Development of a New Technical Asset Management Service for Karsten Moholt AS

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Preface

This assignment is written during the spring semester of 2021 at the Department of Mechanical and Marine Engineering at Western University of Applied Scienes (WNUAS) as a Bachelor thesis and a final evaluation for Production Engineers. This Bachelor thesis was written by Silje Furnes Pettersen, Peter Storegjerde Skogen and Åsmund Seim Herskedal.

We would like to take this opportunity to thank Karsten Moholt AS for giving us this project and especially thank Stian Bless, Vice President Maritime, for being readily available and taking his time to thoroughly answer our questions. We would also like to thank our supervisor and Dr. Maneesh Singh for his guidance and help throughout this project. Without his vast knowledge and help we would not have known where to start.

Abstract

The goal of this thesis is to help Karsten Moholt AS develop a foundation for offering a Maintenance Management service and provide a blueprint on how to start a Maintenance Management team. An introduction into Asset Management literature is presented to be later used in relation to The Maintenance Loop before going in depth into the Maintenance Management service. Since Reliability Centered Maintenance (RCM) is a central part of the service the team will provide, an overview of RCM is provided along with its benefits and disadvantages. Also, an explanation for why a RCM analysis from Karsten Moholt AS would be beneficial is given. Next, a suggestion on how the service could function step-by-step is presented along with how the team can be structured. Different Computerized Maintenance Management System (CMMS) software options are presented in an attached excel-file (excerpts from the excel-file is presented in 6.1). The thesis also takes a look at the future of maintenance in relation to the next industrial revolution (i.e Industry 4.0). A smart maintenance life cycle is presented, which shows how "smart" maintenance could be structured in the future and suggests how maintenance and condition monitoring might evolve.

Sammendrag

Målet med oppgaven er å hjelpe Karsten Moholt AS med å bygge grunnlaget for å kunne danne en vedlikeholdsstyrings-tjeneste og bygge et team som skal tilby denne tjenesten. Oppgaven begynner med en oversikt over det literære vitenskapelige stoffet oppgaven bygger på som er Asset Management, Vedlikeholdssløyfen og Reliability Centered Maintenance (RCM). Det blir også gitt en forklaring på hva vedlikeholdsstyring går ut på. Videre diskuteres tjenesten og teamets mulige oppbygging, og det blir gitt en stegvis gjennomgang av hvordan tjensten kan fungere i samarbeid med en kunde. Å kunne ha et Computerized Maintenance Management System er sentralt for teamet derfor er ulike alternativer som finnes på markedet i dag gitt både i oppgaven som figurer og i egen excel-fil. Oppgaven ser også på den neste industrielle revolusjon i form av Inudstri 4.0, der en tenkt framtidig vedlikholdssyklus blir gjennomgått, som kan peke på ulike teknologier som kan bli relevante i fremtiden.

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1 Introduction

1.1 Background

Karsten Moholt started his career in Bergen as a newly graduated electrical engineer in 1945 right after World War II. He started a wrapping workshop with three employees and in 1950 they moved to Klosteret on Nordnes with eight employees. [29]

In their first years, the work were mainly focused on ship and industrial service. In the 70´s and 80´s they quickly expanded to become an electro mechanical competence center for a world wide market. The size of the projects had a continuous increase and by 1974 they moved the business to a new and bigger property in Michael Krohnsgate. In 2012, the business was once again expanded and moved to an even bigger and more modern property on the island Askøy, outside Bergen. [29]

In 1991, the founder's son also named Karsten Moholt, took over the company. With his business knowledge, competence and actions he developed the business from a small company with 25 employees to a big company with 170 employees. In 1999, the 3. generation of Moholt, Karsten Aleksander Moholt, became a part of the management team. In 2009, both Karsten and Karsten Alexander Moholt tragically died in an airplane accident on the way home from Brazil where the plane crashed in the Atlantic Ocean. Karsten Moholt´s daughter, Linn Cecilie Moholt, who had been in the company since 2002, immediately took over as daily manager in 2009. Under her management, the company has kept and improved their position on the global market. [29]

Today, the company is a preferred partner in some of the worlds most exciting companies. Karsten Moholt AS (KM) has expertise and three generation experience in electro mechanical equipment, electric motors and generators, something that makes them a leading contractor in this field. Today, KM has 180 skilled and motivated employees, modern and functional facilities, and faithful costumers who value quality. This position is something that KM has ambition to strengthen and further develop in the future. [29]

Karsten Moholt AS is a renowned company on maintenance of rotary machinery and equipment, both in their workshop and out in the field. This was KM main area of competence until 1997 when they started a new department specializing on continuous monitoring of machinery and equipment. [30]

Figure 1: Headquater of Karsten Moholt AS on Askøy

1.2 Motivation of the project

The creation of the continuous monitoring department opened a new market for Karsten Moholt AS, where they now were able to monitor the equipment for a customer and give a condition report on how their equipment was holding up. Condition reports gives information about which maintenance tasks are needed and when, and also how KM would solve the task and how much it would cost. Because of this, the rest of the company experienced a synergy effect due to the increase of maintenance jobs. [29]

The life cycle of rotary equipment with regards to the possible maintenance phases are roughly shown in Figure 2:

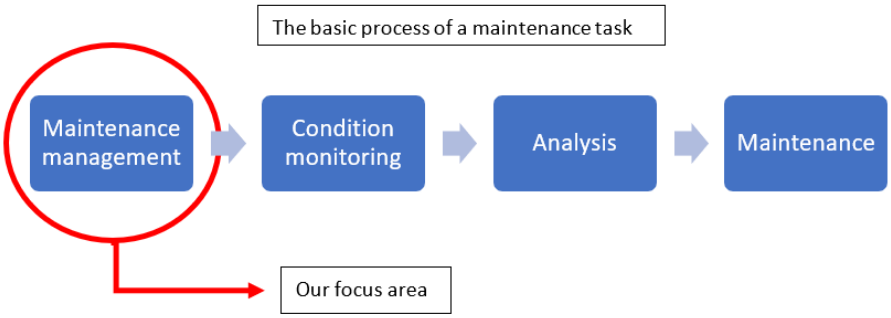

Figure 2: The basic process of a maintenance task

Today, Karsten Moholt AS offers all necessary services except Maintenance Management. Therefore, they want to examine if the inclusion of Maintenance Management tasks are a viable service to offer both old and new customers, and if it will give KM the same synergy effects that continuous monitoring gave in 1997. If KM starts offering Maintenance Management tasks as a service, they will be able to offer a package that includes the whole maintenance chain.

1.3 Aim of the project

The aim of this project is to review the feasibility of a Maintenance Management service that includes Reliability Centered Maintenance (RCM) analysis and provide a blueprint on how to start a Maintenance Management team.

1.4 Limitations

The authors of this thesis would have liked to be able to travel to Karsten Moholt AS facilities to observe and experience their work routines and systems, as well as talk to the employees. However, due to the ongoing Covid-19 pandemic we have not been able to do so. This is unfortunate as this would have immensely increased our knowledge of the organization and their mindset. We acknowledge that this limitation affects many others in the same situation at the time of writing this thesis, but this is nonetheless quite a substantial limitation due to the nature of this thesis.

1.5 Scope of work

This thesis will give recommendations on how Karsten Moholt AS can start a Maintenance Management service. It will review relevant literature regarding Asset Management, Reliability Centered Maintenance and Computerised Maintenance Management System, resulting in a set of recommendations on how the service will be setup, what they can offer the customer and how it can affect the rest of the company. The thesis will not go into detail on how to implement Asset management and it will not contain a market analysis.

1.6 Abbreviations

KM - Karsten Moholt AS

CMMS - Computerized Maintenance Management System

CPS - Cyber Physical System

RCM - Reliability Centered Maintenance

ISO - International Standard Organization

FMECA - Failure mode, effects and criticality analysis

AM - Asset Management

NPD - Norwegian Petroleum Directorate

KPI - Key Performance Indicator

WCM - World Class Maintenance

2 Method

Research methods can be classified in various ways, but one of the most common distinctions is between qualitative and quantitative research methods [32]. Quantitative research is the collection of data that is numerical in nature and can be put into categories, ranked in order, or measured in units of measurements. Using this research method gives access to data that can be used to construct graphs and tables of raw data when analyzed. Although, it can be difficult to clearly define qualitative research, for the sake of this comparison it can be defined as the act of collecting data that is non-numerical in nature. This data is in turn used to gain an understanding of underlying reasons, opinions and motivations [15].

Considering that qualitative research methods are applied in this thesis quantitative research methods will not be further defined nor discussed, but it is important to keep the distinction of the two research methods in mind since this paper is based only on the qualitative method.

2.1 Overview of qualitative research

In the literature the definition of "qualitative" is not clearly defined [9] and because of the variety of what qualitative research is trying to achieve it can be hard to give a clear definition of what qualitative research is. Different definitions are given in different contexts and line of work, but for the purpose of this thesis it can be defined as "empirical research where data are not in the form of numbers". Empirical meaning that data or research is based on something that is experienced or observed as opposed to being based on theory [38].

Qualitative research has the characteristics of being inductive, meaning it starts with collecting data and then looking for patterns or drawing some kind of theories from it. Whereas quantitative research sometimes uses a deductive approach where already established theories are being tested. In qualitative research it is the data that forms the theories and patterns [38].

