project management. This, together with the use of the project management model made it easier to clearly follow the work in accordance with the different stages and steps during the project.

- **Maintenance management skills and competence.** Most members of the project group members were skilled in maintenance and maintenance management issues, which facilitated the understanding of the requirements for a living RCM maintenance programme.

- **Results.** As clear sub-results indicating progress in the introduction were lacking, interest and motivation decreased within the organisations involved.

**A change management perspective**

- **Strategy for managing change.** The lack of a focus and strategy for managing change was a main reason why it became difficult to create organisational commitment.

- **Many projects and reorganisations going on at the same time.** The many projects and reorganisations that were going on simultaneously negatively influenced the general willingness to change.

- **Involvement.** As many regular work tasks were going on parallely, the work situation made it difficult for people in both organisations to participate and devote time and effort to the introduction of RCM. Many of the actors involved in the project had limited time for the tasks they were supposed to do. This affected, among other things, the review procedure. This was also probably a reason why many of the risks identified in the project risk analysis sessions were not managed properly.

- **Resistance.** Especially in the beginning of this phase, the introduction of RCM was by many considered to result in people losing their jobs. This led to a general resistance to the RCM introduction. This phenomenon was especially visible in remote plant groups in the regions. As the introduction of RCM became a cumbersome and long-term project, several employees made parallels to earlier failed improvement projects.

- **Support.** A substantial part of the plant personnel expressed that the purchasers were neither interested in nor supportive of the RCM introduction. They also experienced little support from senior and top management.

- **Training.** The sparse training of VV personnel did not create enough understanding of the method. Furthermore, it generated little interest in being involved in the introduction, for example, in the review procedure. Some
regional top managers and steering group members had too little understanding and knowledge of RCM. This had a negative influence on their commitment to the RCM introduction, as they did not become dedicated to or promoted the RCM introduction.

- **Communication and information.** The difficulties in managing communication and information distribution within the VS organisation were obstacles hindering RCM from becoming a uniform way of working within the whole company. Insufficient information regarding the RCM project promoted the development of rumours that negatively affected the work of strengthening organisational commitment. The information flow from many different initiatives going on parallely resulted in information fatigue among many employees, which affected their involvement and interest in the RCM project. Some senior managers experienced that the large amount of information from the RCM project was difficult to comprehend and that this, to some extent, had contributed to bad decisions earlier. The use of informal communication by one of the project managers made the regional top and middle managers more easily committed. For example, during the informal meetings they could speak and ask questions more freely.

- **Understanding.** For a long time, many of the plant personnel did not understand what was wrong with the current maintenance performance, why the maintenance procedures had to change and become more efficient, and why RCM was a better way of performing maintenance.

- **RCM champion.** The busy situation among managers, and the frequently change of project managers, led to no real RCM champion being available in the project. This contributed to shortages in leadership and clear directions.

### 5.4.4 The analysis phase

**An RCM management perspective**

- **A common way of performing analysis.** Lack of system knowledge among team members and the difficulties of involving I&C personnel made it difficult to achieve a common analysis approach among the RCM teams.

- **Analysis approaches.** The RCM model was interpreted differently among the facilitators, which resulted in divergent analysis approaches.

- **Review procedure.** The reviewers found the RCM model difficult to understand. As a consequence the review procedure did not work as intended.

- **Preparation.** The preparation of the analysis work, for example in developing system descriptions, became a time-consuming task.

- **Probability estimations.** Since historical reliability data were missing, it became difficult to make reasonable probability estimations.

- **RCM computer system.** Without a RCM computer system available, the analysis work became ineffective and strenuous. When the RCM computer...
system became available, it facilitated understanding and made the analysis work more effective, which was experienced by the facilitators.
- **Templates.** The use of standard analyses should make the analysis work more effective and at the same time promote a common way of performing the analyses.

**A project management perspective**
- **Resources.** The regional top and middle managers were not sufficiently committed, as not enough I&C personnel and purchasers of maintenance services were available for the project. Many RCM team members also had to be involved in regular work tasks in parallel with their analysis work.

**A change management perspective**
- **Involvement.** The purchasers of maintenance services, and the technical personnel, had little time for the review procedure during the beginning of the company-wide analysis work, which delayed the implementation of analysis recommendations.

**5.4.5 The implementation phase**

**A change management perspective**
- **Changes in the current maintenance programme.** Since the RCM teams felt that their hard work, performing analysis on time, did not show up in concrete changes in the maintenance programme, their motivation and interest decreased.

**5.4.6 The living programme phase**

**A maintenance management perspective**
- **Routines and guidelines.** The lack of a maintenance management strategy could make it difficult to manage the continuous improvement of the RCM programme as routines and guidelines were lacking.
- **Support system.** Without a CMMS, it would become difficult to manage the analysis recommendations, and implemented tasks, for example, obtaining maintenance plans and packaging of work orders.
- **Integrated work.** The current resistance, in general, to working integratedly between different groups of professionals was seen as major future obstacle to working with continuous improvements of the RCM programme
5.4.7 An analysis of the obstacles and driving forces

Obstacles and driving forces in relation to management perspectives

When studying the obstacles and driving forces above, these are seen mainly to be obstacles that were identified during the case study. However, many times, an obstacle and a driving force are “different sides of the same coin”. For example, the lack of an RCM computer system was an obstacle, as the analysis performance became ineffective and strenuous. When such a computer system was available, it became a driving force. Therefore, obstacles are many times similar to lack and shortcomings in different kinds of preconditions when introducing RCM. The obstacles and driving forces identified in the case study are, on an overall level, in accordance with the findings in Section 3.3.4, and the literature study (Backlund, 2003a). Below, some explanations of the majority of obstacles are proposed.

Obstacles related to RCM management had to a great extent to do with lack of some specific personnel categories and information needed, but also with lack of understanding of the RCM model among RCM teams and reviewers. However, the scope of the case study has not included the complete introduction process, i.e. the analysis phase, implementation phase and the living programme phase. Therefore, it is not possible to fully judge if the RCM management is problematic or not. The reviews of the initial RCM analyses will give a first indication of whether the analyses have been satisfactorily performed. Later on, maintenance effectiveness versus production performance will indicate if the RCM method has been applied correctly.

Many of the obstacles have to do with shortcomings in the current approach to managing maintenance, including maintenance programme and performance. As illustrated in Figure 5.2, managing RCM requires input from the existing maintenance programme, within which recommended new maintenance tasks later on have to be implemented. Therefore, shortcomings in maintenance management have a direct influence on RCM management. As the current maintenance programme and performance were poor, this may be an explanation of the many obstacles related to maintenance management. For example, according to (Steibly, 1995), a critical success factor for introducing RCM is a comprehensive preventive maintenance programme.
Many of the obstacles were related to project management, which can be seen as strange, since most project managers had skills in and experiences of project management, and since a project management model was used. One explanation may be that the activities to be handled by the project management were many and comprehensive. For example, project risk management, benchmarking studies and resource allocation. These kinds of activities often require major efforts to be handled properly, something that was partly lacking in the project. Another reason for the project management’s obstacles was probably the many changes of project managers.

In the Theory Chapter concerning change management, and project management, see Sections 3.3.2 – 3.3.3, different authors stress that managing people is often the most difficult aspect of managing a project. Also, this seems to be particularly difficult in engineering projects, where change management aspects are often underestimated. In accordance with the literature, many of the obstacles in the studied project had to do with shortcomings and deficiencies in managing organisational change. For a long time, the project group lacked skills in change management. Even when such a competence was brought to the group, there did not seem to be enough time and resources for managing change properly. For example, a plan for managing change was not developed. The underestimation of the significance of change management is one explanation of the many obstacles in this management perspective.

**Obstacles and driving forces in relation to the introduction phases**

Very few obstacles and driving forces related to the initiation phase have been identified. An explanation might be that this phase did not include many actors and no “actions in practice”, and therefore should be quite easy to manage. However, during the initiation phase, RCM became of interest for the company.
mainly based on an overall analysis of company needs and the RCM method. There were no real considerations of RCM as a method of working or the implications for the organisation during the introduction and application of RCM. A more scrutinised planning during the initiation phase would probably have facilitated the work in the coming phases to a major extent.

When managing the pilot study phase, the shortcomings in the current maintenance programme and performance seemed not to imply any major obstacles. A main reason could be that during the pilot study, the system analysed was limited and the personnel familiar with the plant. In general, the main problem seemed to be little planning and preparation of the pilot study phase, including, or due to, scarce engagement and involvement from the senior managers.

The planning and preparation phase included maintenance, project and change management issues, with a focus on creating favourable conditions for the coming phases. Most of the obstacles were identified during this phase, which indicates that this phase is one of the most significant in the introduction process.

The analysis phase mainly includes obstacles and driving forces seen from an RCM management perspective. However, all of the obstacles and driving forces in this phase are directly related to the obstacles and driving forces in the planning and preparation phase. That is also true of the implementation phase and the living programme phase. The links to the previous planning and preparation phase also indicate that this phase is a most critical phase in the RCM introduction process. However, it should be kept in mind that the further phases have not been fully studied in the case study.

Very few obstacles and driving forces were identified in relation to the implementation phase. An explanation might be that this phase had not yet been started during the case study. Even so, the scarce attention paid to the implementation phase indicates that the project group did not consider it to be very difficult to manage. However, according to several literature sources, for example, Smith (1993) and August (1997), the implementation of analysis recommendations in a current maintenance programme can be one of the main major obstacles when introducing RCM.

The living programme phase was neither studied during the case study, nor directly planned for. Therefore, few managerial factors were identified as influencing this phase.
In general, it is difficult to comprehend the effect of driving forces and obstacles on the phases that had not been completed during the case study. For example, the resistance among personnel during the preparation, when people were afraid of losing their jobs, could also contribute to bad analysis performance and problems when implementing the new maintenance tasks.

5.5 Case study discussion and conclusions

The managerial factors identified in the case study mainly influence the introduction of RCM in the form of obstacles. As the many obstacles identified can be explained by different causes, they clearly indicate that introducing RCM on a full-scale basis is a complex and demanding task. As stated earlier, the lack or shortcomings in the current maintenance programme and performance are a main reason for many of the obstacles. This implies that even if the introduction of RCM is troublesome and to some extent may be seen as ‘failed’, many tasks are handled, which are essential for a company wanting to perform effective and efficient maintenance management.

As many obstacles, as well some driving forces, have been identified, it might be of interest to point out the most significant or critical obstacles and driving forces. However, the obstacles and driving forces in Sections 5.4.1 – 5.4.6 are strongly related. One obstacle, or driving force, can generate other obstacles and driving forces, within and between factors and maintenance perspectives. Therefore, a classification of significant obstacles and driving forces seems not to be possible or practicable. Managing the introduction of RCM has to be based on a holistic view, where all the obstacles and driving forces identified are of importance.

The theoretical propositions stated in Section 3.5, have all been confirmed in the case study analysis. This implies that an introduction of RCM can be facilitated by means of, see also Figure 5.3:

- **Management perspectives.** The management perspectives indicate what kind of competence is needed to manage the introduction.
- **Factors.** The awareness of different managerial factors that influence the introduction facilitates the identification and management of different obstacles or driving forces.
- **An introduction process.** As obstacles and driving forces can be managed in different phases in an introduction process, the introduction becomes more manageable and controlled.

A successful RCM introduction, on a full-scale basis, seems to require a holistic view where the introduction phases, the management perspectives and the factors are considered jointly. The findings from the case study analysis can be
used as a basis for the development of an RCM introduction strategy, which is the aim of the research project. However, the findings should be validated with other hydropower companies introducing RCM, so as to obtain a more generalisable introduction strategy.

![Diagram](image)

**Figure 5.3.** A successful RCM introduction, on a full-scale basis, seems to require a holistic view where an introduction process, management perspectives and managerial factors are considered jointly.
6 A MULTIPLE-CASE STUDY AND EMPIRICAL VALIDATION

*In this chapter the findings from the longitudinal single-case study, described in Chapter 4 and 5, are compared with a multiple-case study.*

The aim of the multiple-case study, including examinations of RCM introduction in three hydropower organisations, is to validate the findings in the single-case study. According to the reasoning in Section 2.3.1, the goal is to make literal replication, i.e. if two or more cases show upon similar results.

The information from the multiple-case study was mainly collected during interviews with project group members in the respective company. A comprehensive description of the RCM introductions in the multiple-case study has not been within the scope of this thesis. Instead the focus is on managerial factors, obstacles and driving forces. The information from each case, presented in this chapter, is based on a description of the multiple-case study, see Backlund (2003b).

6.1 The organisations and maintenance management

6.1.1 BC Hydro

As one of the largest electric facilities in Canada, BC Hydro, serves more than 1.5 million customers. Approximately 90 percent of BC Hydro’s generation is produced by hydroelectric means. BC Hydro’s 30 hydropower plants, one conventional thermal station and combustion turbine stations provide a total installed generating capacity of over 11,000 MW. Between 43 and 54 TWh of electricity is generated annually from the power plants. The power plants are located within the regions of Lower Mainland, Coastal, Columbia, Peace, and Vancouver Island. BC Hydro is owned by The Province of British Columbia and operates on a deregulated market.

**Background to the initiation of maintenance improvements**

An aging fleet of generating assets, increased demands to push the equipment harder in response to commercial opportunities, and static or declining maintenance budgets, all contributed to the increase of risks associated with continuing to maintain equipment using preventive maintenance practices. For a long time there was a major focus, from the senior management’s side, on decreasing maintenance costs. Earlier experiences of over-maintained plants,
where it had been possible to cut costs without any serious consequences occurring for the assets, led to a general focus on cost reductions. However, in the end of 2002, the CEO formally announced maintenance management as a prioritised area within BC Hydro. BC Hydro lacked an overall comprehensive review of work tasks and their frequency based on logic that maximises the benefits from doing maintenance. As also regulatory issues became more pronounced the documentation in the maintenance programme became more and more important.

6.1.2 Statkraft
Statkraft is a power company that owns, wholly or partly, 91 hydropower plants in Norway. The company is responsible for operating 55 of these plants. In total, Statkraft produces approximately 34 TWh, amounting to 30 percent of the country’s electric power production capacity. The plants are situated in four regions: North Norway, Mid Norway, West Norway, and East Norway. The Norwegian power market was the first in the world to be opened up to general competition. Statkraft is a wholly state-owned power company but operating on a deregulated market.

Background to the initiation of maintenance improvements
Even though maintenance requirements differed among the Statkraft plants, maintenance was performed similarly among all plants. In the long run, the approach generally combined too much preventive maintenance of systems and equipment that could be considered uncritical. Statkraft had valued the different plants equally for many years, but started to valuate the plants differently according to their significance for production. That was also a trigger for looking for a way of performing maintenance in accordance with the significance of a specific plant. As many people will be retired in the maintenance organisation before the year 2010, Statkraft find them selves forced to develop a more effective ways of working with maintenance management.

6.1.3 Snowy Hydro
Snowy Hydro Ltd., former Snowy Mountains Hydro-electric Authority, is located in Australia’s Southern Alps in an area of 8,200 square kilometres. Snowy Hydro is a corporative organisation working within the National Electricity Market and supplies 76 percent of the renewable energy available on the eastern Australian mainland electricity grids. The seven hydropower plants generate an average of 5 TWh of electricity each year. Snowy Hydro has a generating capacity of approximately 3,800 MW, which means that it has the capability of providing up to 11 percent of the total power requirements of Mainland Eastern Australia. However, it is not possible to sustain high levels of generation continuously, because of a limited supply of water into its reservoirs.
Consequently, it provides a considerably lower proportion, approximately 3 percent, of the total energy production in the National Electricity Market for the eastern Australian mainland. Broadly, the hydropower plants are located in two regions: The Snowy Murray Diversion, where three power plants are located, and The Snowy Tumut Diversion, with four power plants.

**Background to the initiation of maintenance improvements**
Before 1993, there were many employees at Snowy Hydro. Due to shortcomings in the maintenance performance the hydropower plants were generally over-maintained. As the situation became clear, key business drivers to reduce the costs of production, such as reducing maintenance costs and decreasing the labour staff, were initiated by the senior management.

**6.1.4 Summary of company characteristics**
Some characteristics of the organisations involved in the comparison are summarized in Table 6.1.

*Table 6.1. Some characteristics of the organisations involved in the comparison. Vattenfall is also included in the presentation, as comparisons will be made with the case study on Vattenfall in a coming Section.*

<table>
<thead>
<tr>
<th>Companies</th>
<th>Plants and time period for construction**</th>
<th>Regions</th>
<th>Generating capacity (MW, approx.)</th>
<th>Production per year (TWh, in average)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vattenfall</td>
<td>54 (1920 – 1980)</td>
<td>4</td>
<td>8500</td>
<td>33</td>
</tr>
<tr>
<td>BC Hydro</td>
<td>30 (1915 – 1985)</td>
<td>5</td>
<td>11000</td>
<td>48</td>
</tr>
<tr>
<td>Statkraft</td>
<td>55* (1905 – 1995)</td>
<td>4</td>
<td>9000</td>
<td>34</td>
</tr>
<tr>
<td>Snowy Hydro</td>
<td>7 (1955 – 1973)</td>
<td>2</td>
<td>4000</td>
<td>5</td>
</tr>
</tbody>
</table>

* Totally 91 plants, but Statkraft is responsible for operating 55 of these plants
**Reinvestments in plant systems occurs continually
6.2 Milestones in the RCM introduction

The introduction progress in the three hydropower organisations will be referred to according to the introduction process in Figure 6.1.

<table>
<thead>
<tr>
<th>Initiation phase</th>
<th>Pilot study phase</th>
<th>Planning and preparation phase</th>
<th>Analysis phase</th>
<th>Implementation phase</th>
<th>Living programme phase</th>
</tr>
</thead>
</table>

Figure 6.1. An RCM introduction process.

Some milestones in the three RCM introduction processes will be presented. However, it is a question of definition when some phases begin and end, when the planning and preparation of full-scale introduction begins, and where and when the pilot studies were completed. However, the estimations should give an indication of the activities within the different introduction processes:

- **BC Hydro.** During the pilot study phase, four different pilot studies were performed. One was in 1990, but was not followed up. Two pilot studies were made between 1995 and 1998, and one in 1999. Based on these pilot studies, a planning and preparation phase started in 1999. The analysis phase, which is highly integrated with the implementation phase, begun in 2002.

- **Statkraft.** Statkraft initiated a pilot study in 1993, which was completed 1994. A company-wide introduction was supposed to emerge from the pilot study experiences, but faded away. Between 1999 and 2001 two new pilot studies were performed, followed up by an analysis phase and implementation phase 2002.

- **Snowy Hydro.** Snowy Hydro performed a pilot study in 1993 – 1995. A planning and preparation phase was performed between 1995 and 1997, followed up by an analysis phase and implementation phase between 1996 and 1998. The living programme phase was begun in 1998.

Snowy Hydro was the only company that began the living RCM programme phase. Even if the other companies, including Vattenfall, had started their pilot projects during different time periods, and had performed different numbers of pilot studies, they were all more or less in the analysis and implementation phases at the time of the study.

6.3 Introduction experiences and characteristics

The findings of the multiple-case study are structured according to the management perspectives and the factors in Table 5.2. The findings are summarised and presented in Table 6.2. An additional factor, identified during the empirical validation, is italicised in the table.
Table 6.2. The findings of the multiple-case study are structured according to the management perspectives and the factors from the analysis of the single-case study. An additional factor, identified in the empirical validation, is italicised.

<table>
<thead>
<tr>
<th>Factors affecting RCM introduction</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>RCM management</strong></td>
<td><strong>Maintenance management</strong></td>
</tr>
<tr>
<td>RCM team competence</td>
<td>Strategic maintenance management</td>
</tr>
<tr>
<td>Analysis performance approach</td>
<td>Maintenance programme and performance</td>
</tr>
<tr>
<td>Documentation and information</td>
<td>Maintenance culture</td>
</tr>
<tr>
<td>RCM computer system</td>
<td>Outsourcing of maintenance</td>
</tr>
<tr>
<td><strong>The view of RCM</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Project management</strong></td>
<td><strong>Change management</strong></td>
</tr>
<tr>
<td>Planning</td>
<td>Planning and preparation for managing change</td>
</tr>
<tr>
<td>Introduction strategy and approach</td>
<td>Commitment and support</td>
</tr>
<tr>
<td>Monitoring and control</td>
<td>Work situation</td>
</tr>
<tr>
<td>Measuring and evaluation</td>
<td>Behaviour characteristics</td>
</tr>
<tr>
<td>Resources</td>
<td>Involvement</td>
</tr>
<tr>
<td>Project risk management</td>
<td>Training</td>
</tr>
<tr>
<td>Benchmarking studies</td>
<td>Information and communication</td>
</tr>
<tr>
<td>Project group competence</td>
<td></td>
</tr>
</tbody>
</table>

6.3.1 RCM management

**RCM team competence**

During the first pilot projects at BC Hydro the people involved were not sufficiently familiar with the RCM method, and the consultant involved was not familiar with hydro equipment. At Statkraft, the first pilot involved a consultant as facilitator, who had skills from using RCM analyses in other kinds of industries. Also at Snowy Hydro a consultant was involved during the pilot study, together with an RCM team consisting of plant personnel and one senior engineer.

During the analysis phase all companies mainly used maintenance engineers as facilitators, but consultants or trade persons were used on some single occasions. However, due to lack of cooperation between trade representatives and the engineers at Snowy Hydro, one of the senior engineers in the project group considered it better using a trade person as a facilitator, to improve the
conditions for teamwork. At Statkraft four maintenance engineers assumed the role of facilitator. Since these persons had no direct relation to the maintenance personnel, this was considered to facilitate the making of ‘objective’ analyses. Based on the experiences from the pilot studies the project group at BC Hydro expected that the introduction of RCM would lead to a cultural change within the maintenance organisation. Therefore, the consultants were not used as facilitators in the ongoing analysis work, with the aim of improving the conditions in order to produce a living programme.

At Statkraft operators were occasionally involved to be interviewed by the RCM team. The maintenance personnel would be involved both during the analysis and the packaging of work tasks. The members involved in the RCM teams were mainly maintenance planners, mechanics and electricians, maintenance engineers and engineers from the technical staff. However, these categories of personnel were not involved all the time, and about three persons were involved at the same time. The project group considered that the regional managers in general picked out suitable people for the project, personnel with long experience and good skills. However, the level of competence and skills among the RCM team members was not really satisfactory, and more training was desired. That had to do mainly with previous resource limitations, which limited the costs of training.

At BC Hydro, the involvement of both trade people and engineers was expected to improve the skills in the failure mode analysis, and also lead to a better understanding of the equipment among the staff. At Snowy Hydro the RCM teams consisted of four to six people, a facilitator, an engineering specialist and maintenance personnel. Three facilitators led the analysis work at approximately two plants each. However, when trying to restart the living programme phase, it became difficult to find people skilled in RCM.

**Analysis performance approach**

All companies used a classical RCM model as a basis for their analysis work. A main driving factor introducing RCM at Snowy Hydro was to capture the knowledge available in the current organisation, due to the major reductions in personnel during 1990 to 1999. That was an important reason why a streamlined RCM model was not used.

In all companies it was noticed that the RCM analyses made during the first pilot project were characterised by too many details, covering an excessive number of systems in a plant. This was in general not approved of by senior managers, who considered that the analysis work was too time and resource consuming. Therefore, all companies focused on, in different ways, making the RCM analysis work simpler, user-friendlier, more effective, and less resource
consuming. At Statkraft they had been talking about “RCM light”. One way to make the introduction process more effective at Statkraft was to have the technical engineers identify the most relevant and critical failure modes for the most critical equipment. Only these were to be targeted for detailed RCM analysis. At BC Hydro RCM was to be applied to critical equipment required to produce electricity, including some auxiliary equipment. The project group at BC Hydro did not consider it meaningful to make comprehensive analyses of some of the smaller plants, however, where templates or streamlined RCM versions were considered to be more suitable. At Snowy Hydro RCM was first to be applied to all critical systems in every plant, mainly turbines, generators, and transformers. Auxiliaries and software systems were not in the scope of this project. The remaining systems were to be considered only in the living programme. At BC Hydro the project group tried to make the analysis teams avoid too extensive analyses and focus on ‘creditability failures’, i.e. failures with a high probability of occurrence. However, several of the analyses became either too superficial, or too deep, where a system analysis by one RCM team could take approximately three times longer to perform by another RCM team.

All companies experienced some difficulties in finding an appropriate level of analysis, and also to control that the analyses made remained at a specific level. Since the level of detail affected the resources needed, the project group at BC Hydro considered that this was a very important issue. However, they did not really know how to decide which level was appropriate. A general approach was to avoid too many details in the initial analysis, and instead postpone the final choice of level of analysis until the living programme. Another problem was that traceability differed between the analyses made in the RCM teams. For example, function failures were not always documented when the RCM teams focused directly on the failure modes. This was also seen as an activity that could be improved in the following living programme. The project group at Statkraft also looked into maintenance tasks based upon internal and external requirements that were not to be analysed until the living programme. In general, the project group at BC Hydro considered RCM a dynamic process and it was not considered effective to make perfect analyses the first time, a view shared by Snowy Hydro.

Snowy Hydro experienced that the identification of failure modes at the equipment level was generally easy, but evaluating the impact on the system level was more difficult. While the identification of failure modes was manageable, finding measures to handle the failure modes became a tedious activity. Failure modes and maintenance tasks were considered easy to document. However, the huge number of other analyses and considerations needed to make it become an RCM based maintenance programme were more
difficult to handle. Many assumptions had to be made, which affected the traceability.

None of the companies had developed analysis templates. Statkraft had a similar function in their RCM computer system, which made it possible to use analyses made for similar plant systems. They also thought that the traceability was good due to the computer system.

During 2002 the business focus changed in Snowy Hydro from decreasing production costs towards maintaining the highest level of availability. The situation affected previous RCM analyses, as they were based on the previous business driver focused mainly on decreasing maintenance costs.

**Documentation and information**

All companies experienced, to a greater or lesser extent, problems due to shortage of documentation and information, such as reliability data and system description, although this could differ between the plants. At BC Hydro the project group emphasised that they had people available who were very familiar with the different plant systems, and could identify function descriptions. However, the project group experienced difficulties in identifying and documenting system boundaries, i.e. why systems were limited in the way they were, and why they belonged to some specific overall systems. The project group at Statkraft emphasised the importance of documentation and information being available when starting up the analysis work. However, it was not managed in any way by the group. Instead, the RCM teams had to identify by themselves what information and data they needed. Previous work with function coding, in the CMMS, generated system descriptions to some extent. Due to the shortages of information, gathering accurate reliability data could be a time-consuming activity within the RCM teams. This was something that the project groups at BC Hydro and Snowy Hydro emphasised and tried to avoid. For example, at Snowy Hydro, the RCM teams based the analyses on the information available at that time, and also used information collected from the other plants. The accuracy of the information was to be improved during the living programme.

**RCM computer system**

At BC Hydro, one reason for the time-consuming analysis during the pilot studies was that an RCM computer system was not available at that time. Later on they purchased an RCM computer system called RCM Turbo, on advice from Snowy Hydro that also used it. Statkraft also experienced the importance of an RCM computer system to perform analyses effectively. As the Project group had very clear requirements on an RCM computer system they developed their own support as a module in their CMMS, which facilitated the information transfer.
between the two systems. The RCM computer system was also connected to a plant register and a plant evaluation list. A list of different condition-based maintenance techniques was also developed to support the decisions on suitable preventive maintenance tasks, based on the overall recommendations via the RCM analyses.

6.3.2 Maintenance management

Strategic maintenance management
The initiations of RCM in all the three organisations were preceded by the development of one or several asset or maintenance management strategies. RCM was seen as a core structure to support and redevelop an effective and efficient planned maintenance programme. The project group at Snowy Hydro emphasised that RCM was a part of the business process, i.e. a maintenance management process, including issues such as skills, culture, communication, optimisation techniques and a routine maintenance programme. The initiator of RCM at Statkraft pointed out the significance of a strategic document emphasising that RCM is a core structure in maintenance management, as it makes senior management committed to the project and a forthcoming introduction of RCM.

Maintenance programme and performance
At Snowy Hydro, before the introduction of RCM, maintenance performance involved to a high degree unplanned corrective maintenance, while at Statkraft too much preventive maintenance was performed on rather uncritical systems. At BC Hydro and Statkraft the documentation of maintenance tasks varied between the plant groups. Some had comprehensive documentation available, others had not. In general, the maintenance performance lacked documentation for reviewing maintenance results and failures. At BC Hydro, some plants were significantly bigger and newer than other plants. At the bigger plants there were a large number of personnel available, as well as newer technology, better access to computers, good documentation, and relatively good maintenance instructions. The maintenance groups worked comprehensively and focused on preventive maintenance, and had people with maintenance expertise available. The maintenance performance at the smaller plants was, on the other hand, based on very old equipment and systems. At Snowy Hydro maintenance personnel did not in general, after the initial RCM analysis and implementation, make analyses such as checking if failures occurring were new or if a discovered failure mode had been identified earlier in the RCM analysis.

The CMMS at BC Hydro was a module in a business software system. The software system was not appealing to the maintenance organisation that had more or less been forced to use it. Trying to make it user-friendly was a “core
struggle” for the project group to deal with. The CMMS was not only making the RCM troublesome. The CMMS was also connected to many other types of software, such as equipment health indices, and to the use of lubrication programmes. The CMMS at Snowy Hydro was 15 years old and did not fulfil the requirements for working with continuous improvements in a structured way. It was going to be replaced during 2003. Measuring and evaluation depended on people in the field reporting correctly in the CMMS, something many did not do. The maintenance staff at Statkraft was also working a lot on teaching and training the personnel about the importance of reporting the different maintenance activities in a correct manner, which was seen as a basis for working with continuous improvements. At BC Hydro, the CMMS did not support maintenance instructions to the crews as intended. This problem caused a major obstacle in the RCM introduction. Implementing the new maintenance recommendations from the RCM analysis, in the current maintenance programme, was considered to be a major challenge. Among other things, delivering maintenance instructions based on the RCM analyses, via the CMMS, was a major problem. Snowy Hydro also experienced it as a major task to link the computer system with the CMMS, to get traceability all the way. Due to further improvements of the CMMS at Statkraft, where the RCM computer system became a module in the CMMS, there were no problems with the communication between the CMMS and the computer support.

Maintenance culture
The plant personnel at BC Hydro and Statkraft were in general of a high average age, and many people were to be retired within a period of 10 years. At Snowy Hydro major reductions in personnel had taken place during the years 1993 to 1999, and many older people had left the company. Several of the older employees at BC Hydro had limited background knowledge of maintenance work. They had been employed during the construction time of the plants, and had later on become operators dealing with maintenance and electrical issues. At Statkraft, the maintenance personnel, such as the mechanics, were often self-taught in maintenance and maintenance thinking, and maintenance management was generally lacking. However, some change was seen when younger people started to work in the organisation. The different plant group cultures forced the project group to spend a lot of time on preparation efforts, to build up a common view on RCM. Some plant groups considered that the maintenance performance was sufficiently good already. However, at the end of the planning and preparation phase, most of the employees understood that the current maintenance programme had to be changed.

All companies had the experience that the importance of analysis work, optimisation, and continuous improvement activities was not comprehended or appreciated by many people, especially older trade workers. They preferred
working with maintenance in the way they had done for many years, i.e. ‘hands-on’ based on and according to turnouts. The trade representatives did not always have the necessary competence to perform analysis work either. Several of the maintenance personnel at Statkraft and Snowy Hydro considered that the plants should be maintained more extensively. According to a senior engineer at Snowy Hydro, one reason for this kind of maintenance culture was the 50-year-old organisation, influenced by a “construction culture” where plants and plant systems were to be in an excellent shape, but where the people involved were not originally skilled in maintenance. At Snowy Hydro it was to some extent difficult to get operators and maintenance personnel to co-operate. The confidence in the maintenance staff was also insufficient. Also, the project group thought that many times the personnel did not do the job they were supposed to in the RCM project.

Outsourcing of maintenance
None of the companies had outsourced the management of routine maintenance.

6.3.3 Project management

Planning
The overall aim of introducing RCM at BC Hydro was to obtain an optimised planned maintenance programme, a new way of working with maintenance management. The overall aim of introducing RCM at Statkraft was to control the maintenance performance of individual plants. In that way, they would be able to take bigger risks, increase the proportion of planned corrective maintenance, and focus on preventive maintenance of critical systems and equipment. The overall aim at Snowy Hydro was to use RCM as a tool for customising the routine maintenance plans for the plants. In that way more effective application of maintenance resources was to be ensured and hence in return improved main plant capability, and enhanced plant safety.

All companies had as main goals to decrease costs for routine maintenance, but also to increase availability. At Snowy Hydro, the focus had mainly been on decreasing production costs, but due to change in business focus during 2002 the highest level of availability became a new business driver. Snowy Hydro and Statkraft emphasised RCM as a tool for continuous improvement within a living RCM programme. BC Hydro and Statkraft recognised that the work with RCM made it possible also to decrease the fees of insurance. For example, at BC Hydro, the insurance companies demanded that a maintenance engineer should be involved in the systematic maintenance requirement identification, something that would be fulfilled with the use of RCM. Some other objectives and goals defined in the beginning of the project at BC Hydro were:
- Increased revenues, improved resource management and shortened equipment down times.
- Controlled costs by increase of the effectiveness of maintenance spending and help to avoid significant increases in future equipment-related costs.
- Reduced risk of incurring forced outages, the number of events requiring unplanned corrective maintenance, and preserving equipment life, i.e. extending overhaul intervals.

Other main drivers and goals of introducing RCM at Statkraft were:
- The need for a tool for maintenance optimisation.
- The identification of critical failure modes concerning safety and environment.
- Clear maintenance specifications.

None of the companies had clear and measurable goals for “intangible” outcomes and benefits of using RCM, even if they were aware of the potential of such intangible benefits. For example, both BC Hydro and Snowy Hydro saw RCM as a way to make maintenance competence and experience stay in the company, before it was lost through attrition of maintenance personnel. All companies recognised the knowledge and learning capabilities connected with introducing RCM, for example, improved plant system knowledge among the employees. Statkraft also believed that RCM could improve co-operation between operations and maintenance. The project group at Statkraft believed that the intangible benefits would increase the outcomes of the RCM efforts in the long run. RCM was introduced during major reductions in personnel at Snowy Hydro. The project group emphasised that introducing RCM was not a way to justify reductions of the maintenance workforce and maintenance expenditure. However, RCM was needed to work more effectively in an organisation with fewer people.

Introduction strategy and approach
None of the companies had developed a comprehensive introduction strategy. The RCM introduction approach at BC Hydro was developed on the basis of experiences from the pilot studies. RCM was to be introduced at all plants, where six to seven RCM teams would work concurrently at selected locations. In that way, it would be possible to exchange information and results, and build on results as they were generated. The sequence of plants to be analysed within the project was to be determined on the basis of the importance of the plants. The project group considered that one main reason for the failed or problematic pilot studies had been that no approach or strategy was available to make it a living programme. It would be the role of plant maintenance engineers to keep the RCM programme current. However, a concrete plan, to facilitate the living
programme phase, was not developed during the introduction and planning phase, but was to be dealt with during the analysis and implementation phases.

Even if the pilot studies were problematic and lacked results, the experiences gathered were used to plan for a full-scale introduction at Statkraft. The project group was looking for an approach to be able to manage the implementation phase successfully. The overall responsibility for the continuous work would rest on the maintenance staff. However, the project group did not know in what way they should make the plant groups obligated to take care of the results of the project, and to continuously improve the initial analyses. The main approach was to make the plant teams understand the importance of a living RCM programme, and to make them understand what they were going to handle and take care of.

The many years of working with the RCM introduction gave valuable insights for the project group at Snowy Hydro. The group emphasised the importance of looking early on the RCM introduction in a holistic way, and to clearly set plans for how to work with continuous improvements. Such an approach would make the introduction process more stable, and easier to start up again if some major obstacles were preventing progress. The project group also comprehended the importance of aligning RCM with strategic issues and that it had to be performed within a long-term strategy. Snowy Hydro used an introduction approach with discrete projects, where analysis and implementation were performed in about two plants per year. However, this introduction approach was experienced as a “major push” by the project group, which considered this approach not the right way to go. When the living programme phase would be started again, they would most likely running smaller subprojects over the years.

Control and monitoring
To ensure that all RCM teams followed a standardised way of working and to control that the introduction process proceeded according to schedule, the project group at BC Hydro was in contact with the teams every two weeks. However, they could still see that analysis performance differed between the teams and it was a challenge to get the teams to analyse in the same way. It was also a problem to make the reviewers review the analyses in a similar way.

During the first attempt to introduce RCM on a full-scale at Statkraft, the introduction was not performed within a project organisation, but was a part of the overall work with continuous improvements. The regions worked with the introduction process more or less by themselves for several years, and progress was not followed-up. Consequently, the efforts faded away over the years. However, during the second attempt a project organisational structure was used. The project group was responsible for a similar RCM performance in the
different RCM teams. The RCM introduction was also to be controlled by the regions themselves. The project group reported to a steering group each month. The project group also had to evaluate the progress to be able to make adjustments, for example, of the RCM computer system and the RCM analysis performance.

Due to many changes between centralised and decentralised organisational structures at Snowy Hydro, it took a long time before someone was made responsible for managing the living programme phase.

**Measuring and evaluation**

The status of the maintenance performance at BC Hydro and Snowy Hydro was not evaluated sufficiently for it to be a basis for comparison of the future maintenance performance based on RCM. At BC Hydro and Statkraft a ‘pre-evaluation’ was to be performed based on analyses of the first plants for which the implementation phase was completed. A problem was that no plan was developed for measuring and evaluating the RCM introduction progress, and measuring criteria were lacking. Both companies looked at such plans during the analysis and implementation phases. They considered that it would take at least one to two years before it would be possible to show any results. However, the project group at Statkraft emphasised that it was very important to quickly present results in order to keep the management and the workforce motivated. No cost-benefit analysis had been made, but they were going to calculate costs and benefits based on two plants in the ‘pre-evaluation’. The project group at BC Hydro considered that intangible outcomes were difficult to measure.

At BC Hydro, the evaluation was also difficult to perform due to the poor CMMS making it problematic to extract data from the RCM analyses. They were also somewhat uncertain about what criteria to use in order to assess whether the RCM introduction had been successful or not. In fact, measurement of benefits associated with successful project introduction was really out of the scope for this project. During the living programme, the management group at Snowy Hydro felt that the feedback loop did not work well, and it was difficult to find a way to measure and evaluate. It was also seen as an obstacle to judge what improvements could be traceable to RCM.

**Resources**

The introduction of RCM became a significant challenge for BC Hydro. Some reasons for this were that a number of initiatives were being made at the same time, maintenance engineers were understaffed, and the general workload was high. Failure to assign adequate resources to conduct the project, and to establish the necessary conditions for a living RCM programme, was seen as a major risk. It was not difficult to appoint facilitators. However, since they were occupied
with daily operations, problems arose when trade people, such as mechanics and electricians, became involved. Technical experts were also difficult to find, and the project group had to involve retired people to assist where ordinary people were not available. The sequence of plants to be analysed within the project was, among other things, to be determined on the basis of the ability of the plant staff to allocate resources during a particular time period. Due to a decreased allocation of resources for the project, the project group had to change the time frames for the project. It was estimated that approximately half of the plants would have completed the implementation phase before the original time for project completion. They considered that the difficulty in getting the resources needed had to do with the strategic nature of the project, where the goals were settled in a long-term perspective. Another circumstance that affected the resource allocation was a change of project sponsor during that introduction phase. The new sponsor was not engaged in the project as the precursor. This also affected the general support from senior management.

The RCM introduction at Statkraft was performed as a project, but did not include a project budget, i.e. the different regions had to find other funding for the money and resources needed. This involved rather difficult decisions considering resource allocation from other regular work projects in their region. However, at the end of the planning and preparation phase, the resource allocation for the project was fairly good. The main reason was that the top management considered the RCM project to be the most prioritised project going on in Statkraft at that moment. At the same time several other projects were going on. For example, a major project was the development of a “production management system”. Later on, in 2004, there was a risk that the production project and the RCM project would “compete” about the same resources.

At Snowy Hydro, the three discrete projects were justified on their economic merits. For a project to be allowed to proceed, it had to demonstrate that the funding allocated to the project would provide an adequate return on the investment.

**Project risk management**

No formal project risk management procedure was used among the companies. However, Statkraft had done that before, during pilot studies, and because adjustments had been made on the basis of the pilot studies, and in the planning and preparing phase, it was determined that there was no need for a formal project risk analysis.
Benchmarking studies
None of the studied companies had performed benchmarking studies. The project group at Statkraft and BC Hydro thought that the experiences of the pilot studies gave enough information.

Project group competence
The RCM project group at BC Hydro consisted of a project manager, skilled in maintenance engineering, and a mechanical engineer, skilled in reliability engineering. Both were familiar with the technology at the plants. The project manager had also worked earlier at some of the plants as a maintenance engineer. Approximately seven maintenance engineers in 10 maintenance groups, located in some of the five regions, were subordinated to the RCM project group. The maintenance engineers were in charge of the RCM introduction progress at their specific locations.

A senior maintenance engineer, with a background in mechanical engineering, became project manager at Statkraft. He had been working with maintenance and maintenance management for a long time at department level, for example, as a maintenance manager in the paper industry. Other people involved in the project group were mainly four maintenance engineers, one located in each region. The project organisation also included a steering group, including the technical manager and the four regional technical managers. The project organisation also contained a reference group consisting of engineers from other technology fields, experienced people working with mechanical, electric and construction issues.

The introduction of RCM was conducted as three different projects at Snowy Hydro, each led by a senior engineer. The senior engineers worked mainly with asset maintenance management issues, and could be seen as a project group. One of these engineers was later put in charge of the living programme phase.

6.3.4 Change management
Planning and preparation for managing change
None of the companies had performed comprehensive planning and preparation for managing the organisational change in connection with the introduction of RCM.

Commitment and support
Based on experiences from the previous pilot studies, one of the project goals at BC Hydro was to gain the personnel’s acceptance of the RCM programme. In the beginning of the planning and preparation phase some risks that could have an affect on organisational commitment, i.e. withdrawal of management and
workforce commitment to completing the programme, were acknowledged. These risks were:

- Incomplete communication of project goals, the RCM process, and time estimates to all stakeholders at the management level.
- Time and cost frames significantly exceeding estimates.
- Pressure of more urgent work causing resources to be diverted.

The middle managers at Statkraft were an important part of the support and coaching in the regions. The project group at Statkraft emphasised that if the top managers were not fully involved in the project, the middle managers would not be either. However, the top management was not sufficiently involved in the full-scale introduction, which was begun after the first pilot project. Consequently, the RCM introduction efforts faded over the years, and were not followed up. One contributing cause was that the technical manager, who was also the RCM initiator, left the organisation shortly after the pilot project completion. However, all companies experienced decrease in senior management commitment due to overly resource demanding analysis performance during pilot studies.

During the main part of the planning and preparation phase at Statkraft, a majority of the employees, and some members of the senior management group had a sceptical attitude towards the introduction of RCM. Therefore, it became somewhat difficult to get people to work in the RCM teams. At the end of the planning and preparation phase support and interest from the top management was, however, satisfactory. Maintenance issues and RCM had become issues on the agenda for the top managers in the regions, and also for the management at division level. Even so, the project group believed that it would take at least one year before the main part of the employees and management would be fully committed to RCM. Not before then could results be presented.

In connection with a sponsor change, the senior management questioned the RCM project at BC Hydro. On one occasion the project manager was forced to defend the project. The difficulty in getting the resources needed was explained by the project group as a result of the strategic nature of the project, where the goals were settled in a long-term perspective. Commitment among the technical managers was also lacking to some extent, which led to difficulties concerning the availability of technical expertise in the project.

The project group at Snowy Hydro did not initially experience any difficulties in getting senior management commitment for the introduction of RCM. Also, in the beginning of the RCM introduction, the senior management believed that introducing RCM would initially solve “all” problems in maintenance
performance. However, the long-term approach was difficult for some senior managers to accept. This became an obstacle to getting enough resources for accomplishing sufficiently good conditions for the continuous improvements. For example, as the maintenance performance improved, it became difficult to make the senior management understand that the organisation also had to continuously improve the work with RCM. A Maintenance Award\(^9\) received in 1998 made it actually more difficult to make the management realise that they had to spend more money on RCM and maintenance improvements. Mainly due to a major reorganisation the progress in the living programme phase declined, and people began losing interest in RCM. As new employees became involved in the continuous work with RCM, many did not have any feeling of personal ownership of the analyses made, and the analyses were questioned due to lack of traceability. The workforce commitment was thus seriously affected.

**Work situation**

At BC Hydro a major reorganisation was going on during the planning and preparation phase. During the analysis and implementation phases another major reorganisation started, which was expected to have a huge impact on BC Hydro’s entire business performance. The project group experienced the present understaffing and the number of new initiatives being undertaken in the BC Hydro organisation as a significant challenge. The project group saw a major risk for the management of the RCM introduction, related to the high workload. The best conditions for a genuine shift in maintenance performance due to RCM were most likely to be found at those plants where they had time to deal with preventive maintenance, i.e. at the bigger plants. Since the personnel at the smaller plants were involved in a lot of fire-fighting tasks it was difficult to find time to modify preventive maintenance activities there.

The reorganisation at the end of 1999 involved a huge staff turnover within the Snowy Hydro organisation, with a reduction of personnel from about 800 to 350 employees. At some plants all the maintenance personnel had to leave, including a great number of senior people. As a consequence, the RCM project lost several complete RCM teams, causing a break in the living programme phase. Due to aspects such as organisational change, employee turnover, focus on more immediate projects, and organisational culture, the living programme phase has been inactive for the past four years. In the beginning of 2003 the focus was to be on the introduction of a new business system and a new CMMS. This would

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\(^9\) The Institution of Engineers, in Australia, recognises excellence in the science, management and practice of maintenance engineering. The Institution of Engineers distributes the Australian Maintenance Engineering Excellence Award as part of the National Engineering Excellence Awards, in view of the importance that maintenance engineering contributes to the assurance of asset capability in Australian industry. From [http://www.icoms.org.au](http://www.icoms.org.au).
affect the further work with RCM simply due to the unavailability of key resources and focus.

At Statkraft, reorganisations and several projects were going on in parallel with the RCM introduction, but the project group considered that this would not lead to resource problems for the RCM project. The RCM project, as well as maintenance management issues, had over time got more and more attention from the senior management.

**Behaviour characteristics**

During one of the early pilot studies at BC Hydro, the tasks recommended from the analysis work differed a lot from the existing maintenance standards. As the will to change was not present, the implementation became difficult. Another pilot study implementation also became a struggle, as the culture was very conservative at the plant. The employees had appeared to defend the maintenance standards they had been involved in creating. Due to work with overhauls at the same time as the pilot study, the RCM teams were dispatched and the analysis was never completed. However, the project group at BC Hydro considered that the change willingness in the organisation was relatively high, due to the many changes that had been going on since the middle of the 1990s. However, some older trade people did not immediately accept changes in work tasks. Some did not understand why maintenance performance had to change, as it was experienced as successful, and some believed that RCM was a way for the company to reduce employees. The project group thought that it could become more of a challenge to introduce RCM in the bigger plants, since it was not obvious that RCM would make the current maintenance performance better. The personnel at the smaller plants were thought to be more willing to co-operate, since they had no real alternative. Since there were already few people in the maintenance organisation, no major problems were considered to occur due to job reductions caused by the RCM introduction. However, due to the work situation, it could likewise be difficult to introduce RCM at the smaller plants. However, it was still not clear to all personnel why the company had to introduce RCM, and what was in it for them.

The plant groups at Statkraft were, during a major part of the planning and preparation phase, generally sceptical to RCM. Since many of the employees had experiences of previously failed or problematic projects, the project group had also to consider and handle a negative attitude towards change projects in general. Similar scepticism and unwillingness to change had been experienced during the introduction of the CMMS some time ago. During the analysis phase a majority of the people involved in the project started to understand the significance of a living RCM programme. Some people at the plants noticed that RCM could lead to job reductions, especially since the number of people was
large, and Statkraft was going to slim the organisation. Statkraft involved many consultants in their company and these were most likely the ones that would be losing their contracts. However, the project group emphasised that it was important to inform the employees that RCM was not a means to reducing jobs, but instead a way of increasing the competence among the employees. It was also important to inform the staff that possible ‘leftovers’ were to be used in other work tasks.

During the introduction at Snowy Hydro some plant personnel looked upon RCM as something “scientific”. Some managers also believed that RCM could solve most of the maintenance-related problems. Therefore, it became an important issue for the project group to have the managers and employees understand what RCM was and what the goals and objectives were of introducing RCM. The project groups at Statkraft and Snowy Hydro experienced that the different regions could be rather autonomous, which resulted in different plant group cultures.

**Involvement**

According to the current project group at BC Hydro, the first pilot studies were not sold in properly. Therefore, making qualified plant staff participate in the process was considered a key factor for ensuring the establishment of a living programme. Trade representatives would also be involved to promote ownership of the maintenance programme, as well as contribute their plant and equipment knowledge. However, there were some difficulties in making the technical managers sufficiently committed to the project, which created problems when people from the technical service department were needed in the RCM teams.

Due to the sceptical attitude towards the introduction of RCM among some plant personnel during the planning and preparation phase, it became somewhat difficult to get people to work in the RCM teams at Statkraft. This was something the project group had to manage. The project group also invested a great deal of effort in making the reference group take an interest in the RCM work and understand the principles of RCM. That was a very important activity since the reference group had a major network in the organisation, among different kinds of technical specialists. For example, this category of personnel was the one that identified the critical failure modes before starting up the analysis phase. The reference group also had to formally approve the analyses made before they would be implemented. It was therefore very important to have the reference group involved in the project. Another risk was that the personnel outside the RCM teams became too little involved. Therefore, maintenance personnel and operators should be able to join the teams for some time. Since the unions were not usually involved in maintenance matters they were not involved in the introduction of RCM either.
The project group at Snowy Hydro strove especially to involve people with credibility in the organisation, and people in charge of developing maintenance requirements. This approach made people motivated and engaged during the pilot study, and was seen as a key reason for the progress in the initial RCM analysis and implementation. Engaged people with credibility in the organisation were indirectly selling in RCM to personnel at the shop floor, as well as to senior technical managers. Site people also had to be involved in order to overcome resistance and to create ownership of the analyses. A person with trade background was for a short time in charge of the work with continuous improvement in the living programme phase. He was in charge of updating analyses at all plants, including some systems to be analysed for the first time. He made the analyses by himself, by means of an RCM computer system, while other personnel supplied him with information. When the person left the company in 2002, the progress of the living programme phase stopped again. The project group had experienced some factors that had influenced the progress of the RCM introduction: organisational culture, management and employee commitment, the effective integration of the RCM programme in the daily business activities, and maintenance skills.

One way to motivate and involve people in the project at BC Hydro was to use incentive-based salaries, i.e. if RCM was introduced in time the staff got more money. The operators and maintenance personnel had a lot of other work tasks, and in general found it more interesting to work with the regular work tasks. The incitement connected to progress in the RCM work facilitated the progress.

The project group at Statkraft tried to motivate people by pointing at personal benefits of using RCM, but found it rather difficult. The safety focus in RCM could be appealing to the personnel, since it implied a safer work environment. However, it was easier for the top management to see the benefits of RCM.

**Training**

The project group at BC Hydro started a training programme with one day of training for the RCM team members, and four days of training for the facilitators. Also the upper management got training with the aim of making them understand the importance of a living programme. Information about RCM to senior managers, maintenance engineers and crew leaders was also held to reduce the risk of decreasing commitment among managers and other key personnel. In the analysis and implementation phases they came to the conclusion that the training held earlier was not enough, and considered starting additional training, even if the previous analysis work in itself became a kind of training exercise.
At Statkraft the facilitators got one week of training led by a consultant. The other team members, and remaining maintenance personnel, got one day of training and information led by the project group. The project group considered that one day of training was too little, but during that time the resource restrictions forced them to limit the efforts on training. When the start of the analysis phase was delayed, another problem was that most of the training had been held long before, and the employees were not updated. A reason for this lack of coordination was that the project group had to set aside time for training four to five months before the intended start of the analysis phase, due to other work tasks going on in the organisation. According to the project group, the level of competence and skills among the RCM team members was not satisfactory, and more training was wanted. However, the RCM teams learned a lot while making the analysis, something that was considered the most fruitful training by the project group.

Information and communication

The project group at BC Hydro emphasised the importance of ‘openness’ in the project, i.e. availability of information to the people involved in the project and to the entire organisation. A web site was developed on the Intranet, where, for example, a lot of information about the project and general topics on RCM, maintenance and reliability, could be found. At Statkraft the Intranet was also used as a channel for information regarding the introduction of RCM. However, the project group at Statkraft believed that probably too little information about what was going on was presented at the beginning of the planning and preparation phase. That made the project too anonymous with several managers and employees not really committed to the project as a consequence.

Based on the experiences from the pilot study, the project group at BC Hydro recognised the importance of discourse with the employees. People in the organisation had to understand the RCM and the advantages of using RCM. This had to be shown to them in a concrete way by making the analyses visible to the personnel, letting them in to discuss the method and results. That was considered the only way of getting doubters to change their minds. In that way, it was also possible to demonstrate that the RCM recommendations were better than the current maintenance programme. Snowy Hydro also used this approach, which they called ‘challenge groups’.

BC Hydro and Statkraft communicated with the RCM teams through telephone meetings and videoconferences. Project group members also visited some of the plants and RCM teams.

The terminology used at BC Hydro was more or less taken from the one available in the RCM computer support. A review of the RCM terminology was
seen as very important to ensure a common understanding. The maintenance terminology used at Statkraft was based on a European standard. The maintenance staff also had an overall responsibility for spreading a common maintenance language in the Statkraft organisation.

6.3.5 Results and views on RCM

Results and benefits
New maintenance instructions, supported by improved documentation and reductions in unplanned corrective maintenance and breakdowns were results of some of the pilot studies at BC Hydro. The pilot studies had also shown that design issues could be identified in a systematic way and that key trade representatives’ knowledge could be “captured” in the organisation. However, according to the project group, many of the company-wide analyses indicated that the “right things” were already being made, especially at the bigger plants. Even if the majority of analyses and implementation efforts still remained, some results, benefits and trends were recognised. According to the project group no real cost savings had been achieved. The analyses had mainly resulted in a shift of maintenance tasks, i.e. more maintenance of some systems and less maintenance of other systems. Even if the project group did not fully comprehend the potential, they became more and more aware of the intangible benefits of RCM, for example, as a catalyst for cultural change and for improving maintenance knowledge. During the introduction, they apprehended the structured approach in which RCM could generate an objective way to learn from and about maintenance. Because of the insurance companies’ demands that a maintenance engineer should be involved in systematic maintenance requirement identification, the work with RCM also made it possible to decrease insurance fees.

At Snowy Hydro, the project group considered it difficult to judge what improvements could be traced back to RCM, since improvements had to be seen with other improvement work in mind. However, there were still indications that the initial introduction and use of RCM had led to major reductions in routine maintenance tasks, a decrease of maintenance costs up to 30-40 percent, and a general increase of reliability at all plants. Using RCM was also felt to make maintenance performance more strongly focused. The RCM introduction was considered a huge success, but the refinement of the initial results was not made and the living programme was not achieved.

The project groups at BC Hydro and Statkraft made the judgement that the introduction of RCM would show positive results. The considerations were based on early indications from the pre-evaluations that were going on in the companies. However, the companies considered that the major effects of
introducing RCM were to be visible and measurable later on. They believed that it would take at least one to two years before it would be possible to show any major results.

Views on RCM
The view on RCM among the project group at Snowy Hydro changed over time. In the beginning RCM was seen as an analysis “process”, but after a while they started to see it as an analysis “tool”. Their view on RCM was that it only provided overall recommendations, where the user had to define “when”, i.e. frequencies, and “how”, to be able to develop a maintenance management programme.

The project group at BC Hydro emphasised the difference between what they saw as ‘traditional’ versus ‘enhanced’ RCM. Enhanced RCM concerned the way of making analyses and also of creating a maintenance programme based upon RCM. Traditional RCM was limited to the analysis part and did not support the more comprehensive view. They also considered that the strength of RCM was to make maintenance more systematic, while not necessary generating fewer maintenance tasks. Also, they apprehended RCM as a way to generate maintenance requirements, but not a maintenance programme on its own.

At Snowy Hydro, the senior management and employees initially thought that RCM would solve every problem of maintenance performance. Therefore, the project group did not call it RCM any longer, but instead ‘Maintenance requirement analysis’, to indicate that RCM was only one way of making maintenance improvements. Another reason was also that the RCM concept was to some part seen as a “heavy baggage” from the past. Further on, the employees would learn that RCM was only one part of maintenance management and that RCM should be seen as a part of the business process. However, the project group at Snowy Hydro viewed RCM as one core technique among many available techniques. According to the project group, RCM had to become a living philosophy, or a culture, in the organisation. This was seen as a necessary condition for working continuously with RCM, as top management interest and commitment would most likely fade away over time.

During the attempt to introduce RCM at Statkraft, based upon the first pilot project, RCM was viewed similar to a philosophy within the company. Since the introduction of RCM started again, in 1999, RCM has been viewed as an analysis method, as an important part of Statkraft’s maintenance strategy.
6.4 Empirical validation

BC Hydro and Statkraft are, compared to Vattenfall, companies with roughly the same number of plants and generation capacity, see Table 6.1. Even if they had started pilot projects at different times, they were also in similar phases of the introduction of RCM. Snowy Hydro is a smaller organisation than the other three. That is probably one reason why they have come further in the introduction process, even if they started pilot studies at the same time as BC Hydro and Statkraft. The validation of RCM introduction experiences and characteristics may therefore be more accurate between BC Hydro, Statkraft and Vattenfall. However, the introduction work at Snowy Hydro is of special interest in view of their experiences of the living programme phase.

Based on the management perspectives and the managerial factors in Table 6.2, a comparison will be made between the single-case study and the multiple-case study including obstacles and driving forces. However, the scopes of the single-case study and the multiple-case study differ. The single-case study was performed during several years and by means of participant-observation, the combination of which contributed to in-depth understanding and excellent access to primary information. Therefore, the comparison will be on an overall level. Also, in general no consideration is taken to when, or for how long, a factor affected some of the introduction processes.

6.4.1 An RCM management perspective

- **RCM team competence.** All four companies experienced lack of competence among the RCM teams, especially during the pilot studies. Statkraft used engineers promoting objectivity in the analyses. BC Hydro and Snowy Hydro used engineers as the main personnel performing the analysis, where trade representatives supplied information. However, there was an indication that the cooperation between engineers and trade representatives was problematic, which might have affected the analysis work. Vattenfall was the only organisation using trade representatives, i.e. machinists, as facilitators. That may have been a cause of some problems concerning the analysis work, and might have affected credibility among other maintenance personnel.

- **Analysis performance approach.** Vattenfall experienced that the RCM model was diffuse. This situation gave rise to several obstacles. During the multiple-case study, no comments were made considering a diffuse RCM model. However, all project groups in the multiple-case study did emphasise a simple RCM analysis procedure and had experienced many similar obstacles as Vattenfall. For example, both BC Hydro and Statkraft faced differences in analysis performance and the review procedure, too resource-demanding analyses due to too much detail, difficulties in
finding a suitable level of analysis, and lack of traceability. These kinds of obstacles could be traced to deficiencies in the RCM teams’ competence. The RCM work at Vattenfall relied heavily on templates making the work more effective. Some of the other companies were talking about making use of templates, and Statkraft considered that their RCM computer system could assist the analysis work with previous similar analyses made as some kind of templates. All three companies in the multiple-case study emphasised the importance of not making too perfect analyses the first time and avoiding going into excessive detail. Further improvements could be made in the living programme and templates or streamlined versions should be used when suitable.

- **Documentation and information.** All three companies in the multiple-case study experienced lack of documentation and information about such things as system descriptions and reliability data. BC Hydro and Snowy Hydro had experienced shortages of traceability in the analyses made due to lack of system descriptions. These were all obstacles also experienced by Vattenfall.

- **RCM computer system.** Vattenfall and BC Hydro had experienced ineffective analyses performance due to the unavailability of an RCM computer system. The other companies emphasised the importance of having such a system to make effective analyses.

### 6.4.2 A maintenance management perspective

- **Strategic maintenance management.** The lack of a comprehensive maintenance management strategy at Vattenfall created difficulties concerning planning and preparing of the living programme. However, the initiation of RCM in all three companies in the multiple-case study was preceded by asset or maintenance management strategies. Even so, all three companies experienced difficulties when planning or working with the living programme. The initiator of RCM at Statkraft pointed out the significance of a strategic document emphasising that RCM is a core structure in maintenance management, as it makes senior management committed to the project and a forthcoming introduction of RCM.