Furthermore, qualitative research is an iterative process, meaning it can be repeated (e.g a transcript can be read many times, whereas in quantitative research it depends on the testing method). This process is often approached from a broad point of view before it gets limited and refined to get a closer look. Also, it means that other factors and elements can be incorporated into the research at later stages resulting in a more flexible and adaptive method. Moreover, the researcher is a integral part of the research thus their own biases and opinions can influence the data collection [38].

2.1.1 Interview

In order to understand opinions on, reasons and motivations for the subject matter of this thesis there was conducted an interview. The interview can be classified as an in-depth semi structured interview [20]. This means the researcher(s) has topics and questions in mind to ask, but questions are open ended (i.e questions that a researcher poses but does not provide answer options for) and flows according to how the participant responds [11].

3 Interview

3.1 Interview questions

To get a perspective of where Karsten Moholt AS are in their plans to start a Maintenance Management team a meeting was conducted with the Vice President in the maritime department, Stian Bless. Beforehand there was prepared a set of questions on specific topics. The topics were based on ISO 55000 Asset Management [18] (more on ISO 55000 in Chapter 4.1) in order to anchor our questions on a scientific framework. The questions were asked in a way for the respondent to express his opinions and motivations, and the respondent was free to deviate to other relevant topics. The following questions was asked:

Table 1: Questions KM first meeting

Question nr	Question
1	What is the new departement going to offer of services? Have you thought of the standard and procedure around these services?
2	Why do you want an independent asset management team? Why not from exsisting teams?
3	Have you carried out a risk asessment of setting a new team? What procedure have you followed? (ISO?)How does KM evaluate and measure risk? Do you have an existing risk matrix?
4	What will be the relation between this new team and existing asset management teams of KM?
5	What are your expectations and goals for the new department? Do you have a plan to acheive these goals? Where and how is the department working in lets say, 5 years?
6	What are typical challenges that can occure both with regard to clients and other departments that can have an affect on the new department and how are these going to be handled?
7	What is the structure (technical and managerial) of the team? What hierachy tree is going to be used in KM? What roles are going to be in the new team and what are their areas of responsibility? What competence is required for these roles? Management, administration and production
8	What part of the new department is going to be collaborated on (only external), and with who, if any? Are there any formal agreements that define the scope?
9	Do you have an enterprise resource planning system? How does KM document information? How are the system working? are you going to use existing system or a new one? How do you secure that everyone in the department and other departments have all the information that is given?
10	How does KM promote continual improvement? What specific is done to promote this?
11	How is the new department going to evaluate its own results? Is there a plan for this?

The planned questions as seen in Table 1 was used to keep the interview on the right track and to cover the most important areas of the ISO that was relevant for the project. But, as mentioned in Chapter 2.1.1 the participant was allowed to deviate and cover other topics that he found relevant. Thus, the questions was sometimes answered in a broad manner with multiple related topics being mentioned in a single answer, therefore, the text in Chapter 3.2 is compressed with the most important information from the answers with some paragraphs containing answers to multiple questions from Table 1.

3.2 Results of the interview

Karsten Moholt AS wants to start a new team, which will work as a consultation team. The idea is that the team will extend the thread that already exists between the activities that KM already do to sell more of their services, see Figure 2. This team's purpose is to consult with clients and influence their maintenance strategies on a larger scale. The goal is to make it easier and more beneficial for their clients to choose more of KM's services instead of having KM only doing one part of the maintenance and other companies doing the rest. They want to take part earlier in their clients maintenance planning process to influence their maintenance philosophy and assist them in developing a maintenance strategy. The idea is that the maintenance management team will be the first step in their business model and that the team will provide a solution for the customers who needs maintenance activities.

They are also surveying the market to find out if there is a potential to increase their clientele. Especially mentioning that there might be an unexplored market within the maritime sector, as this is an area they are not as fully integrated in as their main domain (i.e the oil and gas sector).

To expand into these areas Karsten Moholt AS is looking to acquire or develop a new software. They want a software that digitalize the process of RCM and FMECA. They use skAIwatch software as a platform where they collect data from sensors, maintenance logs and generally all the data relevant for maintenance. Microsoft Azure can also be used to collect these data, but its main purpose is to process the data into information. Microsoft Azure's task is to contextualize data into information to ease the process of drawing conclusions and decisions from the data.

For understanding the wanting of a dedicated team for this service KM stated that this kind of service requires high competence. In order to dedicate the focus and time that is necessary they want to hire personnel with the right competence and also train existing personnel to create a specialist environment with dedicated resources. Also, with the increase in knowledge and experience that comes with working with customers, the overall level of competence at KM will rise.

They also need to make sure there is a good commercial plan when introducing new services to avoid stressing the economics part and as fast as possible get customer jobs. If the Maintenance Management team lies dormant for too long and does not generate a revenue it is viewed as not successful. The fall pit is that the team takes too long to be functional, therefore, a clear structure must be developed before committing with substantial resources.

They count the team as a success if:

- They are able to sell to markets which they are currently not part of.
- They are recognized as a supplier of maintenance strategies.
- They create a synergy to the rest of Karsten Moholt AS where the result is that their existing departments such as the maintenance department can experience a growth in work orders because of the new team.
- They have a positive impact on their clients maintenance plan and environmental footprint.

Having a plan for continual improvement is important for a new team. KM has a lean mindset when it comes to improvement. This means that they promote continual improvement through scheduled meetings between leaders and floor workers, and different departments and management. Challenges are for example tackled with group workshops and root cause analysis. They also have a suggestion system where anyone can submit an improvement idea that later will be reviewed for possible implementation.

4 Literature review

As mentioned in Chapter 4, the interview questions were based on ISO55000 Asset Management in order to be anchored to a scientific framework. In the literature review an explanation will be given about what Asset Management is according to ISO. The difference between the two definitions of Asset management and Maintenance Management will be explained in order to clearly outline what part of the managerial role in an organization this paper focus on, and to clear up any confusion. The benefits of having an Asset Management system that adheres to ISO will also be listed.

At a later meeting with Karsten Moholt AS the concept of The Maintenance Loop was mentioned since it had been the foundation of a previous engineer's work. Based on this information, a decision to analyse the loop was made. In the literature review, a short history recap will be given and the paper it originates from is also mentioned. The Maintenance Loop is analyzed in order to explain how it fit in relation to the ISO55000 standards.

4.1 Asset Management

The Asset Management Council in Australia defines Asset Management as "The management of physical assets life cycle in order to achieve certain outputs and goals in an enterprise" [5]. Looking at ISO 55000, which covers Asset Management and is written by The International Organization for Standardization, Asset Management is defined as "coordinated activity of an organization to realize value from assets" [18]. This last definition is broad and rather strict so let us dissect the terms used in the definition.

The term "activity" has intentionally a broad meaning as to cover all aspects of an organizations work e.g. the approach, the planning and implementation of the plans to achieve the organizational goals. An "asset" is defined as an item, thing or entity that has potential value or actual value to an organization, where value can be both tangible or intangible. Where tangible assets covers all physical assets in an organization (e.g equipment, tools) and intangible assets covers all non-physical assets (e.g. technical knowledge, loyal customers, good brand name). [18]

A blog post written by FTMaintenace called "What is Asset Management in maintenance?", explains how the term "Asset Management" covers the whole lifecycle of an asset and that maintenance is just a small part of it. Figure 3 shows the different phases of a lifecycle.[13] Our paper will focus on the red part of Asset Management, which is maintenance in Figure 3. Also, the paper will dive more into detail between the definitions between Asset Management and Maintenance Management.

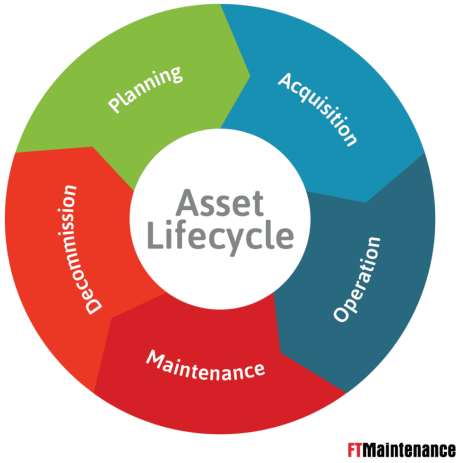

Figure 3: The total asset lifecycle according to FTMaintenance [13]

Figure 3 shows the general phases of the life cycle of an asset, but does not show which activities are performed in Asset Management and the connection with Maintenance Management activities. The research was based on "Review and Application of ISO 55000" [37] to find the connections between Asset Management and Maintenance Management, but there was not found any figures that show clearly how they are connected. Therefore, Figure 4 and Figure 6 was made and show Asset Management in relation to Maintenance Management. It would be possible to have the comparison in one figure, but this would cause clustering and poor overview. Therefore, the two figures are basically the same figure where the difference is that it is shown from two different viewpoints. From the viewpoint of Asset Management (Figure 4) and Maintenance Management (Figure 6). The two figures consists of two rings where the outer ring shows Asset Management since it is the broadest definition and the inner shows Maintenance Management because it is the most focused of the two.

Figure 4 shows activities of Asset Management and their relations with each other and with Maintenance Management. Red activities are the same as with Maintenance Management, therefore they have the same colour. A one-way arrow indicates that the influence is only one directional. For example, in a Asset Management system the leadership aspect will influence the Maintenance Management and planning, but not vice versa. A two-way arrow, such as between operation and Maintenance Management, indicates that the influence goes both ways.