- **Maintenance programme and performance.** The deficiencies in the maintenance programme at Vattenfall created major obstacles concerning ‘projects in the project’, especially considering the lack of a CMMS, a uniform maintenance terminology, and a plant register. Also, all the three companies experienced difficulties considering the use and/or availability of the CMMS. Vattenfall was, however, the only company that completely lacked a common CMMS. BC Hydro and Snowy Hydro experienced difficulties connecting the CMMS and the RCM computer system, while Statkraft had their RCM computer system as a module in the CMMS, which
promoted communication and traceability between the systems. To some extent, all companies lacked plant system descriptions. However, Statkraft worked a great deal with function descriptions as a part of their CMMS, which gave them valuable documentation for the RCM analyses. They also had a working plant register. At Statkraft, the need for information and documentation was up to the RCM teams to fill. As they were in the beginning of their analysis and implementation phase, indications of the availability of system descriptions were not accessible during the study.

- **Maintenance culture.** As within Vattenfall, the maintenance culture at all the three companies in the multiple-case study were to some extent influenced by conservatism. This was specific among older personnel where people had worked for a long time according to usage and custom. All companies had experienced obstacles such as limited interest in maintenance optimisation and analysis. BC Hydro and Statkraft had experienced difficulties in making different personnel categories work integratedly. Snowy Hydro had also experienced obstacles concerning problems in cooperation between senior engineers and trade personnel.

- **Outsourcing of maintenance.** Vattenfall was the only company studied that had outsourced the management of routine maintenance.

### 6.4.3 A project management perspective

- **Planning.** Vattenfall experienced obstacles due to unclear aims and goals. Snowy Hydro and BC Hydro experienced lack of senior management commitment due to the long-term goals, something Vattenfall to some extent also experienced. The overall aim for all four companies was to optimise the routine maintenance programme, i.e. decrease maintenance costs. Another overall aim of introducing RCM at Vattenfall and Statkraft was to control maintenance performance in individual plants, by using risk management principles. Another overall aim at Snowy Hydro and BC Hydro was to increase availability. Intangible benefits were focused on to some extent, but not measured in any company. Statkraft found it difficult to identify personal goals for the employees involved in the introduction.

- **Introduction strategy and approach.** All four companies lacked a comprehensive introduction strategy, for example, how to make the introduction a living RCM programme. The project group at Snowy Hydro found it difficult to manage the “major push” of introducing RCM to all plants and emphasised that a holistic management view was essential to make it work. The group also considered an incremental introduction approach to be more suitable when introducing RCM.

- **Control and monitoring.** All companies, except Snowy Hydro, commented on the difficulties in making the RCM teams analyse in a similar way, as well as in making comparable reviews. Snowy Hydro’s work with a discrete
project was probably a main reason why they were able to avoid those obstacles. Statkraft had experienced insufficient introduction progress, after the first pilot project, as no formal project organisation or monitoring activity was used. A project organisation was used during their second attempt at introducing RCM, which facilitated the control of the introduction.

- *Measuring and evaluation.* All three companies in the multiple-case study experienced shortcomings in measuring and evaluation of the maintenance performance, which made it difficult to evaluate the current maintenance performance. Also, the companies considered it difficult to trace improvements back to the RCM introduction and to measure and evaluate RCM progress. All four companies lacked a comprehensive measurement and evaluation plan. None of the companies measured or evaluated intangible aspects, where performance indicators of improved knowledge, a common way of working, or teamwork, were lacking. BC Hydro also emphasised the difficulty of defining criteria for when RCM could be considered introduced in the company.

- *Resources.* All four companies had experienced lack of resource allocation and that too resource-consuming analysis work resulted in lack of management commitment. Due to scarce resources, Statkraft and BC Hydro had experienced lack of competence among the RCM teams, due to too little training. These companies had also faced delays in the time schedules because there were not sufficient resources. As the RCM project at Statkraft later on became a highly prioritised project, resource allocation was no longer a problem.

- *Project risk management.* Vattenfall performed project risk analyses, while the other companies did not use any formal project risk management, but relied on earlier experiences and general concerns about risks.

- *Benchmarking study.* None of the four companies performed any comprehensive benchmarking studies before introducing RCM.

- *Project group competence.* The strength of the project group competence at Vattenfall was mainly within maintenance management and project management. The ignorance of change management had led to some obstacles. Also, the project groups’ competence, in the multiple-case study, was mainly within maintenance management and project management. As these project groups were not studied for a longer period of time, it is difficult to find out what effect this factor has had on the introduction. However, it seems that the companies studied in the multiple-case study also experienced difficulties in managing change, as such skills, at least formally, were lacking.
6.4.4 A change management perspective

- **Planning and preparation for managing change.** All four companies lacked a plan or comprehensive preparation for managing organisational change.

- **Commitment and support.** All companies had experienced shortcomings in senior management commitment and support, which, for example, resulted in decreased resource allocation and employees’ commitment. Lack of senior management commitment was also a main reason why the first attempt at introducing RCM at Statkraft failed. An RCM champion was not available at Vattenfall, neither at project management level nor at senior management level. It is difficult to determine whether an RCM champion existed in the other organisations, as these introduction processes have not been studied as comprehensively as the single-case study. However, the other companies had the same project group for a long time, which is a precondition for obtaining a RCM champion. Nevertheless, all the companies lacked, or had lacked, an RCM champion at senior management level.

- **Work situation.** Statkraft was the only company among the four that did not experience a stressful work situation that had a significant affect on the RCM introduction progress. The other two companies in the multiple-case study had experienced competition for resources with other projects and work reorganisations that prevented project continuity.

- **Behaviour characteristics.** All four companies experienced somewhat negative attitudes to introducing RCM, and a general change resistance among managers and employees. The reasons for this were largely due to experiences of earlier failed projects and lack of management and employee understanding of why RCM had to be introduced. Just as at Vattenfall, BC Hydro and Statkraft had also experienced employees unwilling to accept change due to fear of job reductions.

- **Involvement.** All four companies experienced, more or less, difficulties in involving managers and employees in the introduction. BC Hydro and Statkraft had, for example, experienced some difficulties in making people participate in the RCM teams. Snowy Hydro had involved personnel with credibility in the organisation in the RCM teams, which became a major driving force. The project group also emphasised the involvement of trade members, and people ‘outside’ the RCM teams, so as to promote motivation and ownership of the RCM programme. However, Snowy Hydro had also experienced decreased ownership among employees when only one person was in charge of making the analysis at some plants. Only BC Hydro used incitements that made people more involved in the introduction process. Statkraft found it difficult to identify suitable personal goals, i.e. incitements, to motivate and make the employees more involved.

- **Training.** All companies, except Snowy Hydro, had experienced that lack of training contributed to obstacles such as insufficient competence in the RCM teams.
- *Information and communication*. All companies experienced, in different ways, lack of information and communication during the introduction, leading to obstacles such as lack of understanding and involvement, and a project becoming too anonymous. A main reason seems to be the spread of regions and plant groups in the organisations. BC Hydro and Snowy Hydro made use of so-called ‘challenge groups’, which promoted understanding and acceptance. BC Hydro and Statkraft also emphasised the use of Intranet and a web site to obtain project openness.

### 6.5 Discussion

As stated in the analysis of the single-case study, a driving force and an obstacle are many times different sides of the same coin. Therefore, related obstacles and driving forces can be viewed as a specific way in which a factor affects an RCM introduction process. In summary, all three organisations in the multiple-case study have faced a major part of the ways in which the factors influenced the introduction at Vattenfall. There are also characteristics indicating that many of the obstacles and driving forces experienced at Vattenfall could be valid for the other organisations as well, and vice versa. For example, there are similarities between the four organisations as regards size and generation capacity, except for Snowy Hydro, and in the historical maintenance performance and culture. Also, the plants can be looked upon as individuals and are located in several regions, and along rivers.

Except for validating factors, driving forces and obstacles in the single-case study, some other aspects of the comparison with the multiple-case study will be discussed further below. These findings are structured according to the four management perspectives. A discussion will also be made concerning the proposed introduction process, according to Figure 6.1.

#### 6.5.1 An RCM management perspective

**Pilot team competence**

All the companies in the multiple-case study used experienced consultants in their pilot studies. However, several of the companies were faced with very resource demanding pilot studies. According to one project group member, a reason for this could be found by looking at the consultants involved, who were often experienced in performing RCM analyses at more safety-focused industries, such as nuclear and offshore. Vattenfall involved a consultant as facilitator only during the “second pilot study”, although rather inexperienced in RCM. Before that, only trade representatives were involved. Such an approach could be risky, as the results of the pilot studies are the main basis on which senior management decides whether to proceed with the project or not. Also, the
company-wide analyses are based on the RCM model used and developed during the pilot study.

**Facilitators**
During the analysis phase all companies in the multiple-case study used engineers as facilitators. Vattenfall was the only organisation using trade representatives, i.e. machinists, as facilitators. However, Vattenfall seems to have put more efforts in training of the facilitators than the other companies.

**The view on RCM**
The comprehension and view of RCM changed within the project groups over time. From being seen as something able to solve everything, RCM became thought of as, for example, an analytical tool. However, what could be a major problem is the lack of a view of RCM as a method of working when starting a full-scale introduction. Such a view should be essential to share among senior managers and the project group, realising that to create an RCM programme, several support systems and routines are needed, and that many people have to be involved and committed. This should, in a next step, be a precondition for a comprehensive and well thought-out planning and preparation, especially concerning the resource allocation. This is to some extent in accordance with the need for a holistic view when introducing RCM, stated by the project group at Snowy Hydro. The view of RCM can be seen as a factor affecting the introduction of RCM.

**Classical versus streamlined RCM**
All four organisations used a classical RCM model. Capturing knowledge was, for example, a major reason why Snowy Hydro did not use a streamlined RCM model. However, at the same time all companies tried making their RCM analysis work as simply as possible. A question is whether some kind of a streamlined RCM model would have been more appropriate, or not, to use in the very beginning.

**6.5.2 A project management perspective**

**Project risk management**
None of the project groups in the multiple-case study used formal project risk management. Instead they relied on previous experiences of pilot projects. Considering the complexity of introducing RCM, a more comprehensive and systematic approach to managing risks should probably be preferred.

**Aims and goals for both managers and employees**
The aims and goals of introducing RCM were mainly stated in ways that were appealing to senior managers, such as decrease in routine maintenance and
increased availability. To realise such goals, and to continuously improve the analysis and measures, the plant personnel would also need goals and aims that benefit them more personally. The plant personnel are the ones closest to the systems and equipment. If they are motivated, properly trained, an introduction of RCM will most likely be successful for both managers and employees.

**Measurement and evaluation**

None of the studied companies measured or evaluated intangible aspects of the introduction of RCM, such as improved knowledge, way of working or increased satisfaction among the employees. The focus was on tangible aspects, such as reduced routine maintenance and increased availability. This indicates that introducing RCM in order to change the way of working with maintenance in the organisation was not sufficiently emphasised by the project groups and senior management. Realising, and being able to measure RCM as a method of working in the organisation is most likely a necessary precondition for achieving a living RCM programme.

**A broad versus an incremental introduction approach**

Snowy Hydro is a smaller organisation than the other three studied companies. The introduction process at Snowy Hydro was performed within discrete projects, and, until the living programme phase, it went very well. A major reorganisation caused the obstacles in the living programme phase, which was still not working well at the end of the case study. Since the other organisations experienced many obstacles, often due to reorganisations and other ongoing initiatives, they could learn from the Snowy Hydro experiences. An incremental change seemed to be more suitable in many ways, facilitating, for example, information and communication, quick results, control and monitoring.

**Project group competence**

Competence to manage the four management perspectives must be available in an RCM project group. However, change management skills should probably be given special attention, as the other management perspectives seem to be more natural to emphasise.

**Results and benefits**

Since only one of the four companies had been working through the analysis and implementation phases, concrete results have been difficult to find. All the four project groups were of the opinion that measuring and showing results, exclusively contributed by RCM, could be difficult. This would make it difficult to present results even further on in the introduction process. Snowy Hydro claims they made major savings based on the initial implementation. Based on an ongoing pre-evaluation, Statkraft could see indications of positive results with RCM, while BC Hydro had not seen that much. There were several factors
influencing the results, and a more in-depth study of benefits and profits is needed to get a clearer picture. Overall, given the relatively ineffective maintenance management performed at the hydropower organisations before the introduction of RCM, the initial analysis and implementation provided by RCM should be able to contribute to major improvements and profits. The organisations seem mainly to acknowledge and measure savings in routine maintenance. However, a precondition for getting major benefits from introducing RCM should be a focus on a majority of the potentials of RCM. For example, the identification of hidden failures and design modifications during an RCM analysis, as well as intangible benefits, such as improvements, knowledge gain, and increase teamwork.

6.5.3 A change management perspective

Planning and preparation for managing change
All four organisations have to some extent not considered the importance of planning and preparing for organisational change in connection with the introduction of RCM. This has probably to do with the failure to view RCM as a method of working, and also the main focus on technological competence in the project groups and at the senior management level.

RCM during rationalisations
For all companies, RCM was introduced during reorganisations and rationalisations. This could have had an affect on the enthusiasm for and the commitment to introducing RCM. For example, the focus among the senior management was in general on decreasing routine maintenance costs, which most likely is not inspiring for the project groups or the plant groups.

Informal information and communication
One project manager at Vattenfall made use of informal meetings with regional top and middle managers to increase the chances of attaining commitment. Informal meetings were not emphasised by the project groups in the multiple-case study. However, members of the project groups made occasional visits to the plants. BC Hydro and Snowy Hydro also used so-called challenge groups, making the people not directly involved in the analysis work understand the analyses made. According to the project group at BC Hydro, this was a key driving force for making people understand and accept RCM.

A common way of working
The four organisations studied have quite a similar background as regards their maintenance performance and culture. The geographical spread of plants, plant groups and regions have contributed to differences in maintenance performance and subcultures. In some companies they were seeing the regions as ‘companies
in the company’. This situation made it especially important that the introduction of RCM resulted in a common way of performing maintenance among the regions and plant groups. This should be a precondition for working effectively with continuous improvements, for example, using a similar database and sharing experiences of failure modes.

6.5.4 A discussion of the introduction process

The description of the RCM introductions in the multiple-case study has been made in accordance with the introduction process, including different phases, as exemplified in Figure 6.1. Below, some examples from the multiple-case study are presented with the intention of further pointing out the suitability of managing the introduction of RCM within an introduction process.

All companies initiated their introduction of RCM on the basis of some kind of asset management or maintenance management strategy. According to the initiator of RCM at Statkraft, a maintenance management strategy, including RCM as a core structure, should make senior management committed to the introduction of RCM. However, the senior management at BC Hydro questioned the efforts spent on RCM during the planning and preparation. That indicated that the senior managers did not fully comprehend the need for RCM in maintenance management. Also at Statkraft the project group experienced a sceptical attitude from senior management towards RCM. The project group at Snowy Hydro had difficulties in making the senior management understand the importance of a RCM living programme. These examples indicate that the initiation of RCM has to be thoroughly considered, making the senior management initially committed to RCM. This also indicates that the initiation of RCM could be focused as one phase in the introduction of RCM.

All companies experienced different obstacles when performing a pilot study, which forced BC Hydro, and to some extent also Statkraft, to perform several pilot studies. The pilot studies were often resource consuming, and concrete results were to some extent not achieved. This had a negative effect on the commitment of the senior management, who were the ones to decide whether to proceed with the project or not. Performing pilot studies seems to be of great importance for the coming activities in an RCM introduction, and for the decision to continue an introduction initiative. Therefore, the performance of one or several pilot studies should be focused on as a phase in an introduction process.

All companies experienced that tasks not managed properly during planning and preparation affected the coming phases negatively. For example, obstacles related to the CMMS made it difficult to work with continuous improvements,
and obstacles related to training affected the company-wide analysis work negatively. At Statkraft, the two plant groups that were the first to start the company-wide analysis work got the feeling that they were involved in another pilot study. This was a consequence of several activities in the planning and preparation not having been fully completed. Managing planning and preparation in a specific phase in an introduction process, before moving on to company-wide analysis work, seems also to be a suitable approach.

All companies seem to manage the company-wide analysis and implementation as an integrated process. Therefore, analysis and implementation could be viewed as one phase in the introduction process. However, this is probably more valid for changes in routine maintenance than changes concerning new equipment or designs. This phase, or phases, had only begun at BC Hydro and Statkraft during the period of the case study. Therefore, empirical findings are lacking, which would more clearly mark the company-wide analysis and implementation as one or two phases. Snowy Hydro, with a smaller number of plants than the other two companies, used an incremental introduction approach including approximately two plants per year. In that way, analysis and implementation were integrated in a way.

The project group at Snowy Hydro experienced that setting the conditions for a living programme was demanding, required a lot of resources, and was difficult to manage. Most of the plant personnel did not, after the initial analysis and implementation, make further analyses. For example, people did not check if failures occurring were new ones or if a discovered failure mode had been identified earlier in the RCM analysis. It was difficult to find ways of measuring and evaluating, and the feedback loop was not working well. For example, both Statkraft and Snowy Hydro experienced problems with personnel not reporting correctly to the CMMS. These examples indicate that setting the conditions for a living RCM programme should be focused and managed within a phase in the introduction process.

6.6 Some conclusions

The factors, and the ways these affected the RCM introduction in the single-case study, have been validated, on an overall level, by the obstacles and driving forces experienced in the multiple-case study. The factor ‘outsourcing of maintenance’ was not valid for the other organisations, though. However, an additional factor identified during the empirical validation is ‘the view on RCM’, as discussed in Section 6.5.1.

The RCM introductions in the multiple-case study were not studied in-depth, as they were during the single-case study. Even so, the findings from the multiple-
case study indicate that the proposed RCM introduction process could be valid. However, the findings also indicate that it might be more suitable to view the company-wide analysis and implementation as one phase, instead of as separates phases. But the emphasis on an introduction process, including different phases, aims at making the introduction more controlled and manageable. Therefore, managing the analysis and implementation in accordance with separate phases has an advantage.
7 AN RCM INTRODUCTION STRATEGY FRAMEWORK

In this chapter an RCM introduction strategy framework will be proposed, based upon the findings and discussion in the case study analysis and the empirical validation.

Introducing RCM on a full-scale basis puts demands on the organisation, the current maintenance programme as well as the maintenance performance. Managing the RCM introduction can be complex and cumbersome. To judge from the empirical studies, a comprehensive and holistic RCM introduction strategy, including the four management perspectives, seems to be needed. However, such a strategy has not been found in the literature. Based upon the findings and discussions in the case study analysis and the empirical validation, a strategy framework will be proposed in this chapter. According to Section 5.5 managing the introduction of RCM can be facilitated by means of:

- **Management perspectives.** The four management perspectives indicate what kind of competence is needed to manage the introduction.
- **Factors.** The awareness of different factors that influence the introduction facilitates the identification and the management of different obstacles and driving forces.
- **An introduction process.** Managing obstacles and driving forces in different phases should make the introduction more manageable and controllable.

The strategy framework, illustrated in Figure 7.1, and further described in Sections 7.1 – 7.3, is based on the factors identified during the case studies, structured according to the four management perspectives, see Table 7.1.
Table 7.1. Factors affecting RCM introduction.

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<th>Factors affecting RCM introduction</th>
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<td><strong>RCM management</strong></td>
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<td>RCM team competence</td>
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<td>Documentation and information</td>
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<td>Introduction strategy and approach</td>
<td>Commitment and support</td>
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<tr>
<td>Control and monitoring</td>
<td>Work situation</td>
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<td>Measuring and evaluation</td>
<td>Behaviour characteristics</td>
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<td>Resources</td>
<td>Involvement</td>
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<td>Project risk management</td>
<td>Training</td>
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<td>Benchmarking studies</td>
<td>Information and communication</td>
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<tr>
<td>Project group competence</td>
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</table>

More specifically, the strategy will include requirements and recommendations based on the obstacles and driving forces related to the different factors. However, the factor ‘outsourcing of maintenance’ is not included in the strategy, as it has only been of significance in the single-case study. To make the strategy more manageable and controllable, the requirements and recommendations are structured in accordance with the introduction process.

The strategy framework should not be seen as an independent part of this thesis. To understand the significance of the requirements and recommendations, the knowledge from the previous chapters should be kept in mind. Therefore, it is called a “strategy framework”. It could be seen as a structured approach to managing the factors, obstacles and driving forces identified in the case studies.
The analysis, implementation and living programme phases have not really been focused on during the case studies. Therefore, the strategy framework mainly comprises requirements and recommendations for creating favourable conditions for managing these phases. However, obstacles that may turn up during these phases are most likely connected to deficiencies in managing the planning and preparation phase, or the previous phases. In that perspective, the initiation, pilot study and planning and preparation phases could be seen as the most critical phases in the introduction process.
There is no quick and easy way if the aim is to introduce a new way of working with maintenance in the organisation, which is to have an impact on the organisation as a living RCM programme. How extensive and cumbersome an introduction of RCM will be depends to a high degree on the current maintenance programme and maintenance performance. Some of the requirements and recommendations in the introduction strategy framework can be rather comprehensive tasks to manage. One might even think that some tasks proposed are too extensive, considering that it is ‘only’ about introducing RCM. However, it is important to understand that introducing RCM involves introducing a new method of working, which influences both systems and people in the organisation. Some comprehensive tasks involve, for example, evaluation of the current maintenance programme and performance, project risk management and evaluation of the work situation in the organisation. It has been seen from the case studies that if some of these tasks are lacking in the introduction, major obstacles may turn up that will jeopardize the complete introduction process later on. We have also seen examples of the studied companies starting one introduction phase before tasks in a previous phase had been dealt with sufficiently. However, later on, this created problems in the introduction process.

As some of the tasks in the introduction strategy may be extensive, they should be managed as independent projects. This implies that the goal to obtain a living RCM programme has to be seen in a long-term perspective, almost as a vision. These kinds of tasks may many times concern maintenance management fundamentals, such as a CMMS or a maintenance management strategy. Therefore, completing some of these tasks may be of great value for the company and should be seen as subgoals when introducing RCM.

As regards organisational commitment a broad introduction approach, involving several regions simultaneously, seems often to be difficult to manage and control, especially in view of the geographical spread of regions and plants. A more focused introduction approach will probably be more advantageous, focusing on, for example, one region at a time. Such an approach makes it easier to generate quick results and also make the introduction process more stable. For example, during the case studies reorganisation seemed to be going on continuously, which can easily generate delays in the introduction process. An incremental approach would make it easier to start again. However, the steering group involved in the single-case study had experienced problems making CMMS commonly used in the complete organisation, when focusing the introduction to one region at a time. Therefore an incremental approach should be used, but within a broad perspective.
In accordance with the introduction process, the phases should be managed and completed in a sequential order, where each phase is a precondition for the next phase, or phases. However, the requirements and the recommendations do not necessarily have to be managed according to the order presented in the strategy framework. As each company has its own specific organisational and maintenance management characteristics, the requirements and the recommendations should be adapted and managed in a customised introduction strategy. It should also be noticed that the strategy framework proposed is not claimed to be an ‘all-embracing’ RCM introduction strategy. However, it is the author’s belief that the strategy framework will contribute valuable support for hydropower organisations that are going to introduce RCM.

7.1 An initiation phase

The main purpose of the initiation phase is to make the senior management understand the deficiencies and needs, in the company’s current maintenance programme and maintenance performance. Also, the senior management should be aware of the potentials of RCM and the need for RCM in the strategic maintenance management. When completing this phase, the senior management should be able to decide if RCM is suitable for the company, and, on an overall level, to understand the efforts and resources needed for introducing RCM. The managing of this phase should also ensure that different preconditions for the coming phases should be in order. For example, an evaluation of the current maintenance performance is a precondition for measuring and evaluating the changes of introducing RCM in the following phases. Also, a maintenance management strategy is needed in order to plan and prepare for the living programme phase. Below, requirements and recommendations in this phase are presented.

7.1.1 Evaluate the need for introducing RCM

The needs for introducing RCM in the organisation have to be evaluated, which should include:

- *Evaluation of the current maintenance programme and the maintenance performance.* Identify and evaluate deficiencies in the current maintenance programme and performance. This is also a precondition for measuring and evaluating the changes of introducing RCM later on in the process.

- *Maintenance management strategy.* A maintenance management strategy has to be developed in order to identify and understand the current and future needs and directions in maintenance management.

- *RCM potentials.* Identify both tangible and intangible potentials of RCM. For example, reduction of corrective and preventive maintenance, a more
systematic way of working, higher quality maintenance plans, cross-discipline utilisation of knowledge and increased plant safety.

- **Comparison and evaluation.** Compare the company’s needs as regards maintenance programme, maintenance performance and maintenance management, with the potentials of RCM.

### 7.1.2 View RCM as a method of working

The senior management, and later on the project group, middle managers and employees, have to understand that introducing RCM in the organisation, on a full scale, should be seen as introducing a new method of working. This is a fundamental precondition for making the senior management comprehend the major support and resources needed for introducing RCM. Also, committed and dedicated senior management is of significant importance for the progress, as middle managers follow their directions. If the senior management and middle management only comprehend RCM as a ‘tool’ or a ‘model’ there is a major risk that they do not accept the major efforts and resources needed. Also, if the senior management comprehend RCM as a method of working, they should understand better the significance of preparing and managing organisational change. The senior management, especially, must also understand that RCM is not completed when the recommendations from the initial analyses are implemented, i.e. that the goal of the introduction is a living RCM programme.

### 7.2 A pilot study phase

The main purpose of the pilot study phase should be to prepare the company-wide analysis work by developing and testing an RCM model, and an RCM computer system should be available. The pilot study phase should also show concrete results and potentials of using RCM, and a project organisation should be established. These tasks are preconditions for managing the coming analysis phase, increasing management commitment and facilitating control during the introduction. Below, requirements and recommendations in this phase are presented.

#### 7.2.1 Establish a project organisation

A project organisation should be established in order to facilitate control and monitoring, especially during the analysis, implementation and living programme phases. Some concerns are:

- **Project management model.** The use of a project management model should facilitate project management as, for example, the organisational structure and roles become clearer in the project, which facilitates communication and decision-making.
- **Project group competence.** Competence in the four management perspectives must be available in the project group, as well as skills and awareness of managing the introduction within a holistic approach. Change management skills should have especial attention, as the other management perspectives might be more natural to emphasise.

- **Dedicated project manager.** As an RCM introduction may become cumbersome and complex, with many people involved, managing organisational commitment is a very important issue. Therefore, a dedicated project manager, during all the introduction phases, can be of significant importance for the project’s progress.

### 7.2.2 Preparation of the analysis work

To facilitate the analysis work, the following should be considered:

- **RCM pilot team.** Involve a person experienced and skilled in RCM as facilitator. This person should also be familiar with hydropower plant systems. As the RCM model should be used in the company-wide analysis work, it is important that plant groups and others accept the model. Therefore, the members of the RCM pilot team should have credibility in the organisation, both among management and employees. The members of the pilot RCM team also need comprehensive training.

- **RCM computer system.** An RCM computer system makes the analysis work more effective and improves understanding. Therefore, a computer system should be tested and evaluated already in the pilot study phase.

### 7.2.3 Perform analysis

To make the RCM pilot team, or teams, deliver useful and acceptable results, the following should be considered:

- **Analysis level and approach.** Identify an analysis level and approach that are accepted by the senior management in terms of the resources needed. A competent RCM pilot team should be able to find a suitable level with sufficient depth to make changes in the current maintenance programme and the maintenance performance.

- **Implementation of analysis results.** The initial analysis recommendations should be implemented and continuous improvements begun. In that way, valuable experiences for managing the coming phases in the introduction process would be provided, for example, experiences of working in the review procedure. Also, implementing the analysis recommendations generates concrete results, which should be used to demonstrate the benefits of RCM to management and employees in the organisation.
7.2.4 Develop an RCM model
A clear and user-friendly RCM model has to be developed and made available during this phase. The RCM model will be used already during the planning and preparation phase to identify support systems and actors needed in the company-wide RCM analysis work. A clear and transparent RCM model is also a precondition for making the RCM teams, in the analysis phase, perform analyses in a similar way.

7.3 A planning and preparation phase
The purpose of this phase is to plan and prepare for the full-scale RCM introduction, making the organisation committed and capable of introducing RCM on a company-wide basis. A carefully performed planning and preparation should prevent major obstacles from turning up during the analysis, implementation and living programme phases. Obstacles during these phases can be difficult to manage when many people are involved, and where delays can have major effects on organisational commitment. The planning and preparation phase is comprehensive, including many activities and tasks, and the need for project management and change management are more evident than in the previous phases. Therefore, the requirements and recommendations presented below are divided in accordance with the four management perspectives.

7.3.1 RCM management
Requirements and recommendations from an RCM management point of view are:

- **Documentation and information.** Plant system descriptions have to be available for the RCM teams and different kinds of reliability data should be collected. However, avoid too much effort in gathering accuracy of failure data in the initial analyses, since improvements can be made in the living programme.

- **Templates.** Hydropower plants may many times be regarded as ‘individuals’. However, performing individual analyses of all plant systems will most likely be very resource-demanding tasks. The use of templates can support the analysis work on similar systems, making the analysis work more effective and at the same time promoting a common way of performing the analyses. However, when using templates the operational context must be carefully considered.

7.3.2 Maintenance management
In the initiation phase the maintenance programme and the maintenance management strategy should have been evaluated, and an RCM model should
become available in the pilot study phase. By studying the interaction between the RCM model and the maintenance programme and maintenance management strategy, support systems, actors, information and routines needed to obtain an RCM programme could be identified. Some requirements and recommendations from a maintenance management point of view are:

- **CMMS.** A CMMS is a critical support system in the living RCM programme phase as regards for example follow-up and optimisation. If a CMMS is not working during the analysis and implementation phase, there is a major risk that the work with continuous improvements in the living programme phase fades away. Therefore, a CMMS should be available and used properly already during the planning and preparation phase. Also the communication between the RCM computer system and the CMMS has to be working. The RCM computer system as a module in a CMMS may facilitate communication and traceability.

- **Plant register.** By means of a plant register a general plant structure would be provided, including subsystems, apparatus and components. Such a structure promotes traceability in the analyses made and is also needed to communicate between different technical support systems, such as a CMMS and the RCM computer system.

- **Common maintenance terminology.** A common maintenance terminology supports the communication and is needed to avoid misunderstandings between different actors in the introduction process.

### 7.3.3 Project management

Requirements and recommendations from a project management point of view are described below.

**Project risk management and benchmarking studies**

Project risk management should be worked with comprehensively to identify and manage risks systematically. If possible, a benchmarking study should be performed, to learn more concretely from others’ experiences of obstacles and driving forces when introducing RCM.

**Measurement and evaluation plan**

Based on the overall needs for and aims of introducing RCM in the organisation, identified in the initiation phase, a measurement and evaluation plan should be established. This also includes goal identification. Measuring and evaluation should be going on during the complete introduction process, and the following should be considered:

- **Internal and external customer needs.** To make as many as possible committed to the RCM introduction, internal and external customers’ needs and expectations have to be identified. In that way goals that are
appealing to all involved could be identified, which promotes organisational commitment. Especially personal goals for the employees have to be identified, as overall aims and goals are usually in accordance with the senior management’s needs and expectations. Different forms of incitements can be one way of dealing with that.

- **Tangible and intangible potentials of RCM.** Many times, tangible benefits of using RCM are focused on, while intangible benefits, such as improving and capturing knowledge, and increasing teamwork, are usually regarded as something that is just there. However, the intangible benefits should not be ignored, as measuring them makes it possible to evaluate if RCM has become a new way of working with maintenance in the organisation. As for tangible potentials, do not focus too much on decreasing routine maintenance, and also acknowledge, for example, the identification of hidden failures and design modifications during the RCM analysis.

- **Clear goals and aims.** To stay in focus during the introduction process and to make managers and employees committed, the aims and goals have to be clear and communicated to everyone. Directions have to be clear on how the project should be managed and what the final goals are.

- **Quick results.** Demonstrate early results to reinforce employees’ commitment, as they should become more motivated when they rapidly experience that the introduction results in real changes. It is also an important factor to gain renewed confidence from management levels, which is a precondition for getting continued resources. Therefore, subresults, both tangible and intangible, that visualise progress have to be identified during the whole introduction process.

### Control and monitoring
A plan must be developed to make RCM teams perform analyses in a similar way, as well as making the reviewers review in a similar way. Gathering the facilitators during training, as well as jointly performing several analyses of a number of systems promotes a common view of how to perform analyses.

### Resource allocation
The introduction process becomes very difficult to manage if people are too heavily involved with other work tasks going on. Therefore, introducing RCM has to be a high-prioritised project in the organisation. Before starting the major efforts at preparing the organisation, the project manager has to make sure that the senior management are committed and formally give high status to the project. Resource allocation should also be managed with the regular work tasks and other projects in mind, and coordinated with other projects if possible.
7.3.4 Change management

Introducing RCM often leads to a major change for the organisation and managing this organisational change has to be planned and prepared for. Below, requirements and recommendations are presented.

Evaluations of the conditions for change
The conditions for change in the organisation should be evaluated in order to understand what kind of resistance is to be expected. Cultural aspects and behaviour characteristics differ most likely between different plant groups. Therefore, the plant groups should be approached and managed differently. Evaluate the work situation as regards current and future projects, which should support decision-making concerning when and how RCM should be introduced. An acceptable work situation in the company is a precondition for making people involved and engaged. If the work situation is not managed properly, reorganisations and a stressful work environment can make the RCM introduction cumbersome already in the pilot study phase. A stressful work situation may also affect the work in the RCM teams, as they do not get sufficient time for performing the analyses properly. The outcome of previous improvement projects also affects people’s attitude to the introduction.

Involvement of managers and employees
It is important that all the identified actors in the introduction process are involved, which promotes motivation and ownership of the RCM programme. This is especially important concerning trades ‘outside’ the RCM analysis work, and different kinds of specialists that must be available in the analysis work now and then. Some concerns when managing involvement are:

- **Visible and transparent introduction process.** Everyone in the organisation has to understand and ‘see’ the main thread in the RCM introduction process to gain understanding and commitment.
- **RCM team.** Involve people with credibility within the organisation. This makes it easier to make people who are not directly involved in the analysis work accept the changes in the current way of performing maintenance.

Information and communication
Information and communication have to be managed during the complete introduction process. In a hydropower environment, plant groups and other kinds of personnel are spread geographically. Therefore, managing information and communication is of major importance and at the same time arduous and difficult. Some concerns when managing information and communication are:

- **Information and communication routines.** Routines have to be established that make information and communication reach all personnel
involved, to avoid misunderstanding and rumours. However, to avoid information fatigue as regards the different categories of decision-makers, the information from the project has to be targeted.

- **Formal and informal approach.** Informal or personal communication, as a complement to formal meetings and conferences, could increase the motivation of management and employees.

- **Challenge groups.** The use of ‘challenge groups’ promotes understanding and acceptance of RCM and of changes in the current maintenance performance, among the plant personnel not directly involved in the analysis work.

- **Intranet and websites.** The use of the Intranet promotes project openness and overrides, to some extent, the problems with information when plant groups are spread out geographically.

**Training**

Comprehensive training is needed to make middle managers and employees capable of and motivated for introducing RCM. Also senior managers need training to become committed, which is a precondition for getting resources and support. As the spread-out of plant groups generates different plant cultures, training packages have to be customised to the different needs at the plants. Training packages have also to be organised according to regular work tasks and other projects going on in the organisation. The RCM training should preferably be as close to the analysis phase as possible. Some other concerns with respect to training are:

- **Interprofessional work.** Different categories of professionals should learn to cooperate in the performance of maintenance tasks. That is a precondition for making the maintenance work more effective in the living RCM programme.

- **Maintenance skills.** Improved maintenance skills in the plant groups are probably needed, to be able to implement the analysis recommendations and perform optimisation work in the living programme phase. Important activities are, for example, reporting and using the CMMS correctly.
8 SUMMARY OF THE APPENDED PAPERS

This chapter summarises the results and conclusions of the appended papers. First, the papers’ contribution to the managing RCM of introduction will be discussed.

8.1 Contributions to RCM introduction

The summarised papers presented in this chapter have all in common that they contribute to the introduction and use of RCM:

- **Different approaches of managing risk analysis (Paper I).** The evaluation of different risk analysis approaches, in Section 8.2, points out factors that affect the quality of risk analysis results. RCM is a risk-based maintenance method, as identified failure modes should be managed on the basis of their probability of occurrence and the severity of failure consequences. The performance of risk analysis is therefore of importance for the quality of the RCM analysis results as well.

- **RCM as a method of working (Paper II).** The view of RCM as a method of working, affecting people, routines and systems when being introduced in the organisation, as presented in Section 8.3, is essential for the senior and middle management to comprehend. Without that awareness, they will most likely not provide the major resources and make the efforts needed when introducing RCM on a full-scale basis.

- **RCM requirement management (Paper III).** The RCM requirement management approach, described in Section 8.4, is based on process and requirement management principles. The aim is to identify support systems, routines, information, and actors needed during the introduction of RCM to identify potential obstacles that may turn.

- **Introduction of TQM, TPM and RCM – A comparison (Paper IV).** There are several links between quality management and maintenance management such as maintenance influence on product quality. Total Quality Management, TQM, Total Productive Maintenance, TPM, and RCM are frequently mentioned in the literature as methods used for improving these two management areas. There are several examples of problematic or failed introductions of TQM and TPM. Therefore, it is of interest to compare experiences of introducing TQM and TPM with the introduction of RCM. This knowledge would increase the understanding of introducing RCM, presented in Section 8.5.

In the summary of Papers II and IV, the concept ‘RCM implementation’ is used, which is quite common in this type of research. However, over time, the author found it more convenient to use the concept ‘RCM introduction’, as
‘implementation’ many time aims at the specific phase when implementing the analysis recommendations, see Chapter 3 for further discussion on this matter.

8.2 Different approaches of managing risk analysis

A comparative study based on three independent risk analyses, called A, B and C, performed in one specific hydropower plant, is presented in Backlund & Hannu (2002) and included as Paper I in the Appendix. An effective use of resources can be achieved by using risk-based maintenance decisions as guidelines for where and when to carry out maintenance. However, from the comparative study, described in the paper, the choice of risk analysis approach seems to have a major impact on the identification of risk sources, in magnitude and location. Several factors, which most likely affect the quality of the risk analysis results, were also identified.

Risk analysis results can be viewed from various perspectives. It is useful to identify individual and asset risks when the most serious risk sources are of interest. Total individual or total asset risk is of interest when comparing risk costs between different plant systems or subsystems. The total asset risk, measured as the sum of all asset risks, was generated and presented in various magnitudes and units among the analyst teams. The total asset risk in risk analysis A was about five times larger than that of risk analysis B. In risk analysis C a qualitative approach was used in which no translation from risk numbers to asset risk cost was made. The results of the analyses are summarised in Figure 8.1. Here, the bars express the percentage of the total estimated asset risk in each risk analysis, divided among 10 subsystems within the plant. There are major differences among the risk analyses with respect to the distribution of asset risks. For example, in risk analysis A, the turbine represented 42% of the total asset risk, while it represented only 2% in risk analysis C. To scrutinise the total asset risk further, the largest risk sources in each subsystem have been identified and presented in the paper.
There were also big differences in distribution of risk sources within the subsystems. For example, in risk analysis B the risk sources “traversing wheel chamber in bad condition and hit the traversing wheel” was the largest individual asset risk source and represented 67% of the turbine’s asset risk, while for risk analysis C “drainage arrangements” represented 63%. However, there are also some similarities in the identification of risk sources. For example, stator failure in the generator subsystem was identified in all three risk analyses, representing different proportions of the total risk but approximately the same share of the generator risk.

As for the asset risk, there were major differences in identified individual risk sources. For example, risk analysis A identified the generator as a source of high individual risk, while risk analysis C identified building structures. The total individual risk was difficult to estimate since the analyst teams used different units of measurement. Risk analysis B identified maintenance routines while the other two focused on physical assets.

The comparison of the risk analyses showed major differences in approach and results. Therefore, in order to make proper risk-based maintenance decisions, careful interpretation of the risk analysis approach and its results is necessary. Decisions based on misleading results may generate major maintenance efforts.
on uncritical systems, while failing to reduce or eliminate significant sources of risk will lead to unsatisfactory safety levels. Because of the resource limitations the risk analyses could only be regarded as preliminary. According to the analyst teams, subsystems containing serious risks should be analysed further. However, even if the risk analysis approaches differed, it is the authors’ opinion that the serious risks identified should have been similar in location and magnitude. By means of a cause-and-effect diagram, see Figure 8.2, the factors most likely to affect the quality of results are identified on the basis of the evaluation of the three risk analyses. These factors are discussed in the paper.

![Figure 8.2](image-url)

*Figure 8.2. By means of a cause-and-effect diagram, factors that affect the quality of a risk analysis are identified. From Backlund & Hannu (2002).*

From the comparative study it cannot be firmly concluded that a certain approach generates certain results, or that some types of risk analyses can be considered better than others. What can be learnt from the comparative study is that careful preparation, ensuring a systematic approach with clear aims and goals, is needed when performing a risk analysis. A standard such as IEC 60300-3-9 can be used to facilitate the performance. The client needs to have sufficient competence to evaluate and understand the approaches to and results of risk analyses performed. For the analyst team, it is important to understand what the client considers to be an acceptable level of risk for individuals, environment, and assets. The study established the importance of a well-planned requirement specification and the need to analyse and interpret risk analysis results before making maintenance decisions.
8.3 RCM - A method of working

The conference theme during the International Conference of Maintenance Societies, ICOMS, in Brisbane 2002, stated by the Conference Chairman, was:

*For too long, industry has relied upon procedures and structures to bring about change, be it safety, costs, or reliability. Often this has not been successful, and work patterns, philosophies and attitudes have reverted. Today’s maintenance engineers must have an understanding of not only the equipment and technology employed, but of leading organisational change: changing and challenging the attitudes of production, maintenance, engineering, and management.*

*Adrian Rex*

The author presented a paper (Backlund, 2002) at the conference, included as Paper II in the Appendix. The main purpose of that paper was to create awareness of RCM as a method of working, influencing systems and people when implementing RCM on full-scale basis. Driving forces and obstacles presented, identified from the single-case study, were divided into two main areas, both including necessary conditions to obtain a maintenance performance based on RCM, according to Figure 8.3.

![Figure 8.3. Necessary preconditions for managing RCM implementation. From Backlund (2002).](image)

The implementation of RCM within an organisation was described as a human activity system, i.e. a system of actors trying to change the way maintenance is performed. This is inspired by Pidd (1999). The implementation was likened to a transformation process, where input was converted into output, and then passed on to the customer, see Figure 8.4. In this case, the input was the original maintenance performance, mainly based on custom and usage. The system view emphasises the fact that actors, all of whom must be identified and all of whom must be committed to the process, achieve transformation. This involved a holistic approach to RCM implementation. The output desired by the customer, the client, was systematic maintenance performance based on RCM analysis. The actors are the ones who carry out the activities, consisting mainly of an RCM project group and plant groups. Some actors represent the client, 10

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10 The maintenance performance on an operational level was performed by an entrepreneur, and Vattenfall AB Vattenkraft is here seen as the customer, or client.
acting as decision-makers in the review procedure. Environmental constraints that may affect the RCM introduction should also be recognised. These can include other ongoing projects and changes in corporate strategic directions. However, in the paper no emphasis was placed on environmental constraints or on the project group in itself. Instead it considers the group’s efforts to manage and control the planning and preparation.

Figure 8.4. RCM implementation viewed as a transformation process, based on the input–output system, inspired by Pidd (1999). From Backlund (2002).

Initially, RCM could be seen as providing a structured approach to managing fundamental functions within maintenance management. As the current maintenance programme and maintenance performance are often based on usage and custom, the implementation could lead to a major change in the current way of performing maintenance in the organisation. Therefore, the planning and preparation of the implementation have to concern the necessary preconditions for implementing a new way of working within the organisation, where achieving organisational commitment becomes a major issue. The current status of the organisation as regards the motivation for organisational change needs to be reviewed. Also, whether technical support systems and information and communication routines are available has to be evaluated. The results of this comparison will indicate whether the level of organisational and technical maturity is sufficient to enable RCM implementation.

A strategy framework was proposed in the paper for facilitating RCM implementation in the hydropower industry. The proposed strategy recognises the relation between managing the implementation of RCM and managing organisational change. The overall introduction strategy framework presented in this paper is not completely in accordance with the strategy framework presented in the thesis. However, the steps presented are included in the strategy framework presented in Chapter 7.
8.4 An RCM requirement management approach

Top management commitment and support are a prerequisite for the initiation and ongoing introduction of RCM. However, senior or top management commitment can fade for various reasons, including an unforeseen increase of already considerable resource consumption (Jones, 1995; Moubray, 1997). It is a prerequisite that the senior management, at an early stage, understand how RCM fits into overall maintenance management, and what its aims and goals are. By means of comprehensive awareness and understanding of the resources needed to introduce RCM, and what benefits are to be expected, sustainable top management commitment is more likely to come about. Many of these issues are likely to affect the middle management and employees as well. In the paper Backlund & Akersten (2003), included as Paper III in the Appendix, an RCM requirement management approach was presented. The identification of the requirements that the introduction of RCM places on the organisation, and on the existing maintenance programme, should increase the possibility of successful RCM introduction.

To create an RCM-based maintenance programme, the many tasks to be dealt with when introducing RCM had to be seen from various management perspectives. Findings from both the literature and case studies indicated that we had to use a holistic view to identify the requirements to be met by the organisation, as well as by the existing maintenance programme. Therefore, many stakeholders must be taken into account in an RCM introduction. Their needs, demands, and expectations have to be identified, transformed into requirements, and dealt with. The above descriptions and views of RCM have much in common with a process view. Therefore, by applying process and requirement management principles, requirements when introducing RCM could be identified, which should prevent obstacles from turning up later on in the introduction. Using a process view, we can focus on the various subprocesses, activities, actors, and systems involved in an RCM introduction process, which facilitates the identification and specification of requirements. The introduction of RCM can be seen as a core process, the various phases of which can be regarded as subprocesses. These are in turn supported by support processes and management processes. Analysing the processes in Table 8.1 allows us to identify a wide range of customers and other interested parties.
Several obstacles that may turn up during RCM introduction had been described on the basis of a case study. The knowledge of these obstacles was used to reveal the usefulness of process and requirement management as a way of working with RCM requirement management. The case study example does not go into excessive detail, since an RCM introduction looks different depending on the organisation, with differences in terms of aims, goals, and environment. Examples of obstacles, stakeholders and requirements are presented in Table 8.2.

Table 8.2. Examples of obstacles, stakeholders, and requirements in the RCM introduction process. From Backlund & Akersten (2003).

<table>
<thead>
<tr>
<th>Obstacles</th>
<th>Stakeholders</th>
<th>Types of requirements</th>
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<tbody>
<tr>
<td>A common computerised maintenance management system (CMMS) is not available.</td>
<td>- Maintenance manager</td>
<td>The CMMS would provide information for maintenance optimisation.</td>
</tr>
<tr>
<td></td>
<td>- RCM analyst</td>
<td>The CMMS would provide information support for analysis.</td>
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<tr>
<td></td>
<td>- Information system</td>
<td>The various stakeholders’ requirements for CMMS will guide the development efforts.</td>
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<tr>
<td></td>
<td>provider</td>
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<tr>
<td></td>
<td>- Maintenance personnel</td>
<td>The CMMS would provide simple means of reporting, information retrieval, and follow-up.</td>
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<td></td>
<td>- Operators</td>
<td></td>
</tr>
<tr>
<td>RCM computer system is not available.</td>
<td>- RCM team</td>
<td>The RCM computer system would provide a simple means of documentation, information retrieval, and follow-up of RCM analysis records.</td>
</tr>
<tr>
<td>Category</td>
<td>Action</td>
<td>Description</td>
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<td>-------------</td>
</tr>
<tr>
<td>A plant register is not available.</td>
<td>RCM team, Maintenance manager, Maintenance personnel</td>
<td>The plant register would provide system structure, and information of components, equipment status and history.</td>
</tr>
<tr>
<td>System descriptions are unavailable or incomplete.</td>
<td>RCM team, Maintenance personnel</td>
<td>System descriptions would provide information of system composition and use in order to facilitate analysis.</td>
</tr>
<tr>
<td>Common maintenance terminology is not available.</td>
<td>Maintenance manager, RCM team, Maintenance personnel, Designers of systems and equipment, Contractors</td>
<td>The use of a common terminology would facilitate interpretation of requirements and information exchange between different stakeholders.</td>
</tr>
<tr>
<td>An overall maintenance-management strategy is lacking.</td>
<td>Introduction project manager, Maintenance manager, Maintenance planner, Information system provider, Maintenance personnel, Contractors</td>
<td>A clear maintenance management strategy would provide guidance for the project work.</td>
</tr>
<tr>
<td>Goals and benefits are not focused on.</td>
<td>Introduction project manager, Maintenance manager, Maintenance planner, Upper management, Maintenance personnel</td>
<td>The goals and benefits of RCM introduction should facilitate understanding and commitment and reduce uncertainty regarding the work situation.</td>
</tr>
<tr>
<td>Measuring and monitoring of progress is unclear.</td>
<td>Introduction project manager, Maintenance manager, RCM analysts, Upper management</td>
<td>The system for measuring and monitoring progress should continuously point out excess resource consumption as well as obstacles. Moreover, it should make it possible to measure benefits, due to the introduction work.</td>
</tr>
</tbody>
</table>

### 8.5 Introduction of TQM, TPM and RCM – A comparison

Quality management, by means TQM, is considered to foster organisational performance characterised by competitiveness and long-term profitability. Since the benefits of quality management cannot be achieved without the sustained performance of equipment, which affects product quality, maintenance management has become more and more important. This has led to the
development of maintenance methodologies, such as TPM and RCM. However, TQM, TPM and RCM implementation has often failed or been poorly executed. This has affected organisations’ performance and ultimately their survival in a competitive environment.

In the paper Hansson et al. (2003), included as Paper IV in the Appendix, a comparative study is presented, focusing on organisational change during implementation of TQM, TPM and RCM. The paper aimed at facilitating the managing of commitment during implementation. One way of doing that was comparing experiences of obstacles and driving forces when implementing TQM, TPM and RCM. The comparison made it possible to identify common categories pertaining to commitment that are crucial for successful implementation. Such extended knowledge should facilitate implementation of TQM, TPM and RCM, contributing to the successful implementation of quality and maintenance management efforts.

The paper is based upon literature studies considering the introduction of TQM, TPM and RCM, presented in a report (Backlund & Hansson, 2002). The literature sources were chosen so as to identify common experiences pertaining to organisational commitment – important for successful implementation. The case studies were chosen so as to verify and develop the findings derived from the comparative literature study.

The comparative study led to identification of common categories, considered to be important when implementing TQM, TPM or RCM:

- **Support and leadership**, which involve making employees feel recognised, and visibly showing the significance of the implementation to motivate employees. The management should also consider the work environment, i.e. whether employees have the time and resources for improvement efforts. This is fundamental for ensuring that employees are willing to comply with the implementation.

- **Strategic planning**, which involves activities which link TQM, TPM and RCM to the company mission, vision and defined business strategy, and strategic priorities and goals. This gives a clear picture of how the improvement will benefit the organisation and promote desired achievements such as management and employee understanding.

- **Planning the implementation**, which involves developing a clear scope in order to identify obstacles and driving forces. This facilitates monitoring and follow-up and promotes such desired achievements as management and employee understanding and involvement. It also involves activities that promote the participation of all concerned parties (e.g., front-line
staff, unions, and management). The participation of employees promotes such desired achievements as involvement and ownership.

- **Buying-in and empowerment**, which involve such activities as selling the concept to each group, identifying what each group or level of employees and management want. Buy-in activities promote such desired achievements as involvement and ownership, and facilitate the identification and control of expectations. Empowerment activities, such as sharing responsibility, promote involvement, job satisfaction, independence and ownership among employees.

- **Training and education**, which involve activities that develop employee competence, skills and knowledge. Training promotes employees’ belief that the company is investing in them. It also supports understanding and awareness.

- **Communication and information**, which involve open and meaningful communication about aims and goals, and about the concept and how it will affect employees personally. Information and communication promote such desired achievements as understanding and involvement.

- **Monitoring and evaluation**, which involve such activities as obtaining measurable and quantified results and objectives, so as to have a clear scope and focus, and continuously monitoring and following through the process. This shows up progress and results that promote management and employee involvement and understanding. Employees have to see how they can personally benefit from the change, while management must see how it benefits the company. Monitoring and evaluation yields feedback on results that promote creation of a motivated management that continuously provides resources and support for the implementation. Such management also motivates and engages employees as they experience progress.

The knowledge gained from the study is summarised in Figure 8.5 as a structure of categories. The figure should facilitate the awareness and understanding of how to manage commitment during the implementation processes. The activities undertaken within these categories not only promote employee commitment during the change process, they also uphold and develop the management commitment that is a precondition for the activities undertaken.
Figure 8.5. Important categories in managing commitment when introducing TQM, TPM or RCM. From Hansson et al. (2003).

The figure depicts how management commitment – a prerequisite – affects the development and management of the categories of enabling activities, which are crucial for obtaining employee commitment. The performance of activities within each particular category promotes the achievement of intangible factors, such as understanding, involvement and ownership. Since activities undertaken within the categories also support and sustain management commitment, Figure 8.5 depicts a feedback loop from the important categories.

TQM, TPM or RCM implementation involves organisational change. It is imperative that management and employees are committed to the implementation. The management must address intangible factors such as motivation, engagement and acceptance, in order to nurture a willingness to change. In the current literature on implementation of TQM, TPM or RCM, an overall approach regarding the management of intangible factors seems to be needed. The important categories identified in this paper should contribute to such an approach.
TQM, TPM and RCM differ concerning their focus on organisational matters. TQM core values, and to some extent TPM, focus on achieving commitment and other intangible factors such as involvement and engagement. However, implementation often fails due to, for example, lack of commitment. Intangible factors, even if taken account of by TQM and TPM, are difficult to manage and handle. When implementing RCM, there is an additional difficulty since the method itself ignores organisational matters, which is reflected by the rare occurrence of literature on RCM implementation. To handle commitment, we need to be aware of the importance and difficulty of handling intangible factors. Therefore, RCM implementation requires an organisational focus, especially since RCM is often introduced in times of rationalisation (Harris & Moss, 1994) and changing of work routines (August, 1997), which affects job security. Since TQM, TPM and RCM implementation all require consideration of intangible factors, independent of any inherent organisational focus, successful implementation of for example RCM would probably facilitate implementation of the others.

Individual characteristics, such as attitudes and expectations, are also influenced by contextual aspects such as corporate culture (e.g. Kanji & Asher, 1993; McAdam & Duffner, 1996; Saad & Siha, 2000; Yamashina, 2000; Yusof & Aspinwall, 2000). The contextual aspects can be considered to be unique for each organisation, due to, for example, historical events, type of business, and environment. Therefore, contextual issues were not taken into account in the structure of important categories in Figure 8.5. An organisation aiming at implementing TQM, TPM and RCM must naturally consider their context when performing activities within important categories, but considering this is beyond the scope of this paper.
9 GENERAL DISCUSSION AND CONCLUSIONS

This chapter presents a supplementary discussion and conclusions of the results of the research presented in this thesis.

9.1 The research

The studied phenomenon in the presented research project is ‘RCM introduction’. Considering the problem area, described in Section 1.2, one might ask if the research is about RCM or managing an introduction process. Do we need to focus on RCM while cumbersome RCM introductions mainly seem to involve different kinds of managerial obstacles? For example, several authors claim that obstacles that occur during RCM introduction are many times not really connected with RCM, such as, for example, time-consuming analyses due to lack of failure data, a poor use of the CMMS, or lack of documentation (Schawn & Khan, 1994; Hipkin, 1998; Hipkin & DeCock, 2000). From a theoretical point of view, these opinions are of course correct. But what is the meaning of having a good idea if we cannot make use of it in practice? Therefore, according to the author, we have to focus on both the RCM concept and the RCM introduction when introducing RCM on a full-scale basis. RCM has to be viewed as a method of working, where actors, support systems and routines are an integrated part. However, as the introductions of RCM are many times complex and difficult, some people might advocate that an organisation should stick to simpler maintenance approaches and methods. However, it is essential to comprehend that maintenance is not an independent discipline and should be planned and performed with consideration to production requirements, and environmental and safety legislation. As discussed in Section 3.1.3, the use of RCM supports this view. To achieve a better understanding of why some organisations experience a cumbersome introduction of RCM, and to be able facilitating for an introduction of RCM, a couple of research questions were stated in Section 1.4:

- What characterises an RCM introduction?
- What managerial factors affect an RCM introduction?
- When and where do managerial factors affect an RCM introduction in the form of obstacles and driving forces?
- How can obstacles be reduced and driving forces reinforced?
Knowledge attained when answering these questions should be used to develop an RCM introduction strategy, facilitating the introduction of RCM for organisations. The first research question was aimed at increasing the understanding of why the introduction of RCM can become complex and cumbersome. Based on this research question a longitudinal single-case study has been performed and is described in Chapter 4. Also, the introduction of RCM in three other hydropower companies has been described in a multiple-case study, in Chapter 6, and more in detail in a research report, see Backlund (2003b). In the analysis of the longitudinal single-case study and the multiple-case study, in Chapters 5 and 6, managerial factors that influenced the introduction were identified. At the same time, the analysis indicated where these factors, in the form of obstacles and driving forces, affected the introduction, according to an introduction process. The analysis corresponds to the second and the third research questions. Based on the empirical studies, an RCM introduction strategy framework has been proposed, which implies that the aim of the research project has been fulfilled. Requirements and recommendations constitute the central components in the strategy framework, which is in accordance with the last research question.

9.2 Empirical versus theoretical findings

Many of the factors identified in the case studies are, on an overall level, similar to the factors identified in the literature studies on RCM in Section 3.3.4. Similarities and differences will be discussed below.

RCM management
The factors in the literature study concerning RCM management were mainly in accordance with the factors identified in the case studies. As managing RCM analysis usually is focused on in the literature, the similarities between the empirical and theoretical findings are naturally. However, the view of RCM, as a factor affecting the introduction of RCM, was identified in the case studies.

Maintenance management
Concerning maintenance management factors, several authors pointed out difficulties when implementing the RCM analysis recommendations, see, for example, Hipkin & Lockett (1995), August (1997) and Rausand & Vatn (1998). According to Smith (1993) the implementation represents a new and perhaps greater challenge than performing the RCM analyses, as it can be difficult to change the recommendations into work orders, procedures or design changes. Furthermore, in a study by Hipkin & Lockett (1995), many companies studied had not adapted systems and procedures to support the changes recommended from the RCM analyses.
Implementation activities were not possible to study in the research project as the companies had just begun implementing RCM analysis recommendations. One of the companies had implemented changes in routine maintenance, but the work with continuous improvements was not going well. Documented experiences in the literature on an RCM living programme is mainly missing. Several of the studied companies considered RCM one method among many needed in maintenance management and the view of RCM as a method of working was not directly expressed in the project groups. However, over time they had become aware of a more holistic view on RCM. None of the companies emphasised TPM, TQM, or Integrated Logistic Support, ILS, as methods supporting or integrating with RCM, which was emphasised in the literature study. ‘Outsourcing’ was a factor that was only valid for the single-case study. The outsourcing situation was found to increase plant personnel’s understanding and acceptance of a more effective maintenance performance, as was provided by RCM. At the same time, the outsourcing situation could have an affect on the plant personnel’s feeling of ownership and responsibility for the assets.

**Project management**
The findings in the literature study on factors in a project management perspective were also identified in the case studies. Some differences were that the factors ‘project risk management’, ‘project group competence’ and ‘benchmarking’ were identified during the case studies. There was also a difference concerning control and monitoring. Making RCM a common way of working was emphasised in some of the case studies, since the RCM teams analysed in different ways, and reviewers performed differently in the review procedure. This lacks in literature indicate that the introduction of RCM on full-scale-basis, with the aim of changing the overall way of working with maintenance in an organisation, is not so much emphasised.

**Change management**
The factors in the literature study concerning change management were mainly in accordance with the factors identified in the case studies. However, the factor ‘planning and preparation for change’ was discussed in some literature sources, but not directly emphasised in the case studies. Most books and papers on RCM focus on the performance of the analysis, and more in-depth reliability management issues. However, there are not many findings in the literature that emphasise the interaction between managing RCM analysis and change management. During the case studies, several aspects of that kind of relationship have been identified. For example, too comprehensive analyses affect management commitment negatively. Lack of analysis traceability results in lengthy review procedures, in which motivation among analysis teams decreases. A diffuse RCM model creates problems for the RCM teams, as well for the communication to other personnel in the organisation. The
The interrelationship between RCM management and change management has to be acknowledged and managed, so as to create conditions for a successful RCM introduction process. The awareness of change management and project management is especially important in the changeover from the pilot study phase to the planning and preparation phase. During the pilot study phase, the focus is mainly on RCM analysis, while project and change management issues become more important to deal with in the coming phases.