Figure 4: Asset Management activities in relation to Maintenance Management

In this thesis, Asset Management is defined as; a strategic philosophy that helps to organise all parts of a business in order to fully realize the inherent value of its assets. This means it gives structure to the planning of how to use all assets in the most effective way possible, thus making more money out of each asset.

4.1.1 Benefits of Asset Management

There are many benefits to implementing Asset Management. On a general note it enables the organization to map the current value of an asset, to organize the whole organization towards the goal of optimizing the asset's use, and to increase its potential. Essentially, this means optimizing value creation from the asset in relation to invested resources into the asset. Asset Management enables the organization to use its own objectives and make them coincide with the Asset Management objectives to increase the value creation from the asset.

When talking about objectives, it is referred to a result to be achieved. The objectives can be defined on different levels in the organization; strategic, tactical or operational. What "value" is defined as, depends on the objectives, the nature and purpose of the organization and the needs and expectations of its stakeholders. [18]

Asset Management benefits can include but are not limited to the following:

- **Improved financial performance:** improving the return on investments and reducing costs can be achieved, while preserving asset value and without sacrificing the short or long term realization of organizational objectives.
- **Informed asset investment decisions:** enabling the organization to improve its decision making and effectively balance costs, risk, opportunities and performance.
- **Managed risk:** Reducing financial losses, improving health and safety, good will and reputation, minimizing environmental and social impact, can result in reduced liabilities such as insurance premiums, fines and penalties.
- **Improved services and outputs:** assuring the performance of assets can lead to improved services or products that consistently meet or exceed the expectations of customers and stakeholders.

- **Demonstrated social responsibility:** improving the organization´s ability to, for example, reduce emissions, conserve resources and adapt to climate change, enables it to demonstrate socially responsible and ethical business practices and stewardship.
- **Demonstrated compliance:** transparently conforming with legal, statutory and regulatory requirements, as well as adhering to asset management standards, policies and processes, can enable demonstration of compliance.
- **Enhanced reputation:** through improved customer satisfaction, stakeholder awareness and confidence.
- **Improved organizational sustainability:** effectively managing short and long-term effects, expenditures and performance, can improve the sustainability of operations and the organization.
- **Improved efficiency and effectiveness:** reviewing and improving processes, procedures and asset performance can improve efficiency and effectiveness, and the effectiveness, and the achievement of organizational objectives.

[18]

4.2 Maintenance Management

In order to place Maintenance Management in the context of all assets within an organization one may classify assets as shown in (Figure 5). The management of all the various classes of assets is defined as Asset Management, whereas the physical assets are the main objects of Maintenance Management with the other assets functioning in a supporting role. In conclusion, Maintenance Management is responsible for ensuring that the physical assets keep on performing their intended functions in a reliable and efficient manner by creating or improving maintenance processes from relevant information gathered during the maintenance process. This information is often organized by using a Computerized Maintenance Management System/Software to track the organizations resources like materials and the workers competences, more about CMMS in Chapter 6.1. The end product from a Maintenance Management system is informed decisions about how to improve the existing maintenance task.

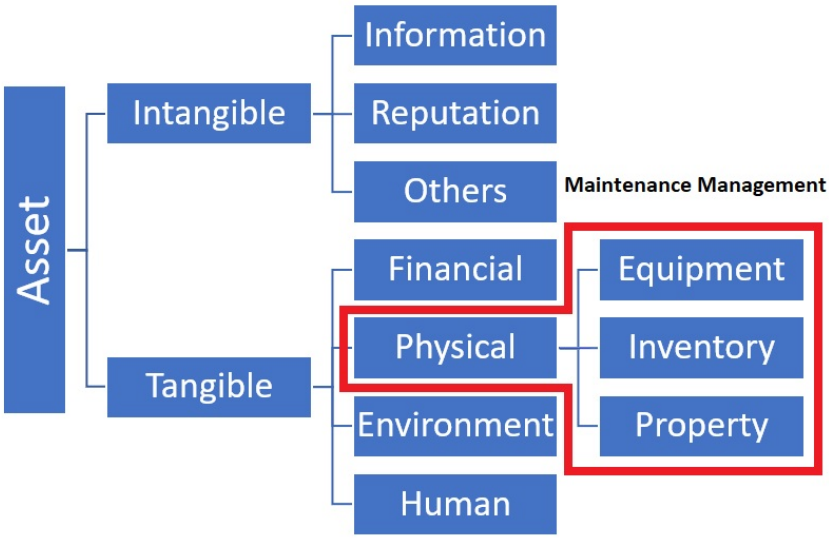

Figure 5: What types of assets Maintenance Management covers

Figure 6 is as mentioned basically the same as Figure 4 but with the viewpoint from Maintenance Management instead. It shows Maintenance Management with its activities in relation to each other and with Asset Management. Maintenance Management is the inner circle with planning and improvement being the same as Asset Management. They are coloured blue to show the connection to Asset Management. The arrows show a general connection between the activities. A one-way arrow indicates that the influence is only one directional. For example, recording and retrieval and Asset Management influence the Maintenance Management planning, and planning can also influence Asset Management.

Figure 6: Maintenance Management activities in relation to Asset Management

4.2.1 The Maintenance Loop

In the autumn of 1996, the Norwegian Petroleum Directorate (NPD) started "The baseline maintenance study" with the stated goal "to develop a method for a systematic and comprehensive assessment of the company's own Maintenance Management system" [12]. Meaning that they wanted a way to make it easier for the companies to assess their management systems in a systematic and a well-executed manner. At the time there was not any standards that described how to asses a management system, thus NPD conducted the baseline study. Following the study other standards was made such as PAS 55 - Asset Management from 2004, which was replaced by ISO 55000 in 2014 and is the most updated standard regarding Asset Management.

With the baseline study report comes a Maintenance Loop that shows how NPD wanted Maintenance Management to be like as shown in Figure 7. The Maintenance Loop is mentioned because it is a commonly used model. Similarities and differences will be outlined, and by having a clearer picture of the similarities and differences, companies can reduce the chance to do unnecessary adjustments. This can pave the way for better evaluations about where the gaps are in order to comply with the ISO 55000 standard.

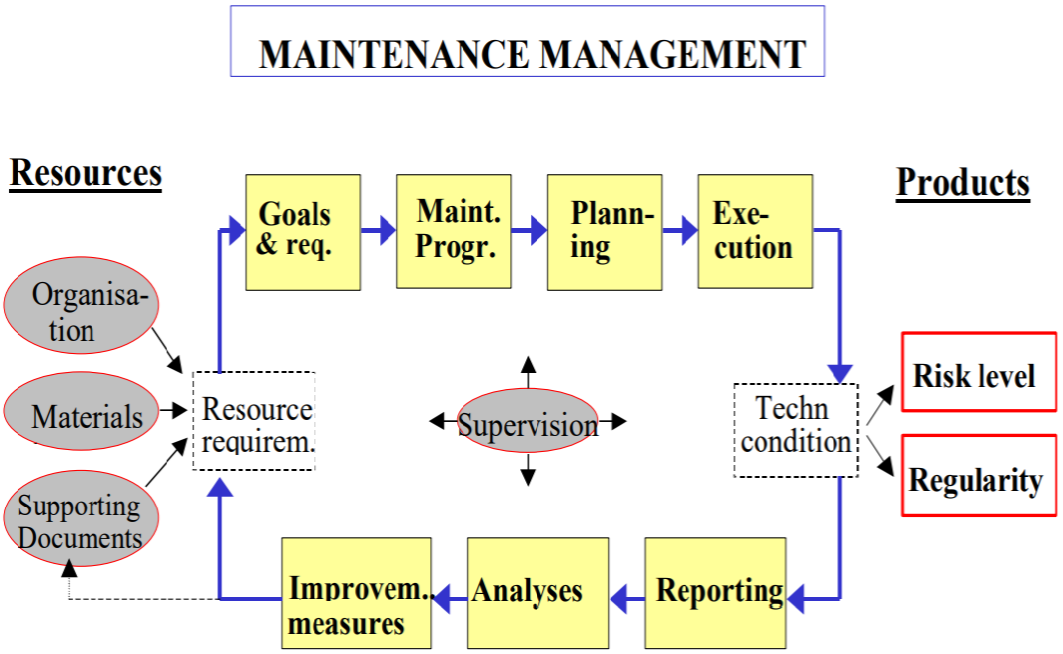

Figure 7: The Maintenance Loop from "The Baseline maintenance study of 1996" [12]

4.3 Differences between ISO55000 and The Maintenance Loop

The ISO55000 series, consisting of ISO55000, 55001 and 55002 have several roles. ISO55000 explains what ISO considers to be a Asset Management system, ISO55001 explains which activities a company needs to do to have an Asset Management system that adheres to ISO's guidelines [18]. The last one, ISO 55002, explains what the company needs to do in order to get an Asset Management system that is ISO qualified. If a company wants to get ISO certified they need to comply with ISO 55001 since this is where the requirements are found. The ISO series splits the company into seven segments:

1. Context of the organization
2. Leadership
3. Planning
4. Support
5. Operation
6. Performance evaluation
7. Improvement

As you can see from the seven segments of ISO55000, there are a lot of similarities with The Maintenance Loop, as seen in Figure 7. An example is improvement measures in The Maintenance Loop and improvement in ISO55000. The reason behind this is simply because ISO55000 is built on the experience from earlier standards and experience, such as The Maintenance Loop itself, and because of this there is a lot of overlap. Even with the overlap between ISO and The Maintenance Loop, the two papers are different from each other in the form of how they are organized. The seven segments from ISO covers several of the activities mentioned in The maintenance loop. For example, the support segment in ISO covers all the topics under "resource" in the loop. The main difference in information is missing in the older Maintenance Loop is how to do the balance between taking risks and business opportunities. [12] [18]

If The Maintenance Loop is compared to a specific ISO standard from the series it would be closest to ISO 55002. This is because the loop asks a lot of self evaluating questions similar to the required activities from the ISO 55002 about how to implement the Asset Management or improve it.[12]

In conclusion, The Maintenance Loop is still relevant today even though ISO 55000 is more recent. The baseline study is also written in a less formal language and asks questions that are simple to understand. Therefore, the baseline study can come in handy if there is something that you do not understand in the standard and cross check it with the baseline study. Even though the study can be a handy tool it is important to remember the age of the Baseline study from 1996. If there are some disagreements between ISO 55000 and The Maintenance Baseline study, the newest paper which is the ISO 55000 from 2014, are to be followed.