Overall analytical validation
The overall comparison with literature findings can be seen as an analytical validation. The analytical validation, as a complement to the empirical validation further indicates that many of the findings in the case studies can be seen as general, and not only valid for the specific cases. One should also bear in mind that the findings in the literature are based upon experiences of many different types of industrial areas, and different kinds of technological systems. It is not possible from that material to make the conclusion that some findings are valid for some specific type of industry. The case study findings have lead to results that can be seen as valid for the hydropower industrial sector. However, the findings are probably valid for other kinds of industries with similar characteristics as the hydropower organisations. The case study findings, compared with the literature also reveal some other contributions to the research area. First, the case study findings make it possibly to more in-depth study RCM introduction, compared with some documented experiences in the literature. For example, why systems descriptions are needed, in what way a problematic CMMS becomes a severe obstacle, and in what way maintenance culture affects the introduction.

Nuclear organisations have in general a systematic and comprehensive maintenance programme and maintenance performance. However, the introduction of RCM is not too easy to manage in the nuclear industry either, see, for example, Bowler & Leonard (1994a), Bowler & Malcolm (1994) and Schawn & Khan (1994). It is interesting to note that many of the experiences from the hydropower organisations are in common with experiences in the nuclear industry. For example, managing involvement, different kinds of behaviour characteristics, and evaluating results. Also, the author has on several occasions had the opportunity to discuss RCM introduction matters with representatives of nuclear plants in Sweden, which has confirmed that many obstacles experienced are similar. That gives an indication of how difficult it can be to introduce RCM within a hydropower organisation, where the preconditions are normally less favourable. However, the significance of the industrial context when introducing RCM is also experienced in the nuclear industry. Worledge (1993b) gives an example of disappointing experiences of introducing RCM in the nuclear industry, when the RCM analyses were mainly performed by
contractors or corporate engineering departments. As a consequence no real ownership of the analysis work was experienced by the maintenance department. These problems were obvious in retrospect, but were not anticipated by the utilities concerned, because the same issues did not arise historically in the airline business (Worledge, 1993b). As a conclusion, the preconditions for success will change when moving from one industrial contextual to another. This should be of importance for managers to comprehend when, for example, performing and evaluating a benchmarking study.

A holistic view and RCM as a method of working
Another contribution of the research project is the focus on a holistic view when managing an RCM introduction. The many findings in the literature study are gathered from several literature sources, where usually one or some of the four management perspectives are focused on. As seen in the case studies, none of the management perspectives can be neglected if the RCM introduction is to be successful. To some extent, the relationships between the factors also have to be considered. Another main contribution that has been possible to generate from the research project, is the emphasis on viewing RCM as a method of working. This view is an essential precondition for managers being able to comprehend that the introduction of RCM will put major requirements on the organisation and the maintenance programme. The research project has also contributed to the development of a comprehensive RCM introduction strategy framework, which, as known to the author, is lacking in the literature.

9.3 The RCM introduction strategy framework
As the analysis, implementation and living programme phases were not really focused on during the case studies, the strategy framework, described in Chapter 7, is mainly focused on the planning and the preparation of these phases. However, planning and preparation could be seen as the most important part of the introduction process, which is also emphasised by different authors in Section 3.3.4. The initiation phase of the strategy framework is, however, not so much emphasised in the literature. According to Moubray (1997), one or two pilot studies enable an organisation to gain first-hand experience of the dynamics of the whole RCM process, what it achieves, and what resource commitments are needed to achieve it. It seems to be a common view that pilot studies give all this information. However, this has not been confirmed in the case studies. It is the author’s opinion that the initiation phase, presented in the strategy framework, is necessary to complete first.

The RCM introduction strategy framework has not been possible to test during the research project. However, it is the author’s opinion that the strategy framework should facilitate the work of hydropower organisations going to
introduce RCM. The requirements and recommendations involved have been experienced as important by several of the hydropower organisations studied. Some aspects that seem to be of specific concern for a hydropower context are a focus on managing change, intangible benefits and a common way of working. Much of the maintenance programme and maintenance performance had for a long time been based on usage and custom, and the spread of plants and regions led to different subcultures. These conditions imply that an introduction of RCM may become a major change for an organisation. Therefore, managing change seems to be especially important to consider in a hydropower context. Trade workers, in general, seem to have good plant knowledge and skills in routine maintenance execution. However, maintenance analysis and optimisation are in general lacking. Making these people comprehend analysis work would probably generate major benefits. A more professional way of working with maintenance would also contribute to improved satisfaction among the maintenance personnel. Another aspect on this issue is that a main cause of the high costs of introducing RCM is in fact all the people involved. It is therefore important to focus on and measure these kinds of benefits, as they may be the most important benefits for the company in the long run. A common way of working with RCM in the organisation is a precondition for working effectively with continuous improvements, for example, using a similar database and sharing experiences of failure modes. The geographical spread of plants and regions contributed to differences in maintenance performance between plant groups. In some companies the regions were even regarded as ‘companies in the company’. These conditions should make it especially important, and at the same time difficult, to make RCM a common way of performing maintenance among the regions.

As the strategy framework developed is based upon experiences from hydropower organisations, one might ask whether the strategy might be suitable for other kinds of industry? As has been discussed earlier, many of the findings are similar to findings in other types of industry. It is the author’s opinion that the requirements and the recommendations in the strategy framework strategy could on the whole be useful for other types of organisations, especially within the basic industry.

The only comprehensive RCM introduction strategy found in the literature study was presented in Schawn & Khan (1994), based upon experiences of introducing RCM in nuclear organisations. As discussed earlier in this chapter, there exist contextual borders between, for example, safety-driven industry and basic industry. Therefore, a strategy developed for a nuclear environment has to be carefully scrutinised before applied in, for example, a hydropower environment. However, even if the strategy is of interest, it is difficult to evaluate, as the background and development of the strategy recommendations are more or less
lacking. A strength in the proposed strategy in this thesis, according to the author, is that the requirements and recommendations can be directly linked to case descriptions and discussions, which improve the comprehension and interpretation of the requirements and recommendations. Without this background knowledge requirements could be ignored, as a ‘user’ might at first find one or several of these too demanding to execute. However, as described in the cases, such a “short cuts” will generate problems later on. Finally, the requirements in the strategy framework could also be used by companies to evaluate the maturity of introducing RCM in their organisation, a kind of maturity model.

According to Mokashi et al. (2002), the lack of a defined approach for introducing RCM could be overcome by the use of TPM, which is seen as a more holistic approach. There are also advocates for integrating or combining TPM and RCM, according to, for example, Geraghty (1996), Ben-Daya (2000) and Mokashi et al. (2002). According to the comparative study performed between introduction experiences of TQM, TPM and RCM, presented as Appended paper IV, there are several examples of problematic or failed TPM introductions as well. There are also major differences between the methods, and scope, which, according to the author, makes it necessary to have an introduction strategy for each concept. However, even if the study was on an overall level, there were also clear similarities between the ways in which the introductions of the three concepts were managed, especially as regards the managing of commitment. Therefore, the experiences of introducing one of the concepts may be very useful when introducing one of the other concepts, as was also discussed in the paper.

9.4 The single-case study – A performance evaluation

A criterion for successful RCM introduction could be that the total earnings of the introduction supersede the total costs associated with it. However, the single-case study was completed when the analysis and implementation phase had begun. As the RCM introduction process is still going on at Vattenfall\(^{11}\), it is not yet possible to draw any conclusion about whether the introduction will be successful or not. However, even if the living programme phase had been completed, some measuring and evaluation problems are related to the above criterion. For example, a relatively long time before results can be measured seems to be needed, and it may be difficult to distinguish between RCM efforts and other improvement efforts taking place simultaneously. In this section, the focus is on performance evaluation of the introduction process, where it should be possible to give some indications based on the evaluation criteria presented in Section 3.2.

\(^{11}\) April 2003
The introduction of RCM at Vattenfall has been very resource consuming and been going on for a considerably long time. A measurement and evaluation plan is not available and relative few potentials of RCM, tangible and intangible, have been focused on in the project specifications. These circumstances have made it difficult to measure and evaluate progress and benefits of introducing RCM. The benefits and goals focused on are mainly in accordance with the senior managements’ expectations and needs, where incitements for employees are to some extent lacking. As the analysis and implementation phase had only begun when the case study was completed, it is difficult to make a judgement about the quality of the analyses or the implemented changes. However, the preconditions for the living programme phase can be discussed. A CMMS is not available, even though the issue had several years before been identified as significant for a living RCM programme. The development of a maintenance management strategy is another extensive task that they are still working on in the Vattenfall Vattenkraft organisation, and have recently started in the entrepreneur organisation. Maintenance management strategies and processes in both organisations are especially important due to the outsourcing situation. For example, matters such as ownership, responsibility and discharge issues of systems and routines must be very clear. According to the analysis of the present situation, see Section 4.11, employee commitment was in general not sufficient. There are several managers and employees that still, in different degrees, felt uncommitted to RCM. The unclearness regarding further resources for completing the introduction to all plants is also a major risk for a failed living programme, which also contributed to the shortages in organisational commitment. There is a risk that these issues, in combination with a stressful work environment, will severely affect the preconditions for managing the RCM living programme phase.

These facts indicate a cumbersome RCM introduction where the preconditions for a successful introduction have decreased over time. At the same time, the introduction of RCM has been, and still is, of great importance for making the maintenance management more effective and systematic. For example, technical support systems, routines, documentations and maintenance culture, which all may be seen as fundamentals in maintenance management, have been focused and worked on. Completing some of these parts of maintenance management will generate major benefits for the organisation. One could conclude that an introduction of RCM provides a structured approach to improve maintenance management in general. The project group, at the Prestudy stage, made similar considerations. Therefore, even if the introduction of RCM would be seen as unsuccessful, the benefits gained during the introduction could be viewed as successful. As discussed in Chapter 7, introducing RCM could be seen as a long-term goal, almost as a vision. This is something the project groups should
make managers and employees comprehend. At the same time, the project
groups should more clearly, and quickly, identify and present subgoals
concerning the improvements of maintenance management. In this way, the
possibility of a successfully RCM introduction should increase.

The reasoning about successful versus unsuccessful introduction has also to do
with expectations in the organisation, especially from senior management. For
example, in the beginning of the pilot study phase, in 1997, the intention was
that RCM should have been completely introduced to all plants already in 1999.
If the senior management had recognised RCM as a method of working, and the
many management perspectives to be considered, the expectations of results and
resources would probably have been different. Therefore, a successful or
unsuccessful introduction must be judged in the light of the expectations and
preconditions settled in the beginning of the introduction.

However, it is important that management and employees experience the
introduction of RCM as successful, as major resources and efforts have been and
still are being invested in the project. Another major reason is that both
managers and employees in the organisations have experienced previous
unsuccessful improvement projects. Several people in the organisation were of
the opinion that if the RCM introduction should fail, the beliefs and motivation
of employees and managers for further improvement projects would be severely
damaged.

9.5 RCM and strategic management
A question is why the management aspects of introducing RCM many times are
lacking, especially considering that introduction processes are heavy
investments of resources? It seems as if almost only technical personnel, such as
engineers, are involved when introducing RCM, and people with comprehensive
change management skills are lacking. This is probably an explanation of why
change management and intangible issues when introducing RCM are ignored or
only vaguely focused on. At the same time, many of the intangible benefits of
using RCM seem to be of high value for the hydropower organisations. Another
explanation might be that RCM is a technology-orientated method compared
with, for example, TPM. This might have resulted in a focus among
practitioners and researchers on technical aspects, overshadowing the
importance of management aspects when introducing RCM within an
organisation. This can be a main reason why obstacles occur when introducing
RCM, since facilitating measures and actions focus too much on technological
aspects instead of organisational and management aspects. The use of RCM as a
management function seems quite simply not to have been recognised to a larger
extent. A comparison can be made with the evolution of the quality area, which
has been developed from a focus on inspection and quality assurance to a strategic quality management focus (Garvin, 1988; Dale, 1999; Bergman & Klefsjö, 2003). The use of RCM today might be at the same phase as the quality area was some 15 years ago, when the focus was on quality assurance, and the importance of strategic management was not yet widely recognised.

9.6 Suggestions for further research

The scope of the research project was mainly on the part of the introduction process before the analysis and implementation phase. The literature findings indicate that major difficulties may occur during the implementation of the analysis recommendations. This means that when all the planning and preparation work, including the analysis work, should finally make real changes in the current maintenance programme, there is a major risk that the introduction progress declines. Several of the obstacles during implementation probably have their roots in the planning and preparation phase. However, it would generate valuable knowledge to follow the implementation work more closely. The same point is made about the living programme phase, which is sparsely documented in literature.

It would also be of interest to study more carefully the measuring, evaluation and realisation of different goals and benefits expected from the RCM introduction. Most of the companies studied focused on decreasing routine maintenance, and intangible benefits were only vaguely focused on. To be able to study an introduction where many of the RCM potentials are focused on and measured, as regards for example design modifications, hidden failures, improvements of skills and knowledge, would be very interesting. Also, measuring and evaluating the effect of RCM several years after completed introduction would be of great interest.
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Can we make maintenance decisions on risk analysis results?
Can we make maintenance decisions on risk analysis results?

F. Backlund and J. Hannu
Centre for Dependability and Maintenance, Luleå University of Technology, Luleå, Sweden

Keywords Maintenance, Decision making, Risk

Abstract For several branches of industry, an increasingly competitive environment has raised important questions concerning maintenance in plant systems. For example, the 1996 deregulation in Sweden's electricity sector has resulted in increased competition among the country's power producers. To survive the competition, suppliers have to reduce maintenance costs, i.e. handle maintenance more efficiently. Risk analysis is one tool decision makers can use to help them prioritise as they plan maintenance actions. There are a number of different approaches to risk analysis. As the results of an analysis must form a reliable basis for decision making, it is important to consider whether the quality of the results will vary significantly with the risk analysis approach chosen. This paper presents a comparative study based on three independent risk analyses performed on a specific hydro-power plant. The comparison and evaluation of the analyses reveal major differences in performance and results, along with various factors that affect the quality of the analyses. The study establishes the importance of a well-planned requirement specification and the need to analyse and interpret risk analysis results, before making maintenance decisions.

Practical implication
An effective use of resources can be achieved by using risk-based maintenance decisions to guideline where and when to perform maintenance. However, from the comparative study described in this paper, the choice of risk analysis approach seems to have a major impact on the identification of risk sources, in terms of magnitude and location. Several factors most likely to affect the quality of the risk analysis results are identified. What can be learnt from the study is that careful requirement identification, ensuring a systematic approach with clear aims and goals, is needed when performing risk analysis. The client needs to have sufficient competence to evaluate and understand approaches and results from the risk analysis performed. When well planned, the client of a risk analysis can more easily control, interpret and evaluate the risk analysis and thereby obtain reliable results, avoiding maintenance efforts spent in less important areas.

For their valuable suggestions and improvements to this paper, the authors would like to thank Per-Anders Akersten, Adjunct Professor of System Reliability; Uday Kumar, Professor of Maintenance Engineering; and Erik Höglund, Professor of Machine Elements, Centre of Dependability and Maintenance, Luleå University of Technology, Sweden. They would also like to thank the personnel at Vattenfall AB Vattenkraft, Division of Power Facilities, for their support.
Introduction

The prioritisation of maintenance measures in plant systems has become increasingly important within several branches of industry due to increased competition. For example, the Swedish electricity market was deregulated in 1996, which led to increased competition between power producers and, consequently, a major reduction in price. In order to maintain profit margins, power producers have to control maintenance costs. In so doing, they need to minimize or eliminate risks to individuals, the environment and assets. A risk is defined here as the:

...combination of the frequency, or probability, of occurrence and the consequence of a specified hazardous event (IEC60300-3-9, 1995).

In order to identify risks in terms of where they are located in a system and how serious they are, risk analysis is often used. The results of a risk analysis can provide guidance as to where maintenance actions should be directed. For example, maintenance methods such as reliability-centred maintenance (RCM) use function analysis in combination with risk analysis in prioritising maintenance actions, according to Nowlan and Heap (1978), Sandtorv and Rausand (1991) and Moubray (1991). There are many different opinions regarding what a risk analysis implies, how it should be performed and what terminology should be used (see for example, Townsend, 1998; Rouhiainen, 1993; Backlund, 1999). Fundamental steps when performing a risk analysis of technological systems are described in the standard IEC 60300-3-9 (see Figure 1).

To facilitate maintenance decision making, the different steps in the process have to be carried out carefully by a group of people which should have access to additional expertise if needed (IEC60300-3-9, 1995).

Since there are various ways to perform a risk analysis, it is of interest to investigate whether the approach used affects the analysis results, i.e. the identification of risk sources in terms of their location and magnitude, and consequently the basis for maintenance decision making. In this paper, a comparative study is presented based on three independent risk analyses performed to evaluate the impending risks in a selected hydropower plant. The aim of the study was to investigate whether different risk analysis approaches give similar results. Furthermore, factors that might affect the results of the risk analyses were considered.

The specific hydropower plant, in operation since 1959, has two units, a total power output of 90MW, and an annual energy production of approximately 390GWh. A major power supplier in Sweden presented a requirement specification to three consultant companies, working independently of each other, to perform a risk analysis of a plant. The main aim of the purchase was to evaluate and compare approaches and methods used in the different risk analyses, and to use the knowledge gained to ensure the quality of risk analysis results in the future. Other aims stated in the requirement specification distributed to the consultants included:
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- identify individual and asset risks;
- evaluate the need of input data; and
- receive recommended actions to eliminate or reduce risk sources.

The purchase gave the authors a unique opportunity to investigate whether different approaches significantly affect the quality of risk analysis results by comparing and evaluating the three risk analyses. The companies were selected based on their varied experience in performing risk analyses. The consultants, hereafter called analyst teams, had to estimate the depth of their analysis taking resource limitations into consideration, where an amount of approximately €36,000 was available for each analysis. The companies received the requirements specification in December 1997, and their final reports were delivered in April 1998.

**Method and material**

The analyst teams did not know the identity of the other companies, but they were aware that an evaluation of their approaches and results would take place based on their final reports. To ensure that neither the requirement specification nor the risk analyses would be affected by the authors’ analysis work, the comparison is based on mainly the final reports delivered by the analyst teams. Afterwards, the analyst teams from each company were contacted to confirm some of the conclusions made from the evaluation of the reports. The criteria given in the IEC 60300-3-9 standard constituted a basis for evaluation and comparison of the risk analysis approaches.

*Summary of risk analyses performed*

The approaches used by the teams cannot, of course, be fully presented in this paper. Based on an internal report made by the authors (Hannu and Backlund, 1999), a summary of the approaches follows. The headings represent the steps in the risk analysis process (see Figure 1), with a general background and the results generated from the analyses.

**Background.** Analyst team A had extensive experience in the hydropower industry and used a quantitative risk analysis approach based mainly on reliability data from different sources. Four specialists with professional backgrounds chiefly in civil, mechanical and power engineering performed the analysis.

Analyst team B had no experience in performing risk analyses within the hydropower industry, and the risk analysis approach used was mainly qualitative, since the availability of reliability data was considered insufficient. Two persons performed the analysis, and their professional backgrounds were mainly in system economy and system safety.

Analyst team C had some experience in the hydropower industry and used a relatively simple qualitative risk analysis approach. The approach was based on the assumption that available data for creating a dependable statistical base are usually inadequate or uncertain. The analyst team consisted of four experts in mechanics, electricity, ventilation, structures, buildings and dams.
Scope definition and documentation of risk analysis plan. All companies determine scope definitions, limitations and assumptions for their analysis work. Analyst teams A and B referred to their course of action in performing the analysis as theoretical reasoning, where A was relatively overarching while B described a systematic approach. Analyst team C presented an overarching stepwise plan. However, none of the teams presented a concrete plan describing and explaining why some steps or methods should be used.

Hazard identification and initial consequence evaluation. None of the analyst teams performed an initial consequence analysis, i.e. a rough preliminary analysis to provide guidance as to where it was most important to start up the main analysis. They made observations at the plant, and the involvement of
plant personnel was to some extent used in each analyst team’s approach. However, during their on-site observations the analyst teams were unable to gather as much plant personnel as they wanted. Analyst team A had access to reliability data and information from its experience of risk analysis in the hydropower and nuclear industries. Other data and information sources were listed in the report, but how and to what extent the listed sources were actually used is not stated. A description of the plant and its subsystems was presented to some extent by means of a functional block diagram. Hazard identification was performed by means of checklists, FMECA (failure mode and effect critical analysis), and fault trees (the fault tree and the FMECA are performed for the local power system, where the methods are considered to be suitable). Analyst team B collected data from some drawings and circuit diagrams. To support hazard identification, fault trees for three scenarios (top events) and checklists were used. The checklist was relatively brief; according to the teams, this was due to their limited experience with the hydropower sector. A block diagram was used to describe the system to some extent. Analyst team C based its analyses mainly on observations and did not use any formal risk analysis method to identify hazards.

Risk estimation. All analyst teams performed a consequence analysis based on their own experiences. Due to its access to reliability data, team A performed a mainly quantitative frequency analysis, while teams B and C used qualitative judgements. All analyst teams presented three levels of severity based on their risk aggregation. However, the risk aggregation approaches differed among the teams. Teams A and B focused mainly on total asset risk and the division of risk sources to different subsystems. Team C focused more on major individual and asset risks and used a qualitative approach, in which no translation from risk numbers to asset risk cost was made. Unlike analyst team B, teams A and C considered exposure time when estimating risk. Only team A performed an uncertainty analysis; however it did so only on individual risks. The team considered the relatively limited resources for performing the analysis, given in the requirements specification, as a reason not to spend more time on further analysis of uncertainty. The limited resources are also the reason why team B discussed only the importance of uncertainty analysis. None of the analyst teams performed or discussed the need for sensitivity analysis.

Analysis verification. None of the analyst teams used analysis verification by people outside the analysis process.

Documentation of risk analysis report. None of the three reports provided sufficiently detailed descriptions of steps taken, choices made, and information sources available and used. Much of the material in the report from analyst team A is contained in appendices, which makes it difficult to see connections to the analysis work performed. Team B’s theoretical description of the performance of a risk analysis presented a structured and systematic approach. However, the work and results presented do not completely follow the approach described. Neither the number of people performing the analysis work nor their professional backgrounds was stated in analysis A or B.
Analyst team C’s report was structured, although it used a relatively simple approach.

*Analysis update.* An analysis update is a standard and fundamental step within risk analysis. However, this step is not relevant in this study since only initial risk analyses are performed.

**Summary of risk analysis results**

Risk analysis results can be viewed from various perspectives. It is useful to identify individual and asset risks when the most serious risk sources are of interest. Total individual or total asset risk is of interest when comparing risk costs between different plants or subsystems.

*Asset risk.* In risk analyses A and B, the total asset risk, measured as the sum of all asset risks, was estimated at approximately 268,000 respectively 42,000 per year. In risk analysis C, a qualitative approach was used in which no translation from risk numbers to asset risk cost was made. In Figure 2, the bars express the percentage of the total estimated asset risk in each risk analysis, divided among ten subsystems within the plant. To scrutinise the total asset risk further, the largest risk sources in each subsystem have been identified (see Table I). The percentage each risk source contributes to the risk of each subsystem is also given in the table.

*Individual risk.* The most severe individual risk sources identified in the analyses are listed in Table II.

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**Figure 2.**
The comparison of results from the three risk analyses illustrated.
<table>
<thead>
<tr>
<th>Risk analysis A</th>
<th>Risk analysis B</th>
<th>Risk analysis C</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Generator</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Asynchronous or unjustified supply 32 per cent</td>
<td>All of these risk sources are responsible for 11 per cent each of the total generator asset risk:</td>
<td>Monitoring equipment 36 per cent&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>Stator failure 26 per cent&lt;sup&gt;a&lt;/sup&gt;</td>
<td>Foreign objects in the generator cause damage</td>
<td>Stator 16 per cent&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>Wrong signals from sensors&lt;sup&gt;b&lt;/sup&gt;</td>
<td>Excitation equipment 14 per cent</td>
</tr>
<tr>
<td></td>
<td>Cease of thrust bearing lubrication&lt;sup&gt;c&lt;/sup&gt;</td>
<td>Generator bearing 11 per cent&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>Burnt stator windings&lt;sup&gt;a&lt;/sup&gt;</td>
<td>Brake and lifting device 10 per cent&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>Water in stator windings&lt;sup&gt;a&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Water in thrust bearing&lt;sup&gt;c&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Unintentional braking during operation&lt;sup&gt;d&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Start of fire when brakes are put in use&lt;sup&gt;d&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Brakes slip&lt;sup&gt;d&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td><strong>Turbine</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Breakdown in traversing wheel hub 56 per cent&lt;sup&gt;a&lt;/sup&gt;</td>
<td>Traversing wheel chamber in bad condition and hit the traversing wheel 67 per cent&lt;sup&gt;a&lt;/sup&gt;</td>
<td>Drainage arrangements 63 per cent</td>
</tr>
<tr>
<td>Traversing wheel chamber 29 per cent&lt;sup&gt;a&lt;/sup&gt;</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Transformer</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Short-circuit 61 per cent&lt;sup&gt;a&lt;/sup&gt;</td>
<td>All of these risk sources are responsible for 25 per cent each of the total transformer asset risk:</td>
<td>Phase R, S, T 67 per cent&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>Three-phase unit breakdown 31 per cent&lt;sup&gt;b&lt;/sup&gt;</td>
<td>Spark-over in T1&lt;sup&gt;a&lt;/sup&gt;</td>
<td>Reactor X1 10 per cent</td>
</tr>
<tr>
<td></td>
<td>Overheating in T1</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Thunder</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Overload at the 200kV line</td>
<td></td>
</tr>
</tbody>
</table>

(continued)
<table>
<thead>
<tr>
<th>Risk analysis A</th>
<th>Risk analysis B</th>
<th>Risk analysis C</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Water path</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hydraulic system of intake gates 50 per cent&lt;sup&gt;a&lt;/sup&gt;</td>
<td>Trash pass ice gate 29 per cent</td>
<td>Intake gates (electrical) 48 per cent</td>
</tr>
<tr>
<td>Water level exceeds maximum permitted water level 50 per cent</td>
<td>Leakage through guide vanes 29 per cent</td>
<td>Intake, shutting off (mechanical) 36 per cent&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td><strong>Wiring</strong></td>
<td>No risks identified</td>
<td>Wiring out of requirements specification 100 per cent</td>
</tr>
<tr>
<td><strong>Local power</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Malfunction in DC component 25 per cent&lt;sup&gt;a&lt;/sup&gt;</td>
<td>Battery system out of requirements specification 100 per cent&lt;sup&gt;a&lt;/sup&gt;</td>
<td>DC distribution 53 per cent&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Malfunction in AC component 75 per cent&lt;sup&gt;b&lt;/sup&gt;</td>
<td></td>
<td>Low-voltage distribution 21 per cent&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td><strong>Control unit</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No risks identified</td>
<td>No risks identified</td>
<td>Relay protection 41 per cent</td>
</tr>
<tr>
<td><strong>Building/structures</strong></td>
<td></td>
<td>Control equipment 27 per cent</td>
</tr>
<tr>
<td>No risks identified</td>
<td>No risks identified</td>
<td>Control room building 43 per cent</td>
</tr>
<tr>
<td><strong>Generator switchboard</strong></td>
<td></td>
<td>Machine station building 29 per cent</td>
</tr>
<tr>
<td>No risks identified</td>
<td>No risks identified</td>
<td>Generator switchboard 51 per cent</td>
</tr>
<tr>
<td><strong>Switchyard</strong></td>
<td></td>
<td>Switchyard 49 per cent</td>
</tr>
<tr>
<td>No risks identified</td>
<td>No risks identified</td>
<td></td>
</tr>
</tbody>
</table>

**Notes:** The percentage each risk source contributes to the risk of each subsystem is also given. Similar risk sources identified by the different analyst teams, in each subsystem, are marked<sup>a</sup>, <sup>b</sup>, <sup>c</sup> and <sup>d</sup>.
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Results from the comparison of the risk analyses
Results were generated and presented in various magnitudes and units. For example, the total asset risk cost for risk analysis A was about five times larger than for risk analysis B. In Figure 2 the total asset risk for each analysis was divided according to different plant subsystems. There are major differences among the risk analyses with respect to the distribution of asset risks. For example, in risk analysis A, the turbine represented 42 per cent of the total asset risk, while it represented only 2 per cent in risk analysis C.

From Table I it can be observed that there are big differences in distribution of risk sources within the subsystems. For example, in risk analysis B the risk sources “traversing wheel chamber in bad condition and hit the traversing wheel” was the largest individual asset risk source and represented 67 per cent of the turbine’s asset risk, while for risk analysis C, “drainage arrangements” represented 63 per cent. However, there are also some similarities in the identification of risk sources. For example, stator failure in the generator subsystem was identified in all three risk analyses, representing different proportions of the total risk but approximately the same share of the generator risk.

As for the asset risk, there were major differences in identified individual risk sources. For example, risk analysis A identified the generator as a source of high individual risk, while risk analysis C identified building structures. Total individual risk is difficult to estimate since the analyst teams have used different units of measurement. Risk analysis B identified maintenance routines, while the other two focused on physical assets.

From the risk analyses results and the different approaches used, as described in section 3, it can be concluded that the risk analysis approach chosen seems to have a major impact on the identification of risk sources, in terms of both their magnitude and their location.

<table>
<thead>
<tr>
<th>Risk analysis A</th>
<th>Risk analysis B</th>
<th>Risk analysis C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Risk of electrical accident in generator switchboard</td>
<td>Transformer, accidental release of carbon dioxide fire extinguisher</td>
<td>Ventilation, battery charging in telecommunication room (ventilation is missing), canal system (fire insulation is missing), fire propagation in control room building and machine station building (protection against combustion gas dispersion is missing)</td>
</tr>
<tr>
<td>Inter-locking device in voltage box</td>
<td>Dam and water path, leakage through spillway gate, inspection of spillway gate</td>
<td></td>
</tr>
<tr>
<td>High risk of asynchronous operation in the generator</td>
<td>Maintenance system/other cleaning of drainage in shaft</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Traverse crane, work with the traverse crane</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sump, drop related to climbing</td>
<td></td>
</tr>
</tbody>
</table>

Table II. Largest individual risk sources identified by the three analyst teams.
Discussion

Factors affecting the quality of the risk analysis

The comparison of the risk analyses shows major differences in approach and results. Therefore, in order to make proper risk-based maintenance decisions, careful interpretation of the risk analysis approach and its results is necessary. Decisions based on misleading results may generate major but non-essential maintenance efforts while failing to reduce or eliminate significant sources of risk, leading to unsatisfactory safety levels. Because of the resource limitations the risk analyses could only be considered as initial. Subsystems containing serious risks should be analysed further, according to the analyst teams. However, even if the risk analysis approaches differ, it is the authors' opinion that serious risks identified should have been similar in location and magnitude. By means of a cause-and-effect diagram (see Figure 3), factors most likely to affect the quality of results are identified based on the evaluation of the three risk analyses.

The requirement specification. The requirement specification given to the analyst teams is described very briefly. It does not clearly indicate what approaches should be used or what units should be used to express the results of the analyses. This is one factor contributing to the differences in results, and it makes it difficult to compare the analyses. However, in this case, more specific instructions would have implied less variation in approach, making the comparison less useful. From the discussion, the following recommendation can be made.

Aims and goals. The purchaser of a risk analysis must clearly determine and state the aims of the analysis, enabling the analyst team to generate measurable, and therefore useable, results. Along with a specific statement of

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**Figure 3.** By means of a cause-and-effect diagram, factors that affect the quality of a risk analysis are identified.
goals, the units in which the results should be expressed and the methods and approaches used should also be specified, allowing comparisons with other risk analyses.

Scope definition and planning. The planning phase by the analyst team, in which, for example, they considered what methods would be most appropriate to use, was not described in detail. As a result, their approaches were not as systematic as might be desired, with less potential for identifying hazardous areas. Such an approach also leads to difficulties in measuring progress in the analysis work as well as in making conclusions regarding the work in the final reports. It is always easier to make adjustments during the planning phase of a risk analysis process, as the consequences are relatively minor and probably less costly at this stage than later on. A well-planned analysis is therefore very important in order to obtain relevant results in an efficient way.

Hazard identification and initial consequence evaluation. In identifying hazards, different analyst teams focused on different areas. For example, analyst team C identified risks in building structures, which none of the other analyst teams did, and team A focused mainly on the power unit in identifying hazards. The analyst teams’ differing levels of experience with the hydropower industry is probably one reason for the varied points of focus. Another reason might be that none of the three teams presented either a systematic initial consequence analysis nor a preliminary hazard analysis to identify the most vulnerable subsystems, and thereby should be objected to for hazard analysis. In combination with individual analysis work on plant subsystems, it seems to generate identification of hazards regarding those subsystems in which the teams have major competence. During their observations at the plant, none of the teams were able to gather as much plant personnel as they wanted. This probably affected their ability to identify hazards, especially for team C, whose analysis was based mainly on observations. The different risk analysis methods used facilitated the analysis work, making a more systematic review of hazards and consequences. However, the lack of reliability data and information would affect the usability of the methods. From the discussion, the following recommendations can be made:

- Preliminary hazard analysis. Where resources are limited, it is necessary to apply a systematic approach at an early stage, indicating from the start where to focus and thereby making the hazard analysis as effective as possible.
- Teamwork. Teamwork is essential for generating a creative work environment and improving the possibilities for identifying hazards.
- Observation. A thorough knowledge of the system is important in identifying hazards. To obtain an up-to-date analysis and increase the understanding of hazards, on-site observations should be performed. To obtain as much relevant information as possible, the visit should be planned thoroughly.
Method. Both qualitative and quantitative methods should be used, increasing opportunities to identify initial hazards.

Data and information. The availability of reliability data and information is important in identifying hazards, especially for analyst teams with limited experience with the analysis object in question.

Experience. Extensive experience in performing risk analysis to specific objects would facilitate similar analyses, considering where failures would most likely occur. However, a systematic approach must be used every time, ensuring that new conditions are identified.

Risk estimation. All companies made a qualitative estimation of consequences based on their own experience and competence. Because reliability data were unavailable, the approach was also used to some extent for estimating frequencies. Resource limitations are probably the reason why company A performed an uncertainty analysis only on individual risks, and why none of the companies performed some kind of sensitivity analysis. It is notable that none of the studies included a function analysis. Analyst A used FMECA, which contains a function analysis, but applied it only to the local power subsystem. That implies that the focus was on physical assets only, where critical functions were not identified. From the discussion, the following recommendations can be made:

- Exposure time. It is necessary to consider exposure time when estimating risk in order to prioritise among risk sources that are similar in terms of consequences and frequencies of undesired events.

- Frequency estimation. Access to reliability data is necessary for making trustworthy estimations, something the client must be aware of when ordering a risk analysis. Simulation techniques or expert judgements can be used when data are scarce. However, making use of expert judgements on rather complex systems with low failure rates, as is the case in hydropower industry, requires access to people with a great deal of experience that covers a broad range of subject fields.

- Consequence estimation. Extensive knowledge of the system is necessary in order to understand individual consequences and how chains of consequences occur. Modelling and making use of event tree analysis might be necessary.

- Method. When reliability data are missing and only reliability information is available, qualitative judgements should be performed. To determine frequencies, quantitative methods are necessary.

- Teamwork. Performing risk estimation of different subsystems in a team reduces subjectivity in risk judgements.

- Function analysis. The functions desirable in a system are the main reason why the system exists at all; therefore, the focus when making
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risk analysis must be on the functions of the different subsystems and equipment.

- **Uncertainty and sensitivity analysis.** Due to the subjectivity that easily affects risk analysis, it is important to apply uncertainty and sensitivity analyses.

*Analysis verification.* In none of the cases was analysis verification performed by people outside the analysis process; however, the client played that role to some extent. The analysis work and the plans made are not thoroughly documented in the analysis reports, which makes it difficult to perform an examination. It is important that the analysis work and the plans made are thoroughly documented to allow examination of results on completion.

*Documentation.* To some extent, all three analyses lacked a clear and distinct description of the approach taken and the results generated. The final reports generated by the analyst teams do not completely describe the reasons why different steps were chosen and how these were executed within the analysis. The number of analysts involved in the teams and their professional backgrounds and experiences are not stated in the reports by A and B. That kind of information is valuable when evaluating the results presented. A lengthy series of appendices in team A’s report made it difficult to identify vital points. None of the analyst teams presented a follow-up and comparison of the risk analysis approach planned nor a discussion of the final results. From the discussion, the following recommendations can be made:

- **Basis of decisions.** A well-documented report that describes the steps taken during the study is crucial for evaluating the analyses and the usability of the results. From the final report it should be easy to evaluate the work performed and thereby see possibilities for improvement as well as driving factors. Delivering material not essential to the client is not in the client’s interest and it represents a waste of effort and resources.

- **Analysis results.** The results should be easy to evaluate, measure and track in the approach used and described.

*Further comments*

The client’s aims as stated in the requirement specifications were fulfilled. Individual and asset risks were identified and recommended actions proposed. However, evaluation of formal methods is not possible since few such methods were used, and these apply only to some parts of the plant system. The comparative study has demonstrated pros and cons of different risk analysis approaches. That knowledge can help the client to make decisions on risk analyses in the future.

From the comparative study it cannot be firmly concluded that a certain approach generates certain results, or that some types of risk analyses can be considered better than others. Analyst team A had the most experience with
the hydropower industry and had most reliability data available. Team B described a systematic theoretical method in a well-documented report. These two teams should put more effort into a systematic and well-documented course of action, which should probably generate very useful analysis work in the future. Team C used a systematic but relatively simple approach, generating results more in keeping with a condition assessment, and they should put more effort into making an in-depth analysis.

What can be learnt from the comparative study is that careful preparation, ensuring a systematic approach with clear aims and goals, is needed when performing risk analysis. A standard such as IEC 60300-3-9 (1995) can be used to facilitate the performance. The client needs to have sufficient competence to evaluate and understand approaches and results from risk analyses performed. For the analyst team, it is important to understand the culture and value within the client’s organisation, i.e. what the client considers to be an acceptable level of risk for individuals, environment and assets.

Conclusions
The comparative study presented in this paper shows that different risk analysis approaches generate different results. Examples of factors identified as affecting the use of risk analysis results included:

- a vague requirement specification;
- lack of systematic preliminary hazard analysis; and
- incomplete documentation of the analysis performed.

The desired functions of a system are the main reason why the system exists at all. Therefore the focus when performing risk analysis must be on the functions required of the associated subsystems and equipment. The client of a well-planned risk analysis can more easily control, interpret and evaluate the risk analysis and thereby obtain reliable results that fit the intended use. Some kinds of quality assurance (see for example, Oakland (1989)) applied to the risk analysis process will probably enhance the conditions for reliable results. Such an approach should involve the client and the analyst team, which will facilitate clear interpretations, comparisons and improvement of the process for future use.

References


Can we make maintenance decisions?


Conclusions from planning and preparation of RCM implementation

Fredrik Backlund
In proceedings of The International Conference of Maintenance Societies, ICOMS, 2002, Brisbane, Australia, Paper 042, 1-8
CONCLUSIONS FROM PLANNING AND PREPARING
RCM IMPLEMENTATION – A CASE STUDY OF A
SWEDISH HYDROPOWER COMPANY

Fredrik Backlund
The Polhem Laboratory and Centre for Dependability and Maintenance
Luleå University of Technology, Luleå, Sweden

Summary: Reliability-Centred Maintenance, RCM, is a well-known method that can support organisations in working towards more systematic maintenance performance. A long-term approach to implementing RCM is preferable, as this will help build commitment and involvement. Implementation can, however, be rather difficult to manage, as obstacles commonly turn up that jeopardise the process. Such obstacles include lack of management support and control, and lack of employee acceptance and motivation. Failed RCM implementation has serious consequences, including the persistence of less effective maintenance performance, despite the resources expended in implementation. In the long run, this will cause involved personnel to distrust future improvement projects. The current research project has been studying efforts towards RCM implementation in a Swedish hydropower company since 1997. Two pilot projects preceded the major implementation phase, which started early in 2002. So far, several factors have been identified which affect the planning and preparation of the implementation phase. Analysis of these factors led us to formulate the framework for an RCM implementation strategy outlined in the paper.

Key Words: RCM, Implementation, Maintenance Management, Hydropower, Planning, Preparation

1 INTRODUCTION
Reliability-Centred Maintenance can be described as a systematic approach for identifying effective and efficient preventive maintenance tasks for objects in accordance with a specific set of procedures (1). RCM basically combines several well-known risk analysis techniques and tools, such as Failure Mode and Effect Analysis (FMEA), in a systematic approach to managing risks. The RCM method was originally developed by Nowlan and Heap (2) with the aim of making maintenance performance more cost-effective in the commercial aircraft industry. Papers on RCM applications treat subjects such as gas compression systems in the offshore oil industry (3), boiler and turbine auxiliaries in the nuclear industry (4) and robots in automobile manufacturing (5). These studies have shown that RCM can, among other matters, improve system availability and reliability, reduce the amount of preventive maintenance and increase safety. Studies on the application of RCM have usually focused only on specific subsystems. However, RCM can also involve a maintenance organisation’s performance in a more overarching way, by, for example, prompting changes to maintenance plans and strategies (6), (7), (8). From that perspective, RCM can be compared with a method, or a way of working within an organisation, a definition used by Akersten and Klefsjö (9). The steps performed when applying RCM may differ somewhat depending on its application context, though on an overarching level they are largely the same (see Figure 1).
Information collection | Identification of systems | Identification of system functions | Selection of systems | Identification of system functional failures and criticality ranking | Identification and analysis of functionally significant items (FSIs) 

Maintenance task selection | Review procedure | Initial maintenance programme | Ongoing maintenance programme | Operational experience | Technical data feedback

Figure 1. Tasks in the development on an RCM based maintenance programme (1).

A long-term approach to implementing RCM should be used, so as to increase the involvement and commitment of the maintenance organisation. Under such conditions, the desired maintenance performance based on an RCM analysis is far more likely to endure. However, this approach is more difficult to manage since it involves a great many people (6). In several cases, organisations have experienced severe difficulties when implementing RCM, difficulties which have resulted in unforeseen, increased resource demands (6), (3), (10). The authors of these papers have identified management issues as the main source of problematic or failed RCM programmes.

Even though RCM implementation problems may be recognised, few papers or literature focus on the management side of implementation. The main documentation of this matter is found in the nuclear sector, where EPRI – the Electric Power Research Institute – has made several studies of RCM implementation (see (11), (10), (12)). The conditions for implementing RCM in safety-focused and high technology sectors, such as the nuclear, aircraft and offshore oil industries, have some specific characteristics. According to Harris and Moss (13), the successful implementation of RCM in the aircraft industry depends, among other matters, on RCM being applied in the design stage with few resource constraints, and on specialists performing the RCM analysis. However, the preconditions differ in more traditional basic industries in, for example, the power, processing and manufacturing sectors. There, RCM is mostly applied to pre-existing plants that were individually designed to meet a wide range of output requirements. Another condition is the level and mix of available resources, usually established by custom and usage, and the introduction of RCM in times of restraint and rationalisation (13).

This paper aims to describe the complex task of obtaining the conditions favourable for managing RCM implementation. The focus is on the hydropower industry, as a representative of the power sector. For the first time in Sweden, RCM is to be implemented in a hydropower company. Two major pilot projects have preceded the RCM implementation phase, which started early in 2002 and will involve over 50 plants. Since 1998 an ongoing research project has studied the preliminary work for RCM implementation. Driving forces and obstacles have been observed that affect the organisation’s capability and commitment to implementing RCM. This paper will focus on the planning and preparation for RCM implementation. The findings to date provide input into an implementation strategy framework, outlined later in the paper.

2 BACKGROUND

Vattenfall AB Vattenkraft is a company in charge of hydropower plant reinvestments and strategic and tactical maintenance planning. The company is the major hydropower supplier in Sweden: the combined output of its over 50 plants averages 33 TWh per year, corresponding to about 20 percent of Swedish electricity demand. A maintenance company, Vattenfall Service Nord (VSN), belonging to the same corporate group, is the contractor that carries out maintenance activities on an operational level. The maintenance company’s four units each deal with plants in different geographical areas.

Deregulation of the Swedish power sector in 1996 has increased competition in the Swedish electricity market. To sustain profitability and competitiveness, Vattenfall Vattenkraft, further on called the client, has had to, among other measures, decrease maintenance costs. Plant maintenance currently consists mainly of overhauls and inspections, executed according to time schedules established by usage and custom. RCM has been considered as an appropriate way to make maintenance more systematic and cost-effective.

The preliminary work for RCM implementation has mainly involved the contractor, and the focus of efforts is on making maintenance more efficient and effective. The work has been performed as a project, consisting of a pilot study phase (1997–1999), an investigation phase (1999–2000) and a planning and preparation phase (2000–2002). Two pilot projects have been performed during this time, the main aims of which have been to evaluate how RCM analysis could be performed and to what extent reductions in maintenance costs could be realised. Based on this experience, and to suit the outsourcing situation, a customised RCM method, here called an RCM
model, has been developed (see Backlund and Jonforsen (14)). However, neither the RCM analyses nor the RCM model have yet been applied in practice. The implementation phase, which started early in 2002, involves all four units. To increase the capability and commitment of the organisation, it has been decided that a long-term implementation approach should be used.

3 A CASE STUDY
Research began with extensive literature studies, followed by an in-depth case study. Such an approach is appropriate when studying managerial processes, since the boundaries between the phenomenon and its context are not clearly evident (15). During 1997 and 1999, the pilot projects were studied during several visits to the organisations, described by Backlund (16), (17). During the planning and preparation phase the author followed the process more closely as an independent member of the RCM project team – a form of participant-observation (see Yin (15)). This approach permitted better access to the people involved and to everyday events and activities.

4 SOME DRIVING FORCES AND OBSTACLES OBSERVED
The pilot study and the investigation phases mainly set out to evaluate whether RCM analysis is applicable in the hydropower environment. The planning and preparation phase can be considered as the main work towards RCM implementation, and is therefore the focus of this paper. During the planning and preparation, time schedules were extended several times and resources were increased. The project group was forced to take on many extensive tasks in order to obtain favourable conditions before the implementation phase began. The case study observed several driving forces and obstacles that affect, in different ways, the capability and commitment of the organisation to implement RCM. Some of these will briefly be described below. To facilitate readability, the examples have been divided into:

- Technical support systems
- Information and communication routines
- Commitment of actors

Driving forces and obstacles noted during the preparation and planning phase affecting the availability of necessary technical support systems include:

- A common computer maintenance management system. A common computer maintenance management system, CMMS, is under development for use in all four units. It will be a major improvement since some units currently lack such a system. However, the fact that a CMMS is still not in place makes it difficult to gather necessary information and data, to handle the initial RCM analyses and to make optimisations.

- Difficulties in developing RCM computer support. Computer support is required to handle the many analyses needed for RCM. Development of it has been complex and time consuming, and has involved identifying important design aspects, making the platform user-friendly and finding a suitable manufacturer for the software.

- Insufficient access to system documentation and information. The possibility of making, for example, functional analysis and consequence assessment is affected by the unavailability of documentation and information. The main reasons for this are the lack of a plant register, an overall CMMS and a standard for documenting maintenance performance.

Driving forces and obstacles experienced during the preparation and planning phase affecting information and communication routines include:

- A clear organisational structure. Both companies are working on restructuring that should clarify working roles and responsibilities. This facilitates attempts to determine who should be in charge of the various roles needed to implement RCM activities. At the same time, more uniform terminology and a plant register are under development. However, restructuring is still in progress, making it difficult to establish a clear working structure and assign responsibilities during work towards implementation.

- Educational and information disturbances. The project has been in progress for a long time, during which time the project leader has changed several times, and some middle managers and a unit manager have been replaced. This has affected information and educational efforts, which have had to be repeated. The long duration has also meant that before the project has been completed, people have already forgotten information and education received.

Driving forces and obstacles noted during the preparation and planning phase affecting actors’ commitment:

- Insight into the need for change. Many employees understand that they have to become more effective in their work, and that maintenance performance and routines have to change. This mainly concerns the new, entrepreneurial situation of the maintenance company. Employees understand that maintenance must be performed cost-effectively, in order to be more competitive.
• **A change in routine work.** Existing maintenance tasks are mainly routine, so some employees welcome the change presented by a chance to work in a development project.

• **Resistance to change.** Regular work tasks, on top of other projects and reorganisations, all require resources and attention, and this affects employees’ willingness to change. To some people in an organisation RCM is synonymous with rationalisation. This affects views on job security and tasks, making it difficult for maintenance personnel to accept RCM as a working method.

• **Lack of credibility of improvement projects.** Employees have experience of earlier, unsuccessful improvement projects. A top-down approach and insufficient computer support are considered as the main causes for previous lack of success. The RCM project has been going on for a long time and its project leader has changed several times. This is interpreted as indicating that the project is not going well, leading to the attitude that ‘it will not work this time either.’

• **Decreased motivation:** Interest in RCM within the organisation has decreased somewhat due to the long project duration. Also, the increase in the resources needed for the work has lessened the commitment of senior and middle management.

• **Lack of understanding.** Managers and employees do not always understand why RCM should be implemented, or what its aims and the goals are. Lack of understanding promotes the spread of rumours to the effect that RCM is mainly a way to rationalise the maintenance company.

Even though the many obstacles have resulted in delays and increased resource demands, the project continues to the implementation phase. Senior management believes that the prerequisites are in good enough condition, and that the benefits expected will exceed the major resources expended so far. The project group has judged that the necessary technical support systems and information and communication routines soon will be in order. Major efforts are now being made to address organisational commitment. Extensive personal communication is taking place between the project management and top and middle managers at the maintenance company.

5 **ANALYSIS**

The study findings point out the need for technical support systems and information and communication routines. It has also become evident that since many actors will be involved, their commitment to RCM implementation will be very important. The amount of time required to prepare the organisation for RCM implementation has a lot to do with the availability of needed support systems. Since many of these were not in place, the RCM project group was forced to take on several resource-demanding activities. At the same time they also had to focus on organisational commitment. The situation indicates that both senior management and the project group to some extent underestimated the efforts needed to plan and prepare for RCM implementation. The execution of the pilot study and the investigation phase probably also influenced the planning and preparation performance. Considering their outcomes, the execution of the pilot projects was somewhat ill-prepared. For example, initial RCM analyses were not applied, and that is a prerequisite to understand how working with continuously improvements of the analyses.

On closer consideration, the nature of RCM implementation is rather complicated. Driving forces and obstacles are many and often interrelated. For example, information and education allow employees to understand what RCM is, and thereby accept the method. However, communication and information is affected by the definitions and terminology used, as well as by the organisational structure. The unavailability of technical support systems can influence long-term commitment. However, the factors affecting actors’ commitment are largely intangible, including motivation, understanding and resistance. Organisational commitment is thus difficult to manage and control. The driving forces and obstacles identified can be divided into two main areas, both including necessary conditions to obtain a maintenance performance based on RCM (see Figure 2).

![Figure 2. Necessary preconditions affecting the conditions for managing RCM implementation](image)

6 **A PROPOSAL FOR AN RCM IMPLEMENTATION STRATEGY FRAMEWORK**

The study findings identified so far grant us the possibility of learning from the mistakes made. From our experience, we recommend formulating an RCM implementation strategy. We do not intend to articulate a
complete master plan or strategy as to how RCM implementation should proceed or be managed; our primary aim is to indicate the necessary preconditions for planning and preparing successful RCM implementation.

6.1 The planning phase

The planning phase is mainly concerned with the necessary preconditions for performing RCM analysis (see Figure 2). In the planning phase we should ask ourselves what is desired from implementing RCM and what is needed to implement it. That should to some extent avert unforeseen resource demands from cropping up during the work towards implementation. Following the four steps below should ensure a more carefully prepared planning phase.

6.1.1 Step I. Evaluate the suitability of using RCM

Before initiating efforts towards implementing RCM in an organisation, some questions are in order. Why implement RCM? What are its aims and goals, and do they accord with company needs? Applying RCM facilitates various ‘hard’ and ‘soft’ contributions, such as reduced spare-part requirements (3), quantitative analysis and optimisation (18) and common language and processes (19). However, the RCM analyses only generate recommendations as to where and how maintenance should be performed; to accrue the desired benefits additional efforts need to be made. As the goals of RCM expand, so do the activities, making implementation ever more complex and resource demanding.

6.1.2 Step II. Decide RCM model

After the suitability of RCM is determined, a customisation of the RCM method may be required, i.e. developing an RCM model. The decision has to be made whether a model should be developed in-house, or an existing one used. RCM has been slightly modified over the years, compared with the original method of Nowlan and Heap. Such modification has arisen mainly in connection with the particular conditions and systems to which RCM has been applied. For example, as mentioned in section 2, an in-house model was chosen to fit the needs of the client. Among the various RCM models are the following:

- RCM II, where, among other matters, an environmental focus is added (6).
- SRCM, Streamlined RCM, which is considered more suitable for industries with many safety-critical items and where maintenance history is available, for example, in the nuclear sector (12), (20)
- An RCM method adjusted for the specific demands of small and medium sized enterprises (21)

6.1.3 Step III The RCM model viewed as a process

The steps performed when applying RCM may differ somewhat depending on the model used, though on an overarching level they are largely the same (see Figure 1). The activities comprising each step should be careful reviewed, so as not to underestimate the effort needed to perform RCM analysis. Comparing the analysis work with a process, in need of different support processes to be accomplished, should facilitates identification of the technical support systems and communication and information routines needed. It also facilitates the identification of actors needed to perform each step.

6.1.4 Step IV. Identify the organisational and technical maturity level

The current status of the organisation needs to be reviewed to determine whether required technical support systems and information and communication routines are available. The results of this comparison will indicate whether the level of organisational and technical maturity is sufficient to enable RCM implementation. This step prevents the organisation from starting a major improvement project, based on only vague insight into the needed course of action. Similar thoughts are articulated by, for example, Muthu et al. (22) when considering the implementation of a maintenance quality system.

6.2 The Preparation phase

Following the steps of the planning phase will ensure that the desired benefits are achievable. It also ensures that the necessary preconditions have been planned for, so as to enable the organisation to perform RCM analysis successfully. The preparation phase is concerned with preparing as yet unavailable technical support systems and information and communication routines. The preparation phase is also concerned with the necessary preconditions for implementing a new method within the organisation (see Figure 2), where obtaining organisational commitment is yet another major issue.

6.2.1 Step I. Set support functions in order

Putting in place technical support systems and information and communication routines can be major tasks. As was seen in this case, the project group had to deal with several of these issues in one and the same project. As
result, the project was difficult to manage and became delayed several times. RCM implementation should therefore be looked upon as a major overarching project, as a long-term goal. Efforts to establish technical support systems and information and communication routines should be sub-goals divided between several separate sub-projects. These could be executed either simultaneously or one at time, depending on the organisation’s overall resource constraints. In either case, this work must be completed before pilot projects commence.

6.2.2 Step II. Performing pilot projects
To obtain more knowledge and experience of analysis work, initially and continuously, one or more pilot projects are appropriate. During pilot projects, adjustments can be made to project components such as the RCM model or the RCM computer support. Conducting the proposed planning steps before pilot project implementation makes it possible to generate measurable and relevant results on which to base decisions. The pilot projects mentioned in section 2 of this study were not performed in such circumstances; as a result, the resulting analyses were never applied in generating new maintenance performance.

6.2.3 Step III. RCM implementation as human activity system
The implementation of RCM within an organisation can be described as a human activity system, a system of actors trying to change the way maintenance is performed. The planning, preparation and implementation of RCM therefore resembles a transformation process (see Figure 3). Input is converted into output, and then passed on to the customer (23). In this case, the input is the original maintenance performance, mainly based on custom and usage. The systemic view emphasises the fact that transformation is achieved by actors, all of whom must be identified and all of whom must be committed to the process. This implies a holistic approach to RCM implementation. The output desired by the customer – the client – is systematic maintenance performance based on RCM analysis. The actors are the ones who carry out the activities, consisting mainly of an RCM project group and the four maintenance units. Some actors represent the client, acting as decision-makers in the review procedure. Environmental constraints that may affect RCM implementation should also be recognised. These can include other ongoing projects and changes in corporate strategic directions. However, this paper will emphasise neither environmental constraints nor the project group in itself; instead it considers the group’s efforts to manage and control the planning and preparation.

![Figure 3. RCM implementation viewed as a transformation process, based on the input–output system by Pidd (23).](image)

6.3 Commitment of the organisation
Organisational commitment to RCM implementation is mainly a matter of preparation. However, to avoid a top-down approach, efforts need to be made before the preparation phase begins. According to the case study findings, obtaining organisational commitment is critical. Due to its intangible nature, it is difficult to manage and control. Nonetheless, we must try to obtain the best possible conditions in order to secure and manage organisational commitment. Discussion follows on how to make the organisation committed to RCM implementation; however, more research is required before conclusive guidelines can be presented.

During the proposed planning steps, senior management will have time to understand the benefits to be expected and the courses of action required. This is an opportunity for senior management to commit themselves early on to RCM implementation. When deciding whether to proceed with pilot projects, the organisation should be
informed of the aims and goals of RCM implementation. Information on the ongoing progress of the pilot projects should also be made continuously available. In this way, employees will have the time and opportunity to understand and evaluate what RCM is. That should improve conditions for the major work on commitment building, to commence after pilot project completion. However, even if efforts to educate and inform are made, organisational commitment cannot be taken for granted: for any company, change is difficult, time consuming and emotionally wrenching (24), (25).

According to Pressman and Wildavsky (26), implementation must not be conceived of as a process that takes place after, and independently of, the design phase. There is no point in having good ideas if they cannot be carried out. From an historic perspective, it appears that implementation issues have not been emphasised in RCM development. Instead, RCM implementation issues tend to have been dealt with on an ad hoc basis. However, the use of some kind of preparatory stage, focused on organisational commitment, may be a useful approach to integrating implementation issues with the RCM method. One kind of preparatory stage is found in the Total Productive Maintenance (TPM) method, another in the dependability system of Akersten and Klefsjö (9). To learn more about TPM, see Nakajima (27), (28). Several papers deal with TPM implementation problems. Bakerjan (29) states that the number of successfully implemented TPM programmes is relatively small, attributing failure to three major obstacles: lack of management support and understanding, lack of sufficient training and failure to allow sufficient time for TPM evolution.

According to Beer et al. (30), most change programs do not work because they are guided by fundamentally flawed theories of change based on oversimplified views of management and organisations. Critics of programmed approaches to change – which a preparatory stage can be seen as representing – allege that such approaches focus organisational change on strategic issues, while ignoring the historical, process and contextual issues that inform underlying organisational dynamics (31), (32). The case study did find that historical and contextual factors could indeed affect progress towards RCM implementation. Based on that insight, we need to integrate guidelines for managing organisational commitment when implementing RCM. This would require deeper examination of change and implementation theory, subject areas dealt with in the organisational development field.

7 DISCUSSION AND CONCLUSION

Many obstacles were observed during the planning and preparation phase. It is easy to understand that many organisations have perceived difficulties in even getting started implementing RCM. The increased resource demands and difficult management tasks we observed resembled those documented from the experience of other organisations trying to implement RCM. The proposed planning and preparation phases should have a great impact on future RCM implementations. A process view combined with an awareness that RCM implementation is a long-term goal should prevent or mitigate unforeseen resource requirements.

Initially, RCM could be seen as providing a structure that facilitates the building of fundamental functions within maintenance management. This probably implies that major organisational change and rationalisations will occur within the organisation. Commitment aspects should therefore be especially important when implementing RCM. Why, then, do the management factors important to planning and preparation usually go unrecognised? One explanation might be that management has not recognised that there are differences between industries in terms of their maturity to implement RCM. For example, many conditions differ between RCM applications in basic industry and in high-tech industry. Another explanation might lie in the evolution of RCM use. The method is technology-oriented, and focused on technical assets. That may have resulted in a general focus among practitioners and researchers on technological aspects, overshadowing the real importance of management factors. The lack of a management focus implies the lack of a fundamental prerequisite for recognising the similarities between RCM implementation and organisational change. However, increased awareness of the importance of management in RCM implementation can be discerned in, for example, Moubray (6), Akersten and Klefsjö (9) and Worledge (10). The change management aspect of RCM implementation might be even more significant in a hydropower environment than in other processing and power industries. Among the conditions affecting the willingness to implement RCM is the broad geographical distribution of units and plants. That creates subcultures that impede communication and information dissemination. This line of reasoning leads to the issue of ‘change maturity,’ for example, where experience of failed improvement projects affects employee willingness to implement RCM.