4.4 Reliability Centered Maintenance

The origin of Reliability Centered Maintenance (RCM) started in the airline industry in the 1960's when the maintenance cost had become too high to be profitable. An investigation team dug deeper into the capabilities of preventive maintenance and different guidelines for aircraft manufacturers to use was created throughout the investigating years. This lead to some impressive results e.g the original Boeing 747 required 66 000 labor hours on major structural inspections before a major inspection at 20 000 operating hours. In comparison, the DC-8 (a smaller and less sophisticated aircraft) required more than 4 million labor hours before reaching 20.000 operating hours using standard maintenance programs at that time. In 1974, the US department of Defense commissioned United Airlines to write a report on the processes that was used in the civil industry to achieve the results of the Boeing 747. Later, Stan Nowlan and Howard Heap published a report titled; Reliability Centered Condition Based Maintenance, which has been the report a majority of new RCM approaches have been based upon.[33]

Since the term Reliability Centered Maintenance has been around and developed for so long it is defined and described in many ways. However, the main ideas presented in reports and textbooks are more or less the same, but the detailed procedures may be different. The standard IEC 60300-3-11 defines RCM as 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.". [8] In more simple terms, RCM can be defined as the process of determining the most effective maintenance approach in relation to the equipment operating context. [33]

To be a functional RCM process there are some criteria that needs to be fulfilled:

1. What are the functions and associated desired standards of asset in its present operating context? (Functional requirements)
2. In what ways can it fail to fulfill its functions? (Functional failures/Failure modes)
3. What causes each functional failure? (Failure causes)
4. What happens when each failure occurs? (Failure effects)
5. In what way does each failure matter? (Failure consequences)
6. What should be done to predict or prevent each failure? (Proactive tasksand task intervals)
7. What should be done if a suitable proactive task can not be found?

[8]

For these criteria to be fulfilled there are several steps that can be followed, as e.g:

1. Preparation for analysis
2. Functional failure analysis (FFA)
3. RAMS data collection
4. Failure modes, effects and criticality analysis (FMECA)
5. Maintenance task analysis (MTA)
6. Maintenance interval assessment (MIA)
7. Maintenance tasks comparison (MTC)
8. Computerized Maintenance Management System (CMMS) database updating

[8]

The fundamental difference between conventional maintenance versus the RCM approach is that in RCM, activities are done to ensure the machine or an asset continues to do what it is supposed to do rather than doing maintenance activities to prevent it from breaking down. It is not unusual that traditional maintenance methods mainly consider manufacturers' guidance and experience factors. With RCM, however, the methods start from the fault consequences of actual equipment operation, and thus RCM can be more scientific and reliable. [33]

Moreover, RCM is not necessarily a maintenance method, but rather a maintenance methodology used to identify which maintenance methods will work best for each piece of equipment. RCM employs Preventive Maintenance (PM), Predictive Maintenance (PdM), Real-Time Monitoring (RTM), and Run-To-Failure (RTF) to increase the probability that a machine or equipment will function in the required manner over its life cycle with a minimum of maintenance. [3] Thus, RCM applies the optimum mix of all the classic and new maintenance practices with the consideration of applicability and effectiveness to ensure equal or greater reliability at decreased cost.

4.4.1 Benefits of RCM

One question that Karsten Moholt AS would like to have answered is; why would a customer want this service? Also, does RCM work outside its original application area of the aviation industry? To answer these questions, the chapter will cover some benefits that come with adapting the RCM methodology and present some results from real-world case studies. Moreover, in Chapter 5.2.1 and Chapter 5.4 the services that KM already provides are directly linked to the result of RCM and how KM can help customers mitigate some of the disadvantages that follows the RCM methodology.

According to Reliability Centered Maintenance written by Norsk Forening for Vedlikehold [8] RCM can lead to speedy and sustained improvements in:

- Plant/production availability
- Equipment reliability (which also reduces the exposure to the risk of injury)
- Product quality

- Safety integrity
- Environmental integrity
- Return on investment
- Competitive advantage
- More proactive maintenance

If RCM is implemented successfully and effectively, the list above are the biggest improvements that a company can expect. Also, a well thought out maintenance strategy can be a competitive advantage in that RCM increases availability with decreased downtime and prolonged equipment lifespan, thus positively affecting the bottom line.

As described, implementing the RCM approach can bring many benefits, and as mentioned in Chapter 4.4, the RCM approach was originally used with great success. But, does the stated benefits translate to the real-world today? The next paragraphs shortly introduces some case studies and their results.

One paper titled "Effective Maintenance Strategy to Improve Performance Through RCM Concept" from the Malaysian company ON Semiconductor, achieved in 2018 good results with the RCM methodology. The semiconductor industry has seen exceptional growth the past decade due to demand increase for communication and consumer electronics, and especially due to increasing use of electronics in automotive and medical industries. For all growth, it is important that the product reliability and quality follows the demand in increased production output. This paper talks about how to make the equipment reliable to ensure the product is also reliable, with the use of RCM. After the analysis, the authors could present results like an overall equipment downtime reduction of 42% on two critical wafer technology devices which in turn will positively affect the company's bottom line [33].

Zener	Non RCM	RCM	% improvement
DVM	257	113	56%
NSOP	78	61	22%
FVM	65	23	65%
PRS	42	72	-71%
NSOL	40	11	74%
CC	36	37	-3%
W/BREAK	33	5	86%
	551	**320.5**	**42%**

Figure 11

Figure 8: Production of zener-diode [33]

Another paper titled "Reliability-Centered Maintenance Methodology and Application: A Case Study" utilized the RCM methodology in a steam-process plant which provides heat energy to an Egyptian Minerals and Salts Company (EMISAL). The proper RCM steps was undertaken on a fire-tube boiler, water pump, condensate tank, dryers and a heat exchanger. In this case, the RCM analysis lead to a 25,2% labor saving cost, a proposed downtime saving cost of 480 000 $/year, and a proposed spare parts program for the plant's main components which will yield a 22,17% saving cost [3].

Table 13. Proposed spare parts program (yearly).

Equipment	Spare part	Quantity (Current)	Cost (current) $/year	Quantity (Proposed)	Cost (Proposed) $/year
Feed water pump	Coupling	2	3000	1	1500
	Mechanical seal	6	12000	4	8000
	Motor bearing	6	24000	4	16000
	Pump bearing	6	12000	4	8000
Fire tube boiler	Gasket	12	12000	10	10000
	Fuel house	2	40000	2	40000
	Fan bearing	4	12000	2	6000
Total cost ($/year)			115000		89500
Saving cost %				22.17	

Figure 9: Example of RCM result: proposed spare parts program [3]

Table 12. Labor saving cost.

Item	Labor type	Number of labors Per day (current maintenance)	Number of labors Per day (proposed)
Engineers (1000$/month)	Mechanical	5	4
	Electrical	5	4
	Control	5	4
Technicians (800$/month)	Mechanical	6	4
	Electrical	6	4
Total cost ($)/year)		295200	220800
Saving cost (%) = 25.2			

Figure 10: Example of labor saving cost [3]

As shown in Figure 9 and Figure 10 above one can see that RCM has been successfully used to improve production availability and potentially significantly reduce costs.

Another paper published in 2019, the researchers proposed a slightly different RCM approach and tested it out on a real case study in Fayoum Sugar Works Company in Egypt. Once the maintenance plan had been developed, they fed them into suitable maintenance planning and control systems for an end sugar production line.[4] The results can be seen in Figure 11.

No	Item	Before Current	After Applying RCM	Improvement %
	Corrective maintenance down time (hrs./year)	9.7	4.3	55.77
	Corrective maintenance cost $\times 10^6$ (L.E/year)	3.89	1.72	55.77
	Preventive maintenance down time (hrs./year)	20	10	50
	Preventive maintenance cost$\times 10^6$ (L.E/ year)	8	3.97	50.4
	Total maintenance cost $\times 10^6$ (L.E)	11.89	5.69	52.17
	Availability (%)	57.1	90.47	36.98
	Reliability (%)	99.73	99.88	0.15

Figure 11: End sugar production line before and after RCM implementation [4]

As for the economical benefits it is important to realise that the maintenance costs overall may be increased in some cases, but the actual economic benefit is found in the bigger picture; increased availability, increased equipment reliability and a higher competitive advantage all contribute more to the bottom line than just reducing the maintenance costs.