The many tangible and intangible factors, together with their inter-relations, clearly demonstrate how complex it is to manage RCM planning and preparation. In retrospect, one wonders whether work towards RCM implementation should have been initiated within the actual hydropower company? Reliability data and system information is largely missing, organisational structures are unclear and a common computer-based maintenance system is missing. According to Kennedy and Doyle (20), RCM is an excellent method when the organisation has to change its maintenance performance bottom line. However, given the many obstacles observed, the
decrease in management commitment and worker interest and motivation was understandable. Before even starting to implement RCM, a carefully performed planning and preparation phase seems, therefore, to be crucial.

This paper identifies several driving forces and obstacles affecting an organisation’s RCM implementation. A strategy framework is proposed to facilitate RCM implementation in the hydropower industry. This framework focuses mainly on comprehensive planning and preparation phases. The strategy proposed in this paper recognises the similarities between RCM implementation management and organisational change management. Therefore, the strategy is highly cognisant of the need for organisational commitment. Input from the organisational development area of change and implementation management seems to be needed.

8 FURTHER RESEARCH

The implementation strategy framework outlined in the paper calls for more specific guidelines, to support project groups in charge of implementing RCM. More comprehensive structuring and analysis of the additional driving forces and obstacles that turned up in the planning and preparation phase will be added. These driving forces and obstacles will be validated both analytically and empirically. A forthcoming paper will provide a more comprehensive discussion of the integration of commitment issues with the RCM method. A comparison of experiences implementing TQM – Total Quality Management – and TPM will also be included. The case study findings will also be compared with the experiences other hydropower organisations have had in implementing RCM.

9 ACKNOWLEDGEMENTS

The research was performed in The Polhem Laboratory, a competence centre initiated by VINNOVA, the Swedish Agency for Innovation Systems (former NUTEK); the author would like to thank them for their generous financial support. The author is also most grateful to Vattenfall AB Vattenkraft and Vattenfall Service Nord for permitting the author to study their efforts towards RCM implementation.

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Paper III

RCM introduction:
Process and requirements management aspects

Fredrik Backlund and Per Anders Akersten
To be published in Journal of Quality in Maintenance Engineering
RCM introduction: 
Process and requirements management aspects

F. Backlund and P. A. Akersten
Centre for Dependability and Maintenance, 
Luleå University of Technology, Luleå, Sweden

Key words RCM, reliability-centred maintenance, RCM introduction, Process management, Requirements, Case study

Abstract Organisations have introduced Reliability-Centred Maintenance (RCM) with a view to changing their overall way of performing maintenance. Many times, however, these organisations have experienced cumbersome or even failed RCM introduction. This is usually because of managerial and organisational obstacles, which more or less unexpectedly turn up during introduction. This paper focuses on managing the introduction of RCM. By applying process and requirement management principles, obstacles that turn up during introduction can be identified early on. As an example of this, we cite the results of a case study of the introduction of RCM in a Swedish hydropower company.

Practical implications
Several organisations introducing RCM seem to have experienced severe obstacles. In this paper an RCM requirement management approach is proposed, based on process and requirement management principles. The aim is to identify severe obstacles early on in the introduction. The findings from both a literature study, and a longitudinal case study, indicate the need for a holistic view when managing RCM introduction. Therefore, process management principles are very useful systematically to identify, for example, actors, routines, and systems needed when managing RCM introduction. By means of requirement management principles, the requirements pertaining to, for example, actors and systems can be set forth in more detail. The identification of the requirements that the introduction of RCM places on the organisation, and on the existing maintenance programme, should increase the possibility of successful RCM introduction.

Introduction and background
Reliability-Centred Maintenance, RCM, basically combines several well-known risk management techniques and tools, such as failure mode and effect analysis and decision trees, in a systematic approach, to support effective and efficient maintenance decisions. According to Smith (1993: 372), RCM can be completely described by its four unique features; it: “1) Preserves functions, 2) Identifies failure modes that can defeat the functions, 3) Prioritises function need (via the failure modes), and 4) Selects only applicable and effective preventive maintenance tasks.” Papers on RCM applications treat subjects such as gas compression systems in the offshore oil industry (Sandtorv and Rausand, 1991), boiler and turbine auxiliaries in the nuclear industry (Srikrishna, Yadava and Rao, 1996), and robots in automobile manufacturing (Pintelon, Nagarur and Puyvelde, 1999). RCM can, among other things, improve system availability and reliability, reduce the amount of preventive and unplanned corrective maintenance, and increase safety. These are all important performance characteristics that most companies wish to sustain in a competitive environment. Studies on the application of RCM are usually limited to focusing on one specific subsystem or pilot study. However, the use of RCM can also involve a maintenance organisation’s performance in a more overarching way, by, for example, prompting changes to the overall maintenance programme (Hardwick and Winsor, 2002; Moubray, 1997; and Smith, 1993). From that perspective, RCM can be considered as a method, or a way of working within an organisation, a definition used in Akersten and Klefsjö (2001). The steps performed when working with RCM analysis may differ somewhat depending on its application context, though at an overarching level they are largely the same. However, initial analyses are insufficient in themselves; the recommendations from the analyses have to be implemented to obtain an RCM-based maintenance programme. The initial analysis and maintenance tasks also
have to be improved continuously due to, among other factors, improved reliability data and new maintenance technology (see Figure 1).

![Figure 1. Steps in the development of an RCM-based maintenance programme. From IEC60300-3-11, 1999.](image)

When preparing to introduce RCM within an organisation, a long-term approach is preferable, so as to increase management and employee commitment. Under such conditions, the desired maintenance performance based on an RCM analysis is far more likely to endure. However, this approach is more difficult to manage since it involves many different people and systems. In a number of cases, organisations have experienced severe difficulties when introducing RCM due to various management and organisational issues (see Smith, 1993; Moubray, 1997; and Schawn and Khan, 1994). The obstacles encountered include lack of management support, information, and communication. The many different obstacles can result in a cumbersome introduction, which has to be examined from various management perspectives.

Successful application of RCM in the aircraft industry depends on specific characteristics; for example, RCM should be applied during the design stage with few resource constraints, and with specialists performing the RCM analysis. However, the preconditions differ in more traditional basic industries in, for example, the power, processing, and manufacturing sectors. There, RCM is mostly applied to existing plants that have been individually designed, and where the level and mix of available resources are usually established by custom and usage. RCM also is often introduced in times of restraint and rationalisation (Harris and Moss, 1994). In more safety-focused industries, such as the nuclear and aircraft industries, maintenance management has usually been extensive due to abundant safety regulations. In such environments, so-called “streamlined” RCM versions are commonly used to evaluate existing maintenance performance (see August, 1997; and Rotton, 1994). However, there are several examples of problematic or failed RCM introductions within the nuclear sector as well (see Bowler and Malcom, 1994; and Schawn and Khan, 1994).

Top management commitment and support is a prerequisite for the initiation and ongoing introduction of RCM. Top management stipulates the resources, and their visible support and involvement motivate middle managers and employees. However, senior or top management commitment can fade for various reasons, including an unforeseen increase of already considerable resource consumption (Moubray, 1997; and Jones, 1995). Another reason for the withdrawal of top management support is insufficient understanding of how, and in what way, the use of RCM will benefit the organisation (Hipkin and DeCock, 2000; and Bowler, Primrose and Leoonard, 1995). Therefore, it is a prerequisite that management, at an early stage, understand how RCM fits into overall maintenance management, and what its aims and goals are. They also should be aware of the requirements the organisation must meet to be able to introduce the method. Management has to understand what it takes to plan and prepare for RCM introduction, and how to perform the analysis, implement the recommendations, and continuously improve the RCM programme. By means of comprehensive awareness and understanding of the resources needed to introduce RCM, and what benefits are to be expected, sustainable top management commitment is more likely. Many of these issues are likely to affect middle management and employees as well.

**Scope and aim of the paper**

The focus of this paper is on the management of RCM introduction with the intention of changing the overall way of performing maintenance in an organisation – in other words, to obtain an RCM-based maintenance programme. By applying process management principles to identify the requirements an organisation must meet if it is to introduce RCM, the aim is to identify various important issues that must be dealt with before initiating the introduction process. Dealing with these issues should increase the likelihood of success when introducing
RCM. As an example of this, we cite the results of a case study on the introduction of RCM in a Swedish hydropower organisation.

**RCM introduction in a Swedish hydropower organisation**

This section summarises observations made during a case study of RCM introduction in the Swedish hydropower company Vattenfall AB Vattenkraft. The aim is to examine aspects of RCM introduction that caused delays and increased resource demands, which as a consequence, made senior and middle management question future RCM efforts.

A case-study approach is appropriate when examining managerial processes, since the boundaries between the phenomenon and its context are not clearly evident (Yin, 1994: 403). In 1997 and 1999, two pilot projects were studied during several visits to the organisation, as described by Backlund (1999a and 1999b). In 2000–2003, during planning, preparation, and part of the analysis phase, the RCM introduction process could be followed more closely, as one of the authors was an independent member of the RCM project team – a form of participant observation (Yin, 1994: 403). This approach permitted better access to the people involved and to everyday events and activities. For more comprehensive description of the study during the planning and preparation phase, see Backlund (2002) and Backlund and Jonforsen (2002).

Vattenfall AB Vattenkraft is the major hydropower supplier in Sweden. The combined output of its over 50 plants averages 33 TWh per year, corresponding to about 20 percent of Swedish electricity demand. A maintenance company, Vattenfall Service, belonging to the same corporate group, is a contractor that carries out maintenance activities at the operational level. The plants are located in four regions around Sweden. Deregulation of the Swedish power sector in 1996 increased competition in the Swedish electricity market. To sustain profitability and competitiveness, Vattenfall AB Vattenkraft considered RCM as way to make maintenance more systematic and cost effective. Plant maintenance currently consists mainly of overhauls and inspections, executed according to time schedules established by usage and custom. Both companies are involved in the RCM introduction; however, Vattenfall Service has more people directly involved in RCM and has the major responsibility for managing the introduction process.

**PLANNING AND PREPARATION OF RCM INTRODUCTION**

To increase the capability and commitment of the organisation, a long-term introduction approach has been used, involving maintenance groups at all plants. During the planning and preparation phase (see Figure 2), time schedules were extended several times and the resources needed increased. The project group was forced to take on many extensive tasks in order to secure favourable conditions before analysis began. This resulted in “projects within the project”, since some of these tasks required major effort. Even so, major preparation activities still had to be dealt with even during the analysis phase. Some of the following problems and deficiencies became obstacles to the progress of RCM introduction:

- **Lack of a computerised maintenance management system.** A common computer maintenance management system (CMMS) was not available. That made it difficult to gather and handle the information and data needed to support initial RCM analyses and to make optimisations.

- **Lack of RCM computer system.** Computer system was required to handle the many analyses made. Development of such system was difficult and time consuming, involving issues such as design, user friendliness, and finding a suitable developer for the software. Consequently, the cost and time needed to develop computer system increased.

- **Lack of plant register.** Lack of a plant register made it difficult to develop RCM computer system, due to lack of a system structure valid for all the plants in the corporation. The lack of a plant register also made it difficult to gather information.

- **Unavailability of documentation and information.** The unavailability of system and function descriptions made it difficult for RCM teams to make correct analyses, and the lack of historical reliability data made it difficult to conduct probability assessment.

- **Problematic routines, roles, and responsibilities.** Review of the analyses is very important, especially when an entrepreneur and a client share the responsibility. However, technical staff and the purchasers of maintenance services – the ones in charge of approving analysis recommendations – were not particularly involved in the introduction. This made it difficult to obtain timely approval of
recommendations. General work pressure and ongoing reorganisations also made it difficult to establish a clear working structure and assign responsibilities for RCM.

- **Communication problems.** Common maintenance terminology was lacking. Such terminology was needed to ensure uniform understanding among, for example, technical staff, middle management, operators, and maintenance personnel, as to the meaning and application of the recommendations arising from the RCM analyses.

- **Lack of overarching maintenance management strategy.** Both Vattenfall AB Vattenkraft and the maintenance contractor lacked an overall maintenance management strategy. That made it difficult to determine how to handle, for example, lists and plans pertaining to maintenance activities and based on the RCM analyses, both initially and in the continuous improvement phase.

- **Incomplete goal setting, and benefit identification and measurement.** The overarching goals pertaining to RCM introduction had been determined. During the planning and preparation phase, additional potential goals and benefits were identified, but not focused on. How to measure results and monitoring progress was to some extent also unclear.

Even though the large number of tasks resulted in delays and increased resource demands, the project is still proceeding. Senior management believes that the prerequisites have been sufficiently met, and that the expected benefits will more than justify the major resources expended. Some of the problems and deficiencies mentioned above have been or are being dealt with, such as lack of a CMMS, plant register, and overarching maintenance management strategy. Even though, with a better knowledge of the many problems that might occur, when introducing RCM, the preconditions for the analysis phase could have been better.

**A holistic view on RCM introduction**

To obtain an RCM-based maintenance programme, the many tasks to be dealt with when introducing RCM have to be seen from various management perspectives. RCM introduction issues experienced in various industrial sectors and application areas are described in an extensive literature study (Backlund, 2003). This study reveals a number of obstacles and driving forces that are best dealt with by four different aspects of management:

- **Maintenance management:** including issues such as a CMMS, a maintenance programme, and workforce competence and skills.

- **RCM management:** including issues such as analysis performance, reliability-data gathering, and computer system.

- **Project management:** including issues such as planning, measuring, and monitoring.

- **Change management:** including issues such as commitment, leadership, and communication.

The findings of both the literature and the case studies indicate that we have to use a holistic view to identify the requirements to be met by the organisation, as well as by the existing maintenance programme. A holistic approach is also a precondition for managing the requirements properly during the introduction of RCM. As revealed by both the literature and the case studies, the introduction of RCM comprises a number of characteristic phases: an initiation phase, a pilot study phase, a planning and preparation phase (for full-scale introduction), an analysis phase, an implementation phase, and a living-programme phase (for determining the conditions for working with continuous improvement). Together these phases constitute an RCM introduction process. Each phase has to be managed carefully, as each can be regarded as a precondition for managing ensuing phases (see Figure 2).

Inspired by the human-activity system described in Pidd (1999), the introduction of RCM within an organisation can be viewed as a system of actors attempting to change existing maintenance performance. The introduction phases can be regarded as parts of a transformation process (see Figure 2), where input is converted into output, and then passed on to the customer. In this case, introducing RCM requires input from the existing maintenance programme, input such as reliability data, system descriptions, maintenance personnel skills, and CMMS information. The output desired by the customer, for example, top management, is effective and efficient maintenance performance. The actors, for example, RCM teams and decision-makers in the review procedure, are the ones who carry out the activities. Environmental constraints that may affect the introduction of RCM can include other ongoing projects and changes in corporate strategic directions. The holistic view emphasises the fact that actors, all of whom must be identified and committed to the introduction, achieve transformation.
As can be seen in Figure 2, the introduction of RCM requires input from the existing maintenance programme, within which recommended new maintenance tasks later on have to be implemented. Therefore, major efforts are required on the part of the organisation in terms of both supporting and changing in accordance with the introduction of RCM.

When introducing RCM, various kinds of roles, support systems, information, and communication routines are needed and have to be established. However, as has been seen from the case study description, these requirements on the part of the organisation and of the original maintenance programme are not always clearly identified before allocating resources, budget, and time. To validate the findings of the case study, three other hydropower companies were studied, all of which were involved in RCM introduction (see Backlund, 2003: 634). Due to space limitations, these will not be described further in this paper; however, at a general level, these studies revealed a pattern similar to that revealed by the longitudinal case study.

**On process and requirements management**

This section briefly describes the concepts of *process* and *requirement*, and also of the related concept of *stakeholder*.

Simply stated, the concept of “process” can be described as a transformation of input into output, subject to constraints from the environment, and utilising resources to make the transformation possible. There are many different opinions as to what a process is, and what it should include. Based on a structured comparison of process management models (see Lind, 2001), some general characteristics are:

- A process can be seen as a value chain, a series of steps designed to produce a product or service (Rummler and Brache, 1995). A process includes activities which transform clearly identified input into output (Davenport, 1993), and which possess a clearly defined beginning and an end, and goals (Ould, 1995).

- A process focuses on the people involved (Rentzhog, 1996) and/or machines (Ould, 1995). A process includes various actors, and a whole set of roles, each carrying out activities and making decisions (Ould, 1995). All processes have internal or external customers, i.e., receivers of the results. There is also a focus on the suppliers of the input (see Bergman and Klefsjö, 1994; and Ould, 1995).
Most processes are performed across various organisational borders and consume resources; therefore, a process owner is needed (Rummler and Brache, 1995; and Bergman and Klefsjö, 1994).

There exist various kinds or levels of process, for example, core processes to satisfy external customers, support process to satisfy internal customers, and management processes to manage the core and support processes (Ould, 1995). These processes can also be divided into sub processes, activities, and operations (Rentzhog, 1996: 619).

The above descriptions and views of process management have much in common with the holistic view of RCM introduction, which indicates the usefulness of a process view when managing RCM introduction. Processes create value for customers and also have an effect on employees and the society. This indicates that the concept of “customer” could be replaced by the wider concept of “stakeholder”, thereby including more groups than just traditional customers. The stakeholder concept has been widely used in the information-system development field. Pouloudi and Whitley (1997) characterise stakeholders in an information-system development process as follows:

*We define stakeholders as these participants [in the development process] together with any other individuals, groups or organisations whose actions can influence or be influenced by the development and use of the system, whether directly or indirectly.*

A comprehensive description of stakeholders is given by Sharp *et al.* (1999), who describe an approach to identifying stakeholders as either baseline, supplier, or client stakeholders. Baseline stakeholders are themselves categorised as *either users, developers, legislators, or decision-makers*. Supplier stakeholders provide information or supporting tasks to the baseline stakeholders, and client stakeholders process or inspect the products of the baseline stakeholders.

This clearly indicates that in an RCM introduction process, many stakeholders must be taken into account. Their needs, demands, and expectations have to be identified, transformed into requirements, and dealt with. The concept of requirement can be described in many ways. In answer to the question “What are requirements?”, Harwell *et al.* (1993) provide the following characterisation:

*Requirements are the descriptions of properties, attributes, services, functions, and/or behaviours needed in a product to accomplish the goals and purposes of the system. If it mandates that something must be accomplished, transformed, produced or provided, it is a requirement.*

With respect to the RCM introduction process, a majority of the requirements relate to information and communication aspects. Some examples will be given in the following section.

### The usefulness of process and requirements management – A case study

Several obstacles that may turn up during RCM introduction have been described based on a case study. The knowledge of these obstacles can be used to reveal the usefulness of process and requirement management, as a way of working with RCM requirement management. The case-study example will not go into excessive detail, since an RCM introduction process looks different depending on the organisation, with differences in terms of aims, goals, and environment.

Using a process view, we can focus on the various sub processes, activities, actors, and systems involved in an RCM introduction process, which facilitates the identification and specification of requirements. The introduction of RCM can be seen as a core process, the several phases of which can be regarded as sub processes. These are in turn supported by support processes and management processes (see Table I).
Core process - RCM introduction process

Sub processes
- The initiation process
- The pilot-study process
- The planning and preparation process
- The analysis process
- The implementation process
- The living programme process

Support processes
- Training and education
- Information and data gathering

Management processes:
- Maintenance-management process
- RCM-management process
- Project-management process
- Change-management process

Table I. Examples of sub processes, management processes, support processes, and sub processes in introducing RCM.

Analysing the processes in Table I allows us to identify a wide range of customers and other interested parties. Examples of various stakeholders are categorised according to the description in Sharp, et al. (1999), using the baseline, supplier, and client stakeholder categories (see Table II).

Baseline stakeholders (e.g. users, developers, legislators, decision-makers)
- Introduction project manager
- Maintenance managers
- RCM team
- Maintenance planners
- Maintenance personnel

Supplier stakeholders (providing information or supporting tasks to baseline stakeholders)
- Information system providers
- Maintenance personnel
- Operators
- Designers of systems and equipment
- Technical personnel

Client stakeholders (processing or inspecting the products of the baseline stakeholders)
- Upper management
- Contractors
- Maintenance personnel
- Operators

Table II. Examples of stakeholders in the RCM introduction process.

Baseline stakeholders require information and service from various supplier stakeholders, and client stakeholders require results, information, and services from the baseline stakeholders. In many cases, baseline stakeholders’ requirements pertaining to supplier stakeholders can be derived from client stakeholders’ requirements. In general, stakeholders of all categories need adequate information about the overarching goals and how RCM introduction will affect the system, including work situations. Explanation of the stakeholders’ requirements is facilitated by referring to the various processes set forth in Table I.

A number of tasks, which became obstacles for the RCM introduction process, have been described earlier. These can be related to stakeholders, with related types of requirements, according to Table III.

<table>
<thead>
<tr>
<th>Obstacles</th>
<th>Stakeholders</th>
<th>Types of requirements</th>
</tr>
</thead>
<tbody>
<tr>
<td>A common computerised maintenance-management system (CMMS) is not available.</td>
<td>- Maintenance manager</td>
<td>The CMMS should provide information for maintenance optimisation.</td>
</tr>
<tr>
<td></td>
<td>- RCM analyst</td>
<td>The CMMS should provide information support for analysis.</td>
</tr>
<tr>
<td>- Information system provider</td>
<td>The various stakeholders’ requirements for CMMS will guide the development efforts.</td>
<td></td>
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<tr>
<td>-----------------------------</td>
<td>----------------------------------------------------------------------------------</td>
<td></td>
</tr>
<tr>
<td>- Maintenance personnel</td>
<td>The CMMS should provide simple means for reporting, information retrieval, and follow-up.</td>
<td></td>
</tr>
<tr>
<td>- Operators</td>
<td></td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>RCM computer system is missing.</th>
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<tbody>
<tr>
<td>- RCM team</td>
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<tr>
<td>- Maintenance manager</td>
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</table>

<table>
<thead>
<tr>
<th>A plant register is missing.</th>
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<tbody>
<tr>
<td>- RCM team</td>
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<tr>
<td>- Maintenance manager</td>
</tr>
<tr>
<td>- Maintenance personnel</td>
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</tbody>
</table>

<table>
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<tr>
<th>System descriptions are unavailable or incomplete.</th>
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<tbody>
<tr>
<td>- RCM team</td>
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<tr>
<td>- Maintenance personnel</td>
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</table>

<table>
<thead>
<tr>
<th>Common maintenance terminology is missing.</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Maintenance manager</td>
</tr>
<tr>
<td>- RCM team</td>
</tr>
<tr>
<td>- Maintenance personnel</td>
</tr>
<tr>
<td>- Designers of systems and equipment</td>
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</tbody>
</table>

<table>
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<tr>
<th>An overall maintenance-management strategy is lacking.</th>
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</thead>
<tbody>
<tr>
<td>- Introduction project manager</td>
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<tr>
<td>- Maintenance manager</td>
</tr>
<tr>
<td>- Maintenance planner</td>
</tr>
<tr>
<td>- Information system provider</td>
</tr>
<tr>
<td>- Maintenance personnel</td>
</tr>
<tr>
<td>- Contractors</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Goals and benefits are not focused on.</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Introduction project manager</td>
</tr>
<tr>
<td>- Maintenance manager</td>
</tr>
<tr>
<td>- Upper management</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Measuring and monitoring of progress is unclear.</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Introduction project manager</td>
</tr>
<tr>
<td>- Maintenance manager</td>
</tr>
<tr>
<td>- RCM analysts</td>
</tr>
<tr>
<td>- Upper management</td>
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</tbody>
</table>

Table III. Examples of obstacles, stakeholders, and requirements in the RCM introduction process.
Even if the RCM introduction process is identified and scrutinised, we have to bear in mind that RCM is just one of many parts of an overall maintenance-management strategy. Therefore, we must develop an overall maintenance-management process, and identify the interfaces with the RCM analysis process. When initiating the introduction of RCM at Vattenfall AB Vattenkraft, an overall maintenance process was not developed, and was consequently unavailable to the contractor. That made it difficult to understand how RCM would benefit overall maintenance management, and how to work with RCM as a living programme. Today, Vattenfall AB Vattenkraft is developing an overall maintenance-management process, and the contractor is considering a similar process, though as of March 2003 this was only at the conceptual stage. When completed, this will comprise the basis for developing the living RCM programme. However, to gain top-management commitment it is important, even in the initiation phase of RCM, to visualise the complete RCM analysis and management processes as well as the interfaces with an overall maintenance-management process.

Discussion and conclusions

Introducing RCM in order to obtain an RCM-based maintenance programme places requirements on the organisation and its existing maintenance programme. A holistic view is necessary to identify and manage these requirements, as a wide range of obstacles crop up during an introduction process. A process view can facilitate the identification of, for example, actors, roles, responsibilities, routines, and support systems. The focus on customers, and on how well and effectively they are satisfied, can be directly linked to the prerequisite of top management commitment.

The requirements for introducing RCM can be major management tasks, for example, the purchase and use of a CMMS or setting common maintenance terminology. As described in the case study, such issues generated “projects within the project”, which made the management of RCM introduction very cumbersome. The RCM-requirement management approach, presented in the paper, gives an indication of an organisation’s readiness to introduce RCM. Some fundamental maintenance management tasks might have to be dealt with before initiating an RCM introduction process (see Steiby, 1995).

Basic process, power, and manufacturing industries have generally worked less systematically and comprehensively with maintenance management, than have, for example, the nuclear and offshore industries. Applying RCM provides a working method for obtaining a core structure as a basis for an effective and efficient maintenance programme. It is therefore of specific interest and importance that basic industrial organisations be able successfully to introduce RCM. The RCM requirement management approach presented in this paper, which features establishing favourable conditions when initiating the introduction process, focuses on the hydropower industry. However, the conditions for maintenance management within the hydropower sector are quite similar to those of other basic industries, described in the introduction.

Acknowledgments

The authors would like to thank VINNOVA, The Swedish Agency for Innovation Systems, and the Polhem Laboratory for their financial support. We would also like to thank Vattenfall AB Vattenkraft and Vattenfall Service for their kind support during the research studies.

References:


Managing commitment: Increasing the odds for successful implementation of TQM, TPM or RCM

Jonas Hansson, Fredrik Backlund and Liselott Lycke
To be published in International Journal of Quality & Reliability Management (2003), Vol. 20 No. 9.
Managing commitment: increasing the odds for successful implementation of TQM, TPM or RCM

Abstract: Quality management, by means of Total Quality Management (TQM), is considered to foster organisational performance characterised by competitiveness and long-term profitability. Since the benefits of quality management cannot be achieved without the sustained performance of equipment affecting product quality, maintenance management has become important. This has led to the development of maintenance methodologies, such as Total Productive Maintenance (TPM) and Reliability Centred Maintenance (RCM). TQM, TPM and RCM implementation have, however, often failed or been poorly executed. This has affected organisations’ performance and ultimately survival in a competitive environment. This paper includes a comparative study of literature on TQM, TPM and RCM implementation, focusing on organisational change. The study found several common categories of activities when implementing TQM and the maintenance methodologies. These categories can be considered crucial to obtain management and employee commitment. Case studies on TQM, TPM and RCM implementation are used to validate the categories identified, and to yield recommendations on the handling of activities within these.

Introduction

Over the past few decades quality management has been recognised as giving the edge for competitiveness and long-term profitability. Total Quality Management (TQM), considered by many to be a holistic approach, seeks to convert the culture and structure of the organisation into a total commitment to quality (Barad, 1996). However, long-term profitability and competitiveness, by means of quality management, cannot be achieved without sustained equipment performance. Any corporation that uses complex facilities in producing products, realises that preventive maintenance plays a key role in their TQM approach (Smith et al., 1991; Ben-Daya & Duffuaa, 1995). Therefore, the quality of maintenance itself is important, since it affects equipment performance and consequently final product quality. This has led to the development of maintenance methods, such as Total Productive Maintenance (TPM) and Reliability Centred Maintenance (RCM). According to Smith et al. (1991) and Kelly (1992), TPM and RCM provide both effective and efficient maintenance in response to the needs of TQM. The many advantages and benefits generated when working with TQM, TPM or RCM are recognised by, for example, Nakajima (1989), Gotoh (1991), Smith (1993), Hendricks & Singhal (1997), Moubray (1997) and McAdam & Bannister (2001). This paper focuses on managing the implementation of TQM, TPM and RCM, as important components of both quality and maintenance management.

Several examples of failed or poorly implemented TQM, TPM and RCM exist in various lines of business and types of organisations; see Brown et al. (1994), Eskildson (1994), Hipkin & Lockett (1995), Bamber et al. (1999), Latino (1999) and Cooke (2000). The relatively frequent incidence of failed or poorly performing implementation is problematic, and adversely affects organisations striving for business excellence and survival in a competitive environment. Unsuccessful implementation may also discourage others from initiating similar implementation efforts. This paper focuses on the organisational change occurring during implementation, in particular, change related to obtaining employee and management commitment. Several papers on TQM, TPM and RCM implementation, e.g., Ryan (1992), Bamber et al. (1999) and Allen & Kilmann (2001), have recognised this to be vital.
Scrutinising the commitment aspect is important, as, according to Kanji & Asher (1993), changing things is much easier than changing people. This paper aims to facilitate commitment management during implementation. One way to do this is to compare experiences of obstacles and driving forces when implementing TQM, TPM and RCM. The comparison allows us to identify common categories pertaining to commitment which are crucial for successful implementation. Such extended knowledge should facilitate implementation of TQM, TPM and RCM, contributing to the successful implementation of quality and maintenance management efforts.

Core aspects of TQM, TPM and RCM

Using TQM, we can apply quality management holistically, encompassing all parts of the organisation. TQM embraces the whole organisation and all its processes, supporting efforts to create satisfied customers (Huxtable, 1995; Dale, 1999). Many writers, such as Garvin (1988), Oakland (1989), Dahlgaard et al. (1994) and Dale (1999) have examined TQM, mentioning issues such as management commitment, customer orientation, process focus and employee participation as important. In this paper we use Hellsten & Klefsjö’s (2000) definition of TQM: a management system in continuous change, comprising values, techniques and tools, the overall goal of which is increased customer satisfaction with decreasing resources.

TPM and RCM can constitute important structures within maintenance management (Hipkin & DeCock, 2000), which itself can be defined as “all activities of the management that determine the maintenance objectives, strategies, and responsibilities…” (Swedish Standards Institute, 2001). TPM was developed for the manufacturing sector, while RCM was originally developed in the aircraft industry; both are now widely used in various industrial sectors. TPM focuses on integrating operators within maintenance work and on continuous and systematic improvement in order to maximise overall equipment effectiveness. The main goal is robust processes, i.e., processes free from disruption (Nakajima, 1988; Nakajima, 1989; Davis, 1997). However, while adequate for simple assets, TPM does not work for complicated physical assets. RCM is more directed towards technology and offers a sound basis for assessing maintenance requirements in this context (Geraghty, 1996). RCM can be described as a systematic approach for identifying effective and efficient preventive maintenance tasks, by means of function and risk analysis. For a more comprehensive description of RCM, see, for example, Smith (1993) and IEC60300-3-11 (1999).

Methodology

This paper examines the implementation of TQM, TPM and RCM by means of literature and case studies. The literature sources have been chosen so as to identify common experiences pertaining to organisational commitment – important for successful implementation. The case studies have been chosen so as to verify and develop the findings derived from the comparative literature study.

Description of the literature review and the development of common categories

The literature review surveyed a range of papers and books dealing with TQM, TPM and RCM implementation, collected over several years of research. The main databases used were Academic Search Elite, Business Source Elite, EconLit and Emerald, while the main keywords used were “TQM implementation,” “TPM implementation,” “RCM
implementation” and “RCM,” combined in some searches with “organisational change.” Since searches for “RCM implementation” generated so few hits, “RCM” was also searched for on its own. Papers of interest were also found by studying the reference lists in the literature sources consulted.

The literature searches located a great deal of material, and approximately 25 to 30 papers on TQM, TPM and RCM were considered relevant to this paper and were compared. By means of affinity-diagram methodology, see Bergman & Klefsjö (2002), the material on TQM, TPM and RCM was grouped into various subject categories. These were then compared and common categories were considered crucial. The complete comparative literature study can be found in Backlund & Hansson (2002). All the references used are not included in the current paper due to space limitations.

The case studies

Case studies were performed to obtain in-depth knowledge of the TQM, TPM and RCM implementation processes. Such an approach is appropriate when studying managerial processes, since the boundaries between the phenomena and their contexts are not obvious (Yin, 1994). In these cases, the phenomena are the implementation processes. Case studies allow us to gain a better understanding of complex social phenomena (Yin, 1994), such as organisations’ implementation of TQM, TPM or RCM. The data collection methods used in the case studies were interviews, documentation collection, participant observation, direct observation and action research. These approaches are further discussed in Gummesson (1991), Denzin & Lincoln (1994) and McNiff (1995).

The TQM case study, performed in 2000, used interviews of management and employee representatives, documentation collection, and, to some extent, direct observation. The study covered all small organisations with 10–49 employees in Sweden that had received a quality award, indicating that they had successfully implemented TQM. Nine organisations, both public and private and in both the manufacturing and service sectors, met the requirements. Since the study concerned the implementation processes in the nine organisations, a multiple case study design was used. For a more comprehensive description of this case study, see Hansson (2001a; 2001b).

The TPM case study was conducted between 1995 and 1998 at a production unit with 320 employees in a Swedish company manufacturing mobile hydraulics. The unit was implementing TPM. The study used interviews, direct observation, documentation collection and action research. For a more comprehensive description of the case study, see Lycke (2000) and Lycke & Akersten (2000).

The RCM case study was conducted between 1997 and 2002 at a Swedish hydropower company with approximately 400 employees. The main focus was planning and preparation for implementing RCM, based on two major pilot projects. The study used interviews, direct observation, documentation collection and action research. For a more comprehensive description of the case study, see Backlund (1999; 2002).

As with the organisations described in the literature, the organisations examined in the case studies differed in terms of size and line of business. Similarities in, for example, size or basic character between the units of comparison is generally desirable in comparative case studies. However, for this paper the cases were not compared with each other, but with the theoretical findings in order to validate and develop them, in what is known as analytic generalisation.
In view of our aim, and in accordance with Eneroth (1986), we deemed it important to examine as many different cases in as many different settings as possible. This procedure permits the discovery of as many characteristics of the phenomena (i.e., the implementation processes) as possible.

**Implications of the theoretical study**

Management commitment is clearly a key factor which must be present before initiating an implementation process. The implementation of TQM, TPM and RCM generally require major resources, such as human resources and funds (Kelly, 1992; Shin et al., 1998; Latino, 1999). Since management is responsible for the availability of resources and the overall implementation approach, management commitment is a prerequisite. However, management commitment can decrease during the process, due to, for example:

- Unclear understanding of what is being done, and of the objectives and methodologies of the concept (Clark, 1991; Hipkin & Lockett, 1995).
- Perceived threats to supervisors’ and managers’ roles (Bardoel & Sohal, 1999).
- Failure to produce results quickly where management has little patience to await benefits and is looking for short-term returns on investment (Schawn & Khan, 1994; Laszlo, 1999). Withdrawal of management support may also occur when benefits cannot be identified or attributed to the concept implemented (Bowler & Leonard, 1994a).

Employee commitment is also necessary since employees actually execute the activities during the implementation. Employees’ willingness to change can be affected negatively for various reasons, including:

- Demoralised staff may resist change due to, for example, fear of losing jobs (Hardwick & Winsor, 2001), status affected (McAdam & McGeough, 2000) or negative experience of earlier problematic change projects (Dale et al., 1997; Bardoel & Sohal, 1999; Hardwick & Winsor, 2002).
- Unwillingness to change due to stressful work conditions or not understanding the process, i.e., personnel are unable to see the benefits of the implementation (Karlsson & Ljungberg, 1995; Shin et al., 1998).
- Conservatism, or upholding existing practices, stemming from insufficient knowledge of the new working methods (Worledge, 1993; Bardoel & Sohal, 1999).

Uncommitted management and employees are obviously severe obstacles for managing an implementation. Difficulties obtaining commitment have to do with the characteristics of individuals, such as perceptions (Saad & Siha, 2000), attitudes (Tsang & Chan, 2000), expectations (Schawn & Khan, 1994) and values (Saad & Siha, 2000), that could obstruct acceptance of and motivation to work with an implementation. Intangible factors such as involvement, ownership and understanding are important in obtaining commitment, in that they affect behaviour characteristics (e.g. Saad & Siha, 2000; Ghobadian & Gallear, 2001; Hardwick & Winsor, 2001). The literature notes enabling activities that promote these intangibles, for example, information (Tsang & Chan, 2000), education (Bardoel & Sohal, 1999) and empowerment (Hardwick & Winsor, 2001). However, several authors point out the difficulty in managing intangible factors and stress the need for an approach or strategy (e.g. McAdam & Duffner, 1996; Hill & Collins, 2000; Hardwick & Winsor, 2002). An approach is needed that facilitates the management of commitment by identifying what, and how, various enabling activities promote intangible factors.
Categories important for managing commitment

As mentioned earlier, management commitment must permeate an organisation before implementation begins. The comparative literature study of TQM, TPM and RCM implementation led to identification of common activities that influence intangible factors. Using affinity diagram methodology, we identified several categories of activities common to TQM, TPM and RCM that affect commitment during the change process. The identified categories, considered to be important, are:

- **Support and leadership**, which implies making employees feel recognised, and visibly showing the significance of the implementation to motivate employees (Hartman, 1992; Allen & Kilmann, 2001). Management should also consider the work environment, i.e. whether employees have the time and resources for improvement efforts; this is fundamental for ensuring that employees willingly comply with the implementation (Shin et al., 1998; Latino, 1999; Cooke, 2000).

- **Strategic planning**, which implies activities which link TQM, TPM and RCM to the company mission, vision and defined business strategy, and strategic priorities and goals (e.g. Riis et al., 1997; Bardoel & Sohal, 1999). This gives a clear picture of how the improvement will benefit the organisation and promote desired achievements such as management and employee understanding.

- **Planning the implementation**, which implies developing a clear scope in order to identify obstacles and driving forces (e.g. Hartman, 1992; Hipkin & Lockett, 1995; Shin et al., 1998). This facilitates monitoring and follow-up, which promotes such desired achievements as management and employee understanding and involvement. It also implies activities which promote the participation of all concerned parties (e.g., front-line staff, unions, and management), usually by means of small teams, in goal setting, and identifying solutions (Kelly, 1992; Schawn & Khan, 1994; Abraham et al., 1999). The participation of employees promotes such desired achievements as involvement and ownership.

- **Buying-in and empowerment**, which implies such activities as selling the concept to each group, identifying what each group or level of employees and management want (e.g. Smith, 1993; Bamber et al., 1999; Allen & Kilmann, 2001). Buy-in activities promote such desired achievements as involvement and ownership, and facilitate the identification and control of expectations. Empowerment activities, such as sharing responsibility (Lewis, 1996), promote involvement, job satisfaction, independence and ownership among employees (Yamashina, 2000; Aghazadeh, 2002).

- **Training education**, which implies activities that develop employee competence, skills and knowledge (e.g. Nakajima, 1988; Thomas, 1994; Bardoel & Sohal, 1999). Training promotes employee belief that the company is investing in them; it also supports understanding and awareness.

- **Communication and information**, which implies open and meaningful communication about aims and goals, and about the concept and how it will affect employees personally (Abraham et al., 1999; Pintelon et al., 1999; Tsang & Chan, 2000). Information and communication promote such desired achievements as understanding and involvement.

- **Monitoring and evaluation**, which implies such activities as obtaining measurable and quantified results and objectives, so as to have a clear scope and focus, and continually monitoring and following through the process (e.g. Bowler & Leonard, 1994b; Wruck & Jensen, 1998; Bamber et al., 1999). This reveals progress and results that promote
management and employee involvement and understanding. Employees have to see how they can personally benefit from the change, while management must see how it benefits the company. Monitoring and evaluation yields feedback on results that promote creation of a motivated management which continuously provides resources and support for the implementation. Such management also motivates and engages employees as they experience progress (e.g. Karlsson & Ljungberg, 1995; Latino, 1999; Allen & Kilmann, 2001).

The theoretical knowledge gained from the literature study is presented in Figure 1 as a structure of categories; this presentation should facilitate understanding of how to manage commitment during the implementation processes. The activities undertaken within these categories do not only promote employee commitment during the change process; they also uphold and develop the management commitment that is a precondition for the activities undertaken.

![Figure 1. Important categories in managing commitment according to the discussed literature review](image)

The figure depicts how management commitment – a prerequisite – affects the development and management of the categories of enabling activities, which are crucial for obtaining employee commitment. The performance of activities within each particular category promotes the achievement of intangible factors, such as understanding, involvement and
ownership. Since activities undertaken within the categories also support and sustain management commitment, Figure 1 depicts a feedback loop from the important categories.

Validation and recommendations based on the case studies

The categories found in the literature review were validated by the case studies. Some aspects of the implementation are highlighted, which leads to recommendations on how to manage the activities within the categories. Even if the recommendations are derived from a specific case study, it is the authors’ opinion that the recommendations could be applicable for the implementation of TQM, TPM and RCM. Examples of aspects that confirm the literature findings, together with some recommendations, follow. As for the enabling activities based on the literature findings, some of the activities may be valid in several different categories.

Support and leadership

As stated in the literature, management support is a precondition for implementation. That is indeed true according to the case studies, as follows. In the TQM cases, employees perceived the organisations as permeated by management commitment – the driving force behind successful implementation. TPM was an initiative of a top manager, implying that TPM implementation received strong, continuous support from top management. Their involvement with the teams was important in motivating team members. During RCM implementation, middle management had to be committed to the process, to ensure sufficient personnel would be available. This was not the case until upper management formally announced that the process would continue full-scale.

Strategic planning

The use of strategic planning by the organisations studied incorporated several aspects and generated the following recommendations:

— *Involving the employees in the strategic planning process*. Involving employees in the development of strategies and goals related to TQM implementation promoted commitment, since it highlighted the concept and the implementation thus made more sense. The situation was similar in TPM implementation, where each team was supposed to formulate goals in line with company and TPM goals. Major implementation plans, with overarching goals and policies, were developed when implementing TPM throughout the organisation.

— *An overall maintenance management strategy*. This strategy was developed during RCM implementation, to guide upper management in implementing maintenance management. This served to promote upper management commitment to the RCM process.

Planning the implementation

Planning of the implementation, by the organisations studied, incorporated several aspects and generated the following recommendations:

— *Teambuilding, participation and a long-term approach*. The use of cross-functional teams for planning and implementing TQM promoted involvement throughout the organisation. Upper management clearly indicated that TPM should be implemented as part of a long-term strategy. A broad, long-term approach was also used when implementing RCM to involve as many of the employees as possible.
Buying-in and empowerment

The use of buying-in and empowerment by the organisations studied incorporated several aspects and generated the following recommendations:

— *Empowering the participants.* Delegating responsibility and empowering those involved in the changes brought about by TQM, created incentives for active participation. The situation was similar with TPM implementation, where upper management involved the employees in the planning process, as they wanted each team to decide by itself, so the teams would develop and mature.

— *Awareness of the customers in the implementation process.* Insufficient involvement of the personnel in charge of changes in the RCM programme resulted in lack of interest and comprehension of the analyses. Therefore, there was a focus on these internal customers in order to speed up the review procedure, and quickly creating visible results, which motivated management and employees.

Training and education

The use of training and education by the organisations studied incorporated several aspects and generated the following recommendations:

— *Include all employees and pay attention to process orientation.* Common to examples of successful TQM implementation was extensive training and education of all personnel. Process orientation proved difficult to comprehend, despite education, and needs special attention.

— *Overcome fear of job loss.* Some maintenance personnel felt TPM threatened their job security. Consequently, training focused on overcoming fear, so personnel would understand their importance to TPM implementation.

— *Co-ordinate training and education efforts.* If the interval between RCM training and practice was too long, people tended to forget what they had learnt, and some people were replaced. Additional training was therefore needed. It is thus important to co-ordinate training efforts.

Communication and information

The use of communication and information by the organisations studied incorporated several aspects and generated the following recommendations:

— *The need of an open atmosphere.* Communication without restraint was an important issue considering information and communication during the implementation of TQM. That facilitated for the detection of any obscurity or misunderstanding during the implementation process.

— *Involvement of the corporate communications department.* The importance of involving the corporate communications department in TPM implementation was recognised during implementation. Ensuring all affected employees received adequate information was vital.

— *The importance of informal communication.* Informal meetings of management and union representatives to discuss RCM were needed to complement formal communications, to generate increased interest and acceptance.
Monitoring and evaluation

Monitoring and evaluation by the organisations studied incorporated several aspects and generated the following recommendations:

- **The use of simple tools for quick feedback.** Regarding TQM, simple tools for monitoring matters such as customer satisfaction or the costs of poor quality generated feedback concerning the progress of implementation and highlighted positive effects. This stimulated employees and management to continue with the change process.

- **Visualise results.** To visualise the results and the continuous improvements during the implementation of TPM, boards were set up so the teams could describe their work in detail.

- **Scrutinise goals and aims to be monitored.** The number of goals and aims of RCM increased during implementation, which inhibited monitoring and evaluation. It was important to highlight the implementation goals to avoid overly complex and resource-intensive monitoring and evaluation and to build management and employee interest, motivation and support.

Discussion and conclusions

TQM, TPM or RCM implementation implies organisational change. It is imperative that management and employees are committed to implementation. Management must address intangible factors such as motivation, engagement and acceptance, in order to nurture a willingness to change. In the current literature on implementation of TQM, TPM or RCM, an overall approach regarding the management of intangible factors seems to be needed. The important categories identified in this paper should contribute to such an approach.

TQM, TPM and RCM differ concerning their focus on organisational matters. TQM core values, and to some extent TPM, focus on achieving commitment and other intangible factors such as involvement and engagement. However, implementation often fails due to, for example, lack of commitment. Intangible factors, even if taken account of by TQM and TPM, are difficult to manage and handle. When implementing RCM, there is an additional difficulty since the method itself ignores organisational matters, which is reflected by the rare occurrence of literature on RCM implementation. To handle commitment, we need to be aware of the importance and difficulty of handling intangible factors. Therefore, RCM implementation requires an organisational focus, especially since RCM is often introduced in times of the rationalisation (Moss, 1997) and changing of work routines (August, 1997), which affects job security. Since TQM, TPM and RCM implementation all require consideration of intangible factors, independent of any inherent organisational focus, successful implementation of, for example RCM, will facilitate implementation of the others.

Individual characteristics, such as attitudes and expectations, are also influenced by contextual aspects such as corporate culture (e.g. Kanji & Asher, 1993; McAdam & Duffner, 1996; Saad & Siha, 2000; Yamashina, 2000; Yusof & Aspinwall, 2000). The contextual aspects can be considered to be unique for each organisation, due to, for example, historical events, type of business, and environment. Therefore, contextual issues were not taken into account in the structure of important categories (see Figure 1). An organisation aiming to implement TQM, TPM and RCM must naturally consider their context when performing activities within important categories, but considering this is beyond the scope of this paper.
The aim of this paper was to compare TQM, TPM and RCM implementation in order to identify similarities in ways of managing commitment. The structure of common categories identified, should facilitate management of intangible factors, thereby promote commitment during implementation. As depicted in Figure 1, committed management, as a prerequisite, should focus on activities within these important categories: leadership and support, strategic planning, training and education, monitoring and evaluation, buying-in and empowerment, and information and communication. This should promote the employee commitment that is so essential to the successful implementation.

Acknowledgements

The authors gratefully acknowledge the financial support of VINNOVA (the Swedish Agency for Innovation Systems), the Polhem Laboratory and Sparbanksstiftelsen i Norrbotten. The authors would also like to thank the organisations that facilitated the case studies: Vattenfall AB Vattenkraft, Parker Hannifin, and all organisations mentioned in Hansson (2001a). For valuable comments on the paper, the authors are grateful to Professor Bengt Klefsjö. Finally, the authors gratefully acknowledge the referees for their observations, criticisms, and constructive suggestions.

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Appendix

Questionnaire Multiple-Case Study
The questionnaire, or basis for discussion, is based on the four perspectives and the different phases occurring during the introduction of RCM, in accordance with the figure. In this way, obstacles and driving forces can be focused on considering “what’, ‘how’ and ‘when’.

<table>
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<th>Perspectives</th>
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<td>*Living programme</td>
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- A focus on the preconditions for making it work

1 ISSUES/QUESTIONS BASED ON THE FOUR PERSPECTIVES

1.1 A maintenance management perspective

1.1.1 Current and previous maintenance programme and maintenance performance

- How was the previous maintenance programme and maintenance performance working (i.e. routines, work orders, optimisation, continuously improvements, etc), before the RCM introduction? How is it working today?
- The amount of preventive, corrective and condition based maintenance before and after RCM introduction?
- Is the maintenance performance in the regions, and the groups, quite similar or mainly different?
- What is your reflection on the maintenance competence and skills in the organisation?
- Historically, how many people have been involved in the performance of maintenance activities?

1.1.2 Documentation

- How well was/is the previous/current maintenance performance documented?
- Was the status of maintenance performance and maintenance management considered before starting up the introduction of RCM?
1.1.3 Support systems
- How do you consider that the computerised maintenance management system (CMMS) is used? Have many different CMMS have been introduced/applied in the organisation?
- Does a plant register exist?

1.1.4 Maintenance culture
- To what extent do different professional categories cooperate to make maintenance performance more effective?
- Does a strong, so-called professional pride exist among the employees?
- Is/was the opinion among the maintenance personnel that the plants would be better maintained (“in an excellent shape”), compared with the view of the engineering staff?

1.1.5 Strategic maintenance management - RCM
- Is maintenance management viewed in an overall process/system?
- How would you characterise the top management view on maintenance (management), a focus on costs or/and maintenance as an investment?
- Is the RCM process visualised as a part of that overall maintenance management process/system?
- What other ‘techniques/methods’ are, or will be, integrated with the RCM process (for example ILS, TPM, etc)? – Why?
- Are some parts of the maintenance tasks/activities outsourced?
- Are the plants evaluated with regard to their significance for the production?

1.2 A RCM management perspective

1.2.1 The view on RCM
- What was your view on RCM when starting up the introduction process? What is your view today (a tool, a method, a technique, a philosophy, etc)?

1.2.2 The RCM model/process
- Is RCM viewed/described in a process?
- Why did you choose/develop the RCM model now used, compared with other alternatives (for example RCM II versus SRCM)?
- Has the RCM model been ‘simplified’ compared with ‘traditional’ RCM models (for example RCM II)? In what way?
- Has a consequence and risk matrix been used? Is an evaluation of plants used as a basis for the consequence matrix?
- When were responsibilities and roles in the RCM process (and its interfaces) identified?

1.2.3 The analysis performance
- How would you characterise the level worked on, what are the advantages and the disadvantages?
- What characterises a ‘right’ level? When did you find a ‘right’ level of performing the analysis, and has it been changed during the process?
- Were templates used?

1.2.4 The review procedure
- What is the experience of the review procedure?
- Are the analyses traceable?

1.2.5 The RCM computer system
- Why did you choose or develop the present one, compared with others?
- When, in the introduction process, did you obtain a RCM computer system?
- Is the computer system considered to be user-friendly?
- What main advantages (and disadvantages?) do you find with using a RCM computer system?

1.2.6 Systems connected to the RCM computer support
- Was the plant register connected to the computer system?
- Was a plant evaluation ‘model/list’ connected to the computer system?
- Was the computer system connected to a CMMS – in what way?

1.2.7 System and function description, and reliability data
- Were system descriptions and function descriptions available and sufficiently documented during the planning and preparation phase or the analysis phase?
- Has an overall system description of a power plant been available?
- To what extent were information and data on reliability available?

1.2.8 The RCM team
- Can the competence and skills among the RCM team members (including facilitators) be considered sufficient? Was some kind of competence profile used?
- Have the team members been interested and motivated, i.e. committed?
- Have the teams felt that they had enough time for performing analyses and that they could concentrate on the task?

1.3 A project management perspective

1.3.1 The project management group
(i.e. the people in charge of the introduction process)
- Has the RCM introduction been performed within a project?
- Who are involved in the RCM project management group? Competences and skills?
- Have there been the same project managers and project group members as long the RCM introduction process has been going on? If not, in what way has the process been affected?
- Has a steering group been involved? Competence and skills?
- Has the sponsor (in charge of resources) been changed during the process, and what has the consequence been of that?
- Do you consider that the people involved in the project management group have/have had sufficient time to work with the introduction process? How do you experience that other activities interfered with the RCM work?

1.3.2 Goals and aims
- Have you/management been aware of the many benefits that can be achieved/obtained by using RCM, both ‘soft’ and ‘hard’ aims/goals?
- What are the aims and goals of introducing RCM? Were they established early in the introduction process? Did they increase/change during the process and why?
- Has there been a focus on both ‘soft’ and ‘hard’ aims/goals?
- Have increased safety and environmental issues been considered important goals?
- Has there been a focus on ‘differentiated’ availability or mainly increased availability.
- Have you aimed at changing the overall way of performing maintenance by means of RCM; has the goal been to obtain a ‘living programme’?

1.3.3 Measuring and evaluation
- Was/is a strategy or approach developed to measure and evaluate the introduction of RCM considering costs and benefits (soft and hard)?
- Has it been possible to quantify results, benefits and costs due to the introduction of RCM?
- Has it been possible to identify what benefits are gained from the RCM introduction compared with other improvement projects and activities going on?
- Have cost-benefit analyses been made?

1.3.4 Control and monitoring
- Was/is there a strategy or approach developed to monitor and follow-up the introduction process?
- In what way, and to what extent, has (project) risk management been used to identify obstacles and driving forces during the introduction process?

1.3.5 Resource allocation
- Have there been any problems as regards the availability of people during the introduction process (key personnel as formal and informal leaders, facilitators, managers and specialists?)
- Have people been replaced during the process?
- Have the resources needed increased during the introduction process, and has this been questioned by managers and employees?

1.3.6 Quality assurance
- How do you work with quality assurance of the analyses made as regards different regions and groups? And to keep up the quality of the results of the analyses made?

1.3.7 Information and communication (a focus on ‘approach’)
- How has the geographical spread of regions, groups and plants affected information and communication routines?
- How to involve (inform and communicate) personnel not directly involved in the analysis work?
- It seems that most people in the organisation know about the RCM project and what is going on? How to make the project visible in the organisation?
- Do you have a common maintenance terminology? Since when?
- Has the involvement of the unions been an advantage in the spread of information and support among employees?
- If many projects are going on, is there a tendency of ‘information fatigue’ in the organisation?
- Has informal/personal communication been used, to what extent?

1.3.8 Benchmarking – consultants
- Has benchmarking being used? - In what way?
- Have consultants been used? - In what way?

1.3.9 Training efforts
- Approximately, how much training did facilitators, team members, middle and top managers/sponsors, union representatives, project group members get?
- How much training and involvement has been offered to the ones that approved the analysis recommendations and are in charge of implementing these?
- Were people changed during the introduction process? – How did this affect information and training efforts?

1.4 A change management perspective

1.4.1 Company situation
- Is it, and has it been, a stressful work environment during the time of the introduction of RCM?
- Are many projects or improvement activities going on at the same time as RCM?
- How about resource allocation among the different projects – coordination etc?
- In what way does the top management prioritise the RCM ‘project’ compared to other projects or improvement activities?

1.4.2 Culture (Company, regions and groups)
- Do you experience that ‘companies in the company’ exist that aim at the status of autonomous regions? Has the geographical spread of plants generated different cultures in the regions?
- Has there been/Is there a negative attitude among employees towards introducing RCM, due to previous failed or problematic introductions of other kinds of improvements projects?
- Are and have many improvement projects been going on?
- Do the groups perform according to the region managers’ direction on RCM?
1.4.3 Information and communication (a focus on the ‘content’)
- Do personnel (managers and employees) understand why maintenance has to be performed in a more effective way? Do they understand why the prevailing/earlier way of working is/was ineffective?
- Do people understand and accept the evaluation of plants, and the risk matrix?
- Do you consider that all personnel involved understand the RCM process/model?
- Were trailing/challenge groups used to increase acceptance of analyses?

1.4.4 Buy-in
- How many people, personnel categories, were/are involved in the introduction process?
- Have you identified and involved external and internal customers in the introduction process?
- How to involve and engage personnel that are not directly participating in the analysis process?
- Have you identified ‘benefits’ appealing to each group/level of employees and management as regards the introduction of RCM? What incitements have been used for working with RCM?

1.4.5 Staff turnover
- How have you handled staff turnover due to the introduction of RCM?
- How have you dealt with people feeling afraid of losing their jobs due to RCM?

1.4.6 Top management and middle management commitment
- In what way can you make the judgement that the top management, middle management, unions and employees have been/are interested and committed to the introduction process?
- What are the driving forces that make management, union and employees committed?
- How involved do you consider that top management and middle management have been in the introduction process?

2 QUESTIONS IN GENERAL

2.1 Overall questions on the introduction approach
- How did you evaluate the preconditions, in general, for introducing RCM?
- When starting up the planning and preparation phase, was a comprehensive view used, e.g. an approach to managing all the coming introduction phases?
- Why is a short-term, or a long-term, introduction approach used?
- How many systems are/have been analysed simultaneously, how many groups (and regions) are/have been involved at the same time, i.e. a broad, or ‘narrow’ approach, during the different phases?
- Approximately, how many of the existing plants and systems are included in the RCM analyses?

2.2 Company specifics
- Does the organisation operate on a deregulated market?
- Approximately, what is the average age in the company?
- How would you characterise the relationship between the top management, management, and employees?
- How similar are systems and plants? Can the different plants be looked upon as ‘individuals’, i.e. built during different time periods, by different manufactures, and with different sub systems?

2.3 Some issues on criteria and perspectives
What main causes have led to obstacles and driving forces during the introduction process management, which have had an affect upon:
- Resources (Costs)?
- Time (Delays)?
- Quality of the outcomes?
- Commitment of the top management, middle management, union, and employees during this process (i.e. Understanding, Resistance, Motivation, Interest, Acceptance, and Engagement)?
- Basis for the continuous improvements (‘living programme’)?

2.4 Contextual issues
- In what way, and to what extent, have contextual issues such as company culture, history and politics influenced the introduction process management?
- Has the introduction process been affected by influential reactionary people?

2.5 Questions considering the specific introduction phases
- Did you have a strategy for or approach to managing each introduction phase?
- Did you make some kind of evaluation at the end of each phase?
- How do you experience the changeover between the introduction phases?

2.5.1 The initiation phase
- Major obstacles and driving forces during the initiation phase?
- Who initiated RCM?
- Why was RCM initiated?
- Were there alternatives to RCM?

2.5.2 The pilot phase
- Major obstacles and driving forces during the pilot phase?
- Were the recommendations from the RCM analysis implemented, and continuously improved?
- How did the work on the pilot plants continue, while the planning and preparation phase was starting for the full-scale introduction?
- In what way were the experiences of the pilot project(s) used in the planning and preparation of a full-scale introduction process?

2.5.3 The planning and preparation phase
- Major obstacles and driving forces during the planning and preparation phase?
- In the beginning of the initiation phase, and the planning and preparation – what were the expectations among the management and the project group? For example, concerning resources needed, timeframes, and a living RCM programme. Has the RCM introduction process become more complex and cumbersome than expected?

2.5.4 The analysis phase
- Major obstacles and driving forces during the analysis phase?
- When starting the analysis phase – were ‘all’ planning and preparation activities completed?

2.5.5 The implementation phase
- Major obstacles and driving forces during the implementation phase?
- Was/is a strategy developed for implementing the recommendations, for managing the change and for having the equipment and knowledge needed?
- How do you handle the recommendations of the initial analyses, i.e. lists of measures and modifications? Have maintenance plans been developed, at a plant or within a group, based on the RCM analyses?
- Do you think there may be a problem as regards the time and people needed to do the changes in the existing maintenance programme, due to the recommendations of the RCM analysis? Do you think there will be resistance to changing existing maintenance tasks?
- Has it been a problem that the analyses made have taken a long time to be reviewed and implemented? Why? What have been the consequences of that?

2.5.6 Favourable conditions for continuous improvements
- Considering the previous status of the introduction process – what judgement do you make of the conditions for success with the introduction process and for attaining a living programme phase?

2.6 Results - benefits
- What have been the main goals and aims of introducing RCM? (‘Soft/intangible’ and ‘hard/tangible’)
- What kinds of results have been obtained? (‘Soft/intangible’ and ‘hard/tangible’)
- What pay-off levels have the sponsor/top management in mind? Were they/are they aware of, and accept, long-term benefits? A focus on increase in knowledge and skills or mainly (short-term) costs?
- Has there been a change in the division of maintenance strategies, i.e. preventive, corrective and condition based (monitoring) maintenance?
- Have savings/reductions in maintenance costs/activities had an effect on availability?
- Do you consider that the maintenance performance today is based upon RCM principles?
- How much, approximately, has been spent on the introduction of RCM?
- How long did it take from starting the planning and preparation phase, before benefits were realised/visualised?