All the examples above show that many of the stated benefits are very much reasonable to expect, if done effectively and properly. The latter one being essential as there are pitfalls to RCM that is necessary to be aware of.

4.4.2 Disadvantages of RCM

As for disadvantages of RCM there are some that one should be aware of:

- Continuous Maintenance
- Requires training and startup cost
- Complexity
- RCM does not focus on economical problems
- Does not consider maintaining costs

[14]

Some of these disadvantages will be discussed in Chapter 5.4 in relation to what the team and Karsten Moholt AS can provide, that in turn excludes some of the disadvantages.

5 The Maintenance Management team

It is important to have a well thought out plan when a new team is to be commenced. In this chapter the service's structure will be defined and described, along with the roles and expertise which are needed. The team's role in KM will be described and how it can influence the rest of the company.

5.1 Maintenance Management service

The different stages in maintaining equipment have previously been discussed with the help of the maintenance loop. The loop is used as a basis for an overview of how the process itself will take form with the customer.

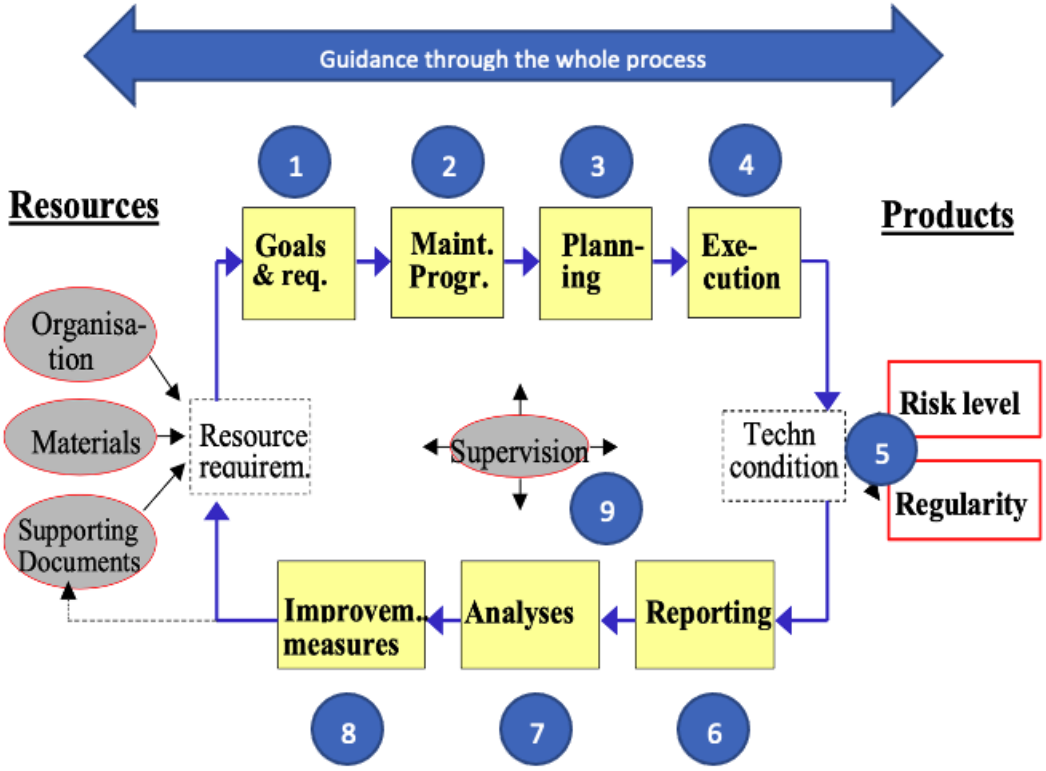

Figure 12: The Maintenance Loop from "The Baseline Maintenance Study of 1996" edited [12]

Description of how Karsten Moholt AS wants to help their clients in the different phases of the process. The way of which the service process will be executed can be compared to the already discussed Maintenance Loop, and will follow somewhat the same path with similar content. But, this is specific for the new Maintenance Management team; what they will do in each step of The Maintenance Loop and how they can help their clients.

1. The team will talk to the clients maintenance team and management in order to establish clearly what they want help with, what their goal with the service is and what KPI's that shall be improved.
2. Maintenance planning is started with the RCM analysis taking place in collaboration with the client's maintenance personnel. A CMMS is used to map and organize the different parts and equipment.
3. The result of the RCM is presented to management.
4. The team will get the maintenance department in KM to execute the maintenance activities on electro-mechanical rotating equipment. Condition-based monitoring is also executed by KM.
5. The clients maintenance team will be responsible for reporting technical condition on equipment or parts that is not condition monitored, and KM will report and analyse those which is.
6. Reporting against KPI´s
7. With using the CMMs system, the team can perform other analysis such as fault tree analysis and RCA. This will give the clients a wider range of analytic data.
8. RCM related improvement measures can be established according to the clients wishes.
9. The Maintenance Management team will function as a consultation team in which the client can get help to maintenance related task whenever needed.

As already mentioned in point 5, the clients can do a lot of the inspection themselves. The Covid -19 pandemic has brought with it a lot of changes to the society because of traveling restrictions, which forces the society to become more digitized than ever. The maintenance industry has already started this digitization-drive before the pandemic started with the growth in continuous monitoring via the internet (7)[7]. Not all the necessary maintenance tasks are possible to digitize, e.g visual inspections at the customers site. Karsten Moholt AS with their maintenance services can take advantage of this drive of digitization by offering customers the possibility to self-assess by giving them a self-evaluating checklist. This will remove the need to send an inspector from KM ,which will also remove the traveling expenses. Moreover, this will benefit the customer by offering them the ability to execute simple visual inspections by themselves, which will lower the price of inspections. Lowering the traveling expenses will give KM an competitive advantage, since they can then reduce the price of their maintenance services.

5.2 The teams place in Karsten Moholt

As shown on Figure 2 the team's role in KM will be to enter the maintenance market at an earlier time than today. KM offers services within condition monitoring and maintenance of rotary machines. The Maintenance Management team will enter the process before these two existing services and they will be independent from the other departments within KM. The reason is that the work tasks the team are going to perform are too time-consuming for the other departments to take on and still do their primary tasks. Since the Maintenance Management team will be the first department to be in contact with the customer it is important that the team has a good communication line with the other departments, this is especially important for the continuous monitoring department at KM. Good communication makes it possible to pass along relevant information to the other departments that will work for the customer in the future.

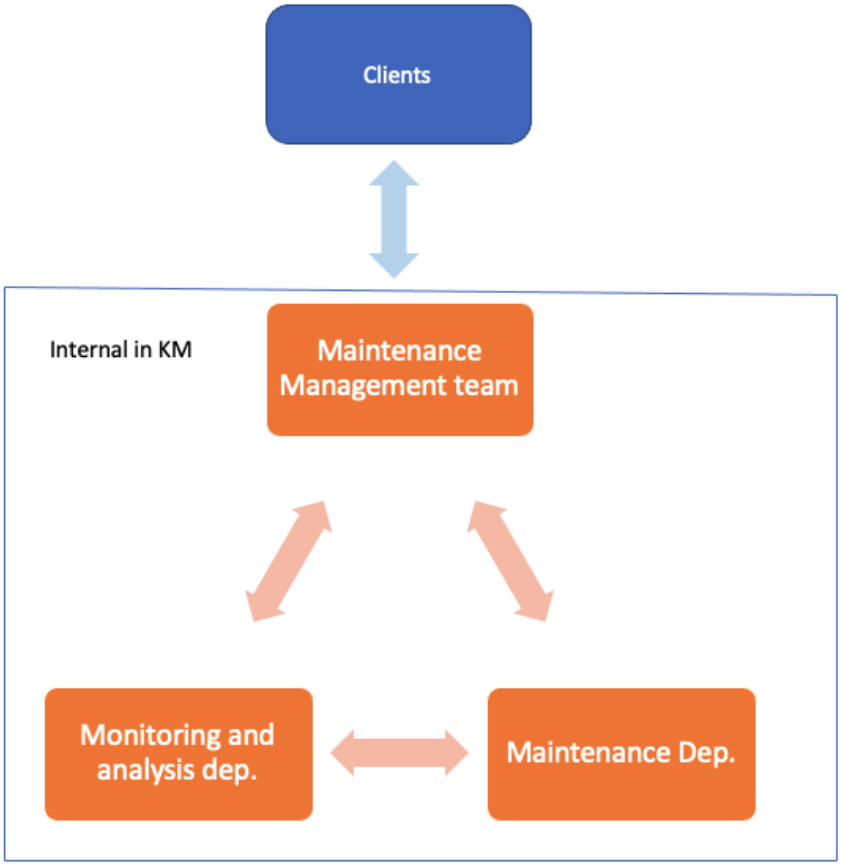

Figure 13: The teams place in KM

Figure 13 shows the teams place in relation to the other departments in KM, at least over time. It shows that the Maintenance Management team will function as the contact department between the clients and the other departments. This is only for the clients that request / buys the service that the team provides, but not all clients in contact with KM. It is important to note that this setup can be integrated over time as the team grows.

5.2.1 The RCM service in relation to the other departments in Karsten Moholt AS

RCM analysis results in a maintenance plan with a combination of different maintenance methods like condition-based maintenance and scheduled maintenance. For the rotating equipment that requires real-time condition monitoring and/or general maintenance Karsten Moholt AS can provide these services right away, without the customer having to deal with another maintenance company for this implementation of continuous monitoring.

The condition monitoring service includes full installation of sensors on the equipment, full installation of software to be able to collect, analyze and most importantly use the data collected from the sensors in the planning of maintenance activities. The software used in this case can be used to free up work capacity for the client. Moreover, the maintenance department can readily execute whatever maintenance tasks that regards rotary machinery. Thus, KM is in a position where they can offer a variety of services that fits directly into the maintenance plan and providing a maintenance package as depicted in Figure 13 in Chapter 5.2.

5.3 Roles and experience

The team will need to be composed of several different roles when fully operated. There are many different ways to assemble a team with regard to Maintenance Management One way to do it is:

- Maintenance Manager
- The maintenance coordinator
- Expert in world class maintenance and RCM
- A sales and marketing person

[25]

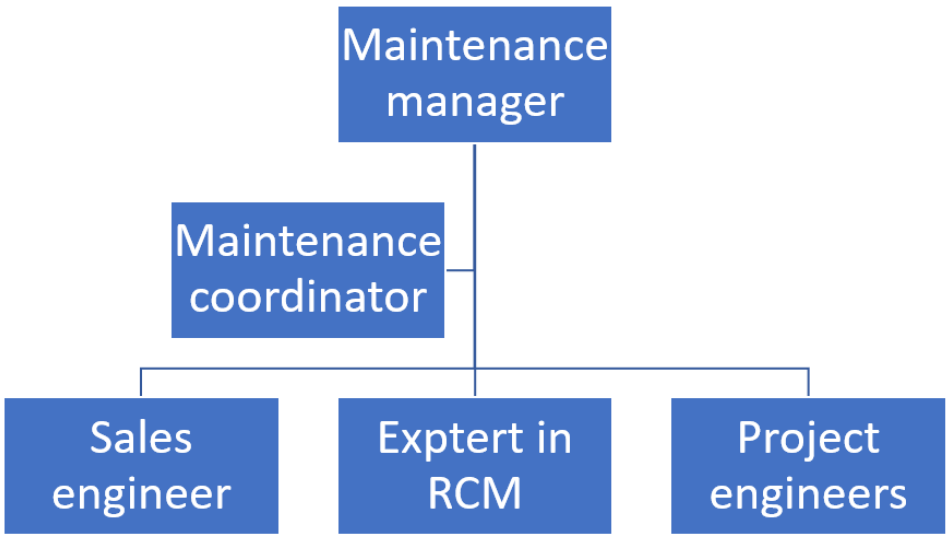

Figure 14: Team hierarchy

The team will start with the maintenance manager and will be built around this role. The maintenance manager´s role is to be the leader of the team. His/her main responsibilities will be to supervise the development of maintenance and implementation plans, assign work-tasks and work orders, and to coordinate with the other departments and clients. The maintenance manager needs to have competence in the following areas: Project management, effective communication skills, leadership skills, RCM (be at least familiar with it) and have relevant work experience from working in the production. [23]

The maintenance coordinator will function as the glue between the maintenance manager and the rest of the team and as support to the maintenance manager. As the team grows the coordinator must have competence to take over some of the maintenance manager's leadership responsibilities. In the hierarchy tree the maintenance coordinator will be under the maintenance manager but above the other roles. The reason is because if the maintenance manager is absent the coordinator will take control of the team. Therefore, the coordinator needs to have competence in the same areas as the manager, but not necessarily to the same extent. The coordinator needs competence in leadership and have organizational skills, be proficient with spreadsheets, social skills and be a good problem solver. [22]

The team also needs at least one expert in World Class maintenance and the principles behind RCM (more on WCM in Chapter 6.2.1). This person will function as a consultant to the manager and the coordinator. In the hierarchy tree he will be located under the manager and the maintenance coordinator, but will be equal with the other roles. It is prudent to assume that he will answer directly to the manager since the team is small and that an extra step will complicate the communication. The expert needs to have years of relevant maintenance experience and a high level of competence in the subject of RCM analysis (including all tools, standards and procedures that are used in and are relevant for RCM analysis). Also, this will be the person(s) that actually perform the RCM analysis in cooperation with the clients maintenance clientele.

A sales engineer would be recommended in the long term because the product needs exposure. The role will be located at the same level in the tree as the RCM expert, and will answer directly to the manager when he is available. The main argument for the need of a sales engineer is that he/she will be experienced in the rhetoric about how to sell a product and will help push the product to a wider clientele. The sales engineer will also have experience in how to form a strong customer relationship which will be important since the Maintenance Management team will potentially in the future be KM's first point of contact with a customer. A sales engineer would bridge the knowledge between the complex engineering tasks and the commercial responsibilities of selling a complex service.

When the team has reached an operational state it will be composed of four core roles as mentioned above. During the operational state an evaluation should be made to determine if the team roles need to change in some form like e.g more people, more specific roles or responsibility changes. Open positions can be filled with project engineers that will fill the void in competence. They will be flexible with regard to competence and can be moved around to where it is needed. In the hierarchy they will be equal to the salesperson and the expert. They will reach out to the maintenance manager if they have to take a decision that will affect the team massively, but for more daily decisions they will answer to the maintenance coordinator.

5.4 How the team can mitigate some disadvantages in RCM

Two of the most substantial of the disadvantages mentioned in Chapter 4.4.2 is that it can be complex and startup costs can be high due to time-consuming training and first time implementation. Companies have undertaken the task of implementing RCM on their own and failed because of the time spent on training and acquiring the necessary knowledge has occupied more time than management had planned for. Thus, the results are delayed and the leadership commitment might fade.

Because KM will have the required knowledge to perform and guide the customer through the RCM steps, both the startup cost and the required training hours for the client will be significantly decreased or negligible. The maintenance management team will collaborate with customer's existing maintenance team on a RCM analysis and thus the work can be started right away, changes and results will come quicker, and the customer's staff will learn as the analysis is undertaken. This both increases the knowledge of the customer's staff and helps the customer to more easily overcome the complexity of RCM.

5.5 Tools to help build the team

The company should make its own guidelines and demands in relation to Asset Management and Maintenance Management. The guideline should reflect the company's values in relation to how they want to run their company. ISO 55000, ISO 55001 and ISO 55002 go in detail about how to implement Asset Management in a company.

ISO 55002 standard gives guidance for the application of an Asset Management system in accordance with the requirements of ISO 55001 [19]. The standard is divided into chapters that comply with the ISO 55001 standard Asset Management system requirements. The system requirements are as follows:

- Context of the organization
- Leadership
- Planning
- Support
- Operation
- Performance evaluation
- Improvement

A tool that can help the team with self-assessment is a model called maturity model. The model uses five maturity levels and can be extended to include additional levels or be otherwise customized as needed [17]. Figure 15 is an example of how performance criteria can be related to the levels of maturity. It is important for the organization to make specific criteria to review their performances against, to identify current maturity levels, and determine their strength and weaknesses. By afterwards doing self-assessment in relation to the criteria the organization can find areas that could be improved and then reach higher maturity levels. [17]

Key element	Maturity level towards sustained success				
	Level 1	Level 2	Level 3	Level 4	Level 5
Element 1	Criteria 1 Base level				Criteria 1 Best practice
Element 2	Criteria 2 Base level				Criteria 2 Best practice
Element 3	Criteria 3 Base level				Criteria 3 Best practice

Figure 15: Generic model for self-assessment elements and criteria related to maturity levels from ISO 9004 [17]

In the ISO 9004 standard they have defined a way to reach success by the points listed below. The points listed relate to a mature organization that performs effectively and efficiently[17].

- understanding and satisfying the needs and expectations of interested parties
- monitoring changes in the organization's environment
- identifying possible areas for improvement and innovation
- defining and deploying strategies and policies
- setting and deploying relevant objectives
- managing its processes and resources
- demonstrating confidence in its people, leading to increased motivation, commitment and involvement
- establishing mutually beneficial supplier and other relationships.

[17]

In Chapter 3.2 some success factors for the Maintenance Management team has been presented. By implementing these success factors to a tool like the maturity model, it will be easier for the team to be in control of where on their success chart they are and strive to be better. This model can also be used to measure or ensure that the environmental aspect of their criteria are focused on. For more complete definition and how to implement the maturity model see the ISO 9004 standard [17].

6 Comparative study of tools and procedures

6.1 Computerized system for RCM and FMECA

A crucial part of the Maintenance Management service is the acquisition of a "Computerized Maintenance Management System" also known as "CMMS".

CMMS systems are not as new as one might think, with the first known use of such systems being reported in 1976. Today CMMS systems can be found around the globe in many different industries, where the manufacturing industry are one of the leading in the usage [36] A CMMS is a computer software that is designed to simplify maintenance management by offering the user a opportunity to organize its assets. This opens up the opportunity to organize the assets in several ways, such as; grouping similar assets, grouping assets that are in the same process, tracking work orders, prioritizing work orders, recording prior maintenance history and selecting which maintenance strategy to apply to the assets.

It is possible to use CMMS to make it easier to perform a RCM-analysis. The methods that can be simplified by using CMMS are for example risk analysis and making hierarchy tree of assets. Karsten Moholt AS have expressed that they want to invest in a RCM software because, today, most of the analysis in KM are done by using excel worksheets. These worksheets are more complex and makes it harder to do RCM analysis than using a tailored software. This problem is likely to become a frustration for the user when doing an analysis that consists of a lot of components and processes, leading to the probability of the project failing in the long run.

KM asked specifically for a system that goes directly on RCM and FMECA. To make a RCM and FMECA worksheet is hard work with the wrong tools. Different CMMS software was organized in an excel spreadsheet. Cut outs from the spreadsheet can be found on the next few pages. The full spreadsheet comes as an attachment to this thesis for a better viewing experience.

In each column there are listed different software and for each row there is a different category with either a check mark, a cross or a description. The check mark means that the software has it and are specifically marketed with that feature. The cross does not necessarily mean that they do not have the feature, it only states that they are not marketing this or that it is not stated specifically on their website.

The variety of software that was evaluated were the ones that was found the most relevant to KM's purpose of use. The spreadsheet is meant to function as a overview of the many software alternatives that is available. The last row from the spreadsheet called "disadvantages" had to be excluded from the pictures below, but can be seen in the excel file.

Table 2: Software analysis 1

Software name / Features	AllAssets	Fiix	ManWinWin
Website	https://www.lr.org/en/allassets/	https://www.fiixsoftware.com/	https://manwinwin.com/en/maintenance-management-software/
Company	Lloyd´s register	Rockwell Automation company	Navaltik Management
Price	✗	Basic version 341kr/mth	✗
Reviews/feedback	Can´t find any feed back	Very positive, 526 people have given 4,4/5 stars on capterra.com	https://www.getapp.com/operations-management-software/a/manwinwin/reviews/
Country	Great Britain	Canada	Portugal
Norwegian software language	✗	✗	✓, basic version
App IOS/android	✓	✓	✓
Free demo	✓ have to register	✓	✓ have to register
Preventive maintenance planning	✓	✓	✓
Predictive maintenance planning	✗	✓	✓
Asset tracking/manage	✓	✓	✓
FMEA / FMECA	✓	✗	✗
Marketed as RCM	✓	✗ but as maintenance management	✗ but as maintenance management
Provides RCM courses	✗	✓	✗ only guidance on the program itself
Marketed top features	*Optimise Planned Maintenance whether is it reliability, availability or commerciality amongst other available methods *Use our library of models to gain access to a vast number of failure rates and equipment classes and types *Use the maintenance optimisation module to fine-tune inspection intervals based on historical failure rates *Use our criticality analysis feature to add a level of assurance to your analysis from a risk perspective	*Easy to switch to from another software *Cross integration between different work fields	* Equipment's list * Work orders list * Corrective work orders * Man-hour, Materials and service registration * Warehouse outputs * Maintenance requests with SLA level

Table 3: Software analysis 2

Software name / Features	RCM Analyzer	UXRisk	RCM++
Website	https://androsysinc.com/rcm-software/	https://proactima.com/uxrisk/	https://www.reliasoft.com/products/rcm-reliability-centered-maintenance-software/key-features
Company	Andromeda Systems	Proactima	ReliaSoft
Price	✗	Free trial, 17kr/mth pr user	✗
Reviews/feedback	Cant find any feed back, but it´s used by the US. Army/Navy/Marin Corps also some airlines, mining companies, Maintenance, Repair and Overhaul (MRO) organizations, workboat operators among other industries.	Little feedback since it is a relatively new product	https://www.g2.com/products/reliasoft-rcm/reviews#survey-response-3634550
Country	USA	Norway	USA
Norwegian software language	✗	✓	✗
App IOS/android	✗	✓	✗
Free demo	✓ have to register	✓ have to register	✓ have to register
Preventive maintenance planning	✗	✓	✓
Predictive maintenance planning	✗	✓	✓
Asset tracking/manage	✗	✗	✗
FMEA / FMECA	✓	✗	✓
Marketed as RCM	✓	✗ as risk management	✓
Provides RCM courses	✓	✓	✓
Marketed top features	* Intuitive interface * Minimize downtime and operating costs by identifying an optimal preventive maintenance program * Minimize setup time and cost through a web-based SaaS platform * Eliminate duplication of effort through a shared data model * Reduce training and problem resolution time with professional technical support and expertise * Improve RCM project efficiency with embedded project management tools and reports	*User friendly *Cheap *Covers the basic HSE management processes	* Optimize maintenance plans * Assess risks at different levels using FMEA analysis * Save time on data entry and analysis processes * Find cost-effective maintenance strategies * Minimize downtime and operating costs * Meet your organization´s specific needs

Table 4: Software analysis 3

Software name / Features and information	IBM Maximo	MPulse	Synergi Plant
Website	https://www.ibm.com/products/maximo	https://mpulsesoftware.com/software/editions/	https://www.dnv.com/Images/Synergi-Plant-RCM-flier_tcm8-58935.pdf
Company	IBM	Mpulse software	DNV GL
Price	1395kr/pr user	80$/100$/130$/mth pr lisence	✗
Reviews/feedback	Mostly satisfied, 4,2/5 stars from 69 reviews on capterra.com	https://www.softwareadvice.com/cmms/mpulse-profile/	Can not find any feedback
Country	USA	USA	Norway
Norwegian software language	✗	✗	✗
App IOS/android	✓	✓	✗
Free demo	✗	✓ have to register	✗
Preventive maintenance planning	✓	✓	✓
Predictive maintenance planning	✓	✗	✗
Asset tracking/management	✓	✓	✗
FMEA / FMECA	✗	✗	✓
Marketed as RCM	✓	✗ as CMMS (computerized maintenance management system)	✓
Provides RCM courses	✓	✗ only guidance on the program itself	✓
Marketed top features	*A great tool for company wide activities, not only maintenance *More efficient traceability and accountability *Many features that are customizable to fit your needs	* PM Scheduling & Tracking * Work Order Management * Asset Lifecycle Tracking * Condition-Based * Maintenance * DataLink Integration Adapter * Preventive Maintenance * Parts and Supplies Inventory *Management * Asset Management * Tablet and Smartphone * Compatibility	They have listed what you get with the software but not markeded what makes them better thasn their apponents.

Table 5: Software analysis 4

Software name / Features and information	Reliability Workbench™	APM reliability	Ørn software
Website	ty.com/page/services/our-methodology/reliability-centered-maintenance-rcm	igital/applications/asset-performance-management/apm-reliability	are.com/maintenance-programvare-for-industrielt-vedlikehold-old
Company	Arms reliability	GE Digital	Ørn software
Price	✗	✗	✗
Reviews/feedback	Can not find any feedback	Can not find any feedback	Can not find any feedback
Country	Australia	USA	Norway
Norwegian software language	✗	✗	✓
App IOS/android	✗	✗	✗
Free demo	✓	✓	✓
Preventive maintenance planning	✓	✗	✗
Predictive maintenance planning	✓	✓	✗
Asset tracking/management	✗	✗	✓
FMEA / FMECA	✓	✗	✗
Marketed as RCM	✗ ,as a service	✗	✗, as maintenance
Provides RCM courses	✓	✗	✗
Marketed top features	• Qualify and justify decisions • Meet your targets • Minimize costs	• Improves reliability, availability, and productivity • Optimizes maintenance costs • Mitigates risk • Maintains technical expertise (tribal/organizational knowledge) • Delivers continuous improvement	• Users are in focus • Roundlists makes your day easier • Access to documents where you are • Effectiv and functional documentation • A functional system • Everything is stored in the cloud

6.1.1 Benefits from a CMMS

In this sub-chapter the benefits and potential problems that a CMMS system will bring along is discussed. One can argue that maintenance is one big balancing act, too much of it and the cost goes through the roof, too little and the machines break down leading to large expenses because of downtime and maintenance work on machines. This is where CMMS comes into the picture since it can work as a balance.

In the study "Implementation and Benefits of Introducing a Computerised Maintenance Management System Into a Textile Manufacturing Company" [36] from 2004 the benefits of implementing a CMMS system is discussed, which this chapter is based on. It is important to remember that a lot have happened in digitization since then, but the results from the study is still relevant today.

Five common problems a company can use a CMMS to overcome:

- Lack of maintenance personnel
- Lack or excess of spare parts
- Not fully utilizing components full life span
- Lack of funding in maintenance
- Doing unnecessary maintenance (performing maintenance work long before it actually is needed)

A lack of maintenance personnel to do the maintenance tasks can be a big problem for some companies. This will lead to a large and increasing backlog of maintenance tasks waiting to be done. There are two obvious solutions to this problem. The first is to hire more maintenance personnel which can be very expensive, and the other is to utilize the existing personnel more efficiently. The CMMS can help to overcome this problem by generating work reports on labour requirements, which makes it easier to know what the different tasks require of work-hours and competence. It is also possible to organize the maintenance workers by when they are busy with other tasks and when they are available, making it possible to schedule when to do the task. Organizing the said workers by competence is also possible. [36]

Another problem a CMMS can handle is the lack or excess of spare parts. A lack of spare parts can lead to a prolonged downtime of the machine in need of maintenance if the part has to be ordered from a supplier that is based in a location far away. An example can be that if a company that is based in Bergen need to order from a supplier in China. An excess of spare parts are the opposite problem. Some of the spare parts can be very expensive, therefore it is not recommended to have a large storage of them. Certain parts also expire, such as rubber parts, which become brittle with age. A CMMS system will have a ledger for each equipment which gives an overview of what spare-parts is needed and when. This will mitigate the problem of excess or lack of parts as the CMMS ensure that right amount of parts are in stock at the right time (essentially reducing waste and, storage and acquisition cost). [36]

A common problem in many manufacturing companies is the lack of will from the administration to fund the maintenance efforts. When the maintenance is done right or the business needs to cut costs, it is easy for people not involved in maintenance decisions to down-prioritize this area. This can make it harder for the maintenance manager to

argument for the funds that is required to perform the maintenance activities. With a CMMS every maintenance task is recorded (with its relevant data) which show the decision makers in the company exactly where funding is needed, and in turn can make it easier to persuade decision makers to allocate the necessary resources to get the competitive advantage.

This system also makes it easier for the administration to become involved in the maintenance since the maintenance plan is real-time updated, making it easier for the people that are not directly involved to follow the process. An increase in involvement and interest from the administration can make it easier to defend the usage of funds towards maintenance. [36]

Moreover, a CMMS can help reduce the preventative maintenance interval by pinpointing more accurate estimates for when the best time for starting maintenance is. By storing all maintenance history one will be able to delay (or time) the maintenance up to the point right before the part will break and thus utilizing the full lifespan of the equipment.

6.1.2 Disadvantages from a CMMS

Trying to implement a CMMS can also bring some problems and disadvantages to the company that want to implement it. These problems are minor compared to the benefits a successfully implemented CMMS system brings.

One disadvantage with implementing a cloud-based CMMS is the increased risk of having intellectual property stolen due to the possibility of hacking. This is most relevant when dealing with sensitive information from new products or about groundbreaking new solutions. This problem can be circumvented by installing the CMMS locally on the company's internal servers and not send information through internet. Doing this reduces the risk of hacking but prevent the maintenance team from Karsten Moholt AS to check the status of the machines from KM's offices. The security risk can also be reduced by using a competent CMMS provider that updates its programs regularly, and some papers argue that this risk is overblown. [2] [36]

Another disadvantage CMMS systems can bring with it is the complexity such a system can entail. For smaller companies taking on such a big task can be daunting This is where the maintenance team can enter the equation with its competence and help the company with setting up the program and organizing the assets. [2]

6.2 Courses and competence

A high level of competence in any business is important, but having evidence of skill to ensure potential clients they are in good hands, and also raise the overall quality image of the service can be important for this team. Having a certification lends credibility to the maintenance professional's qualification. To get this competence and the certification there are some courses that are relevant for the team, which is present in the following subchapters.

6.2.1 World Class Maintenance

World Class Maintenance (WCM) is a term used to describe the best maintenance. Maintenance is the act of maintaining or the state of being maintained [28]. The boundary of World Class Maintenance is always being pushed just like athletes push the boundary of what is world class, in for example running. The best practice in maintenance is always changing as new technology and procedures are developed, so the best maintenance in 2020 will probably not be the best in 2021. [31]

There is not a common reference cited or any uniform definition of what world-class maintenance is. Many engineering and consulting firms provide services for improving the effectiveness and efficiency of maintenance, and have their own definition of what world class maintenance is. They have their own benchmarks they use to assess maintenance performance to determine this. Businesses like Moody´s and Fitch rate companies from AAA through D, and these businesses use general accepted measures that allows companies to know when they have reached world-class status. [31]

To get a clue on how World Class Maintenance is measured there is a list below of common examples of how it can be measured.

- Maintenance schedule compliance is greater than 90%
- Maintenance overtime is less than 5%
- Maintenance direct work is greater than 75%
- Planned maintenance work is greater than 90%
- PM schedule compliance is 100%
- The percentage if work covered by a work order is 100%
- Work order actual hours/ work order hours planned is 90 to 110 %
- Equipment availability is at least 90 %
- Equipment productivity is at least 95 %
- Overall equipment effectiveness is at least 77 %

[31]

World Class Maintenance is not about being good one day or an individual performance. It is not about having the highest up-time or the highest production rate. This is all results of practising World Class Maintenance continuously. World Class Maintenance is future-oriented Maintenance Management that gives the practitioners a competitive advantage [1].

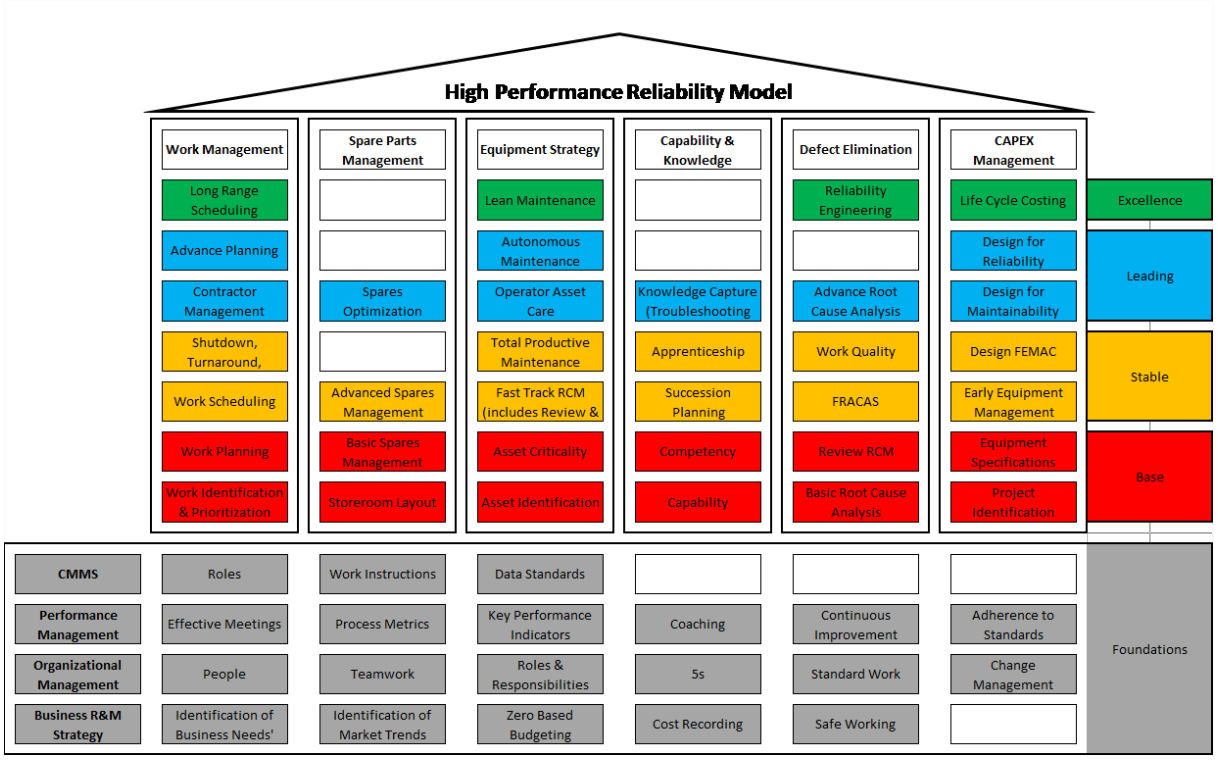

Figure 16: An illustration on steps that need to be achieved to reach World Class Maintenance [39]

The illustration shows what different methods, systems and methodologies a business should be good at in order to be on top of the class in maintenance. Karsten Moholt AS has mentioned that they already do some of these steps e.g lean and wants to acquire a CMMS. With the added competence of RCM and Asset Management Karsten Moholt can both improve their own and client's position on the Reliability Model. It can also be a good way to build a solid foundation, set reachable goals and ensure that improvements are made in suitable incremental steps.

6.2.2 Various potential useful courses

- Maintenance is your competitive factor - Maintenance Management [34]
  - The course will give the participant knowledge of the tools and methods, e.g the Maintenance Loop, that are part of modern maintenance management.
- World Class Maintenance - Maintenance Management [35]
  - The course builds on the standard NS-EN 15628 Maintenance - Qualification of maintenance personnel. Its target group is personnel in maintenance (management) and people with maintenance related responsibility who works in e.g production and process industry, the energy sector and working in supply of maintenance services.

- The course is approved as a basis for theoretical knowledge by accredited certification as a maintenance manager with the opportunity to take a final exam. Upon passing the exam, course participants can apply for accredited certification and IPC certification (international Personnel Certification) if other requirements for education and professional and management experience are met.

Qualitynorway.no has many courses related to maintenance that might be worth taking a look at to find what suits best.

7 Future plans for maintenance industry- Industry 4.0

Business environments have rapidly changed due to emerging information technologies having gradually made the borders between the real world and the virtual world disappear. This change is manifested in the knowledge intensive and service focused industry seen today.[24] Trends of the future show that the world gets more digital and more devices get connected to the internet, and thus more are getting "smart". This smart industry or Industry 4.0 refers to the fourth technological revolution from embedded systems to cyber-physical systems (more on CPS later on). This new industry connects embedded system production technologies and smart production processes to pave the way to a new technological age which will radically transform industry and production value chains and business models. [27]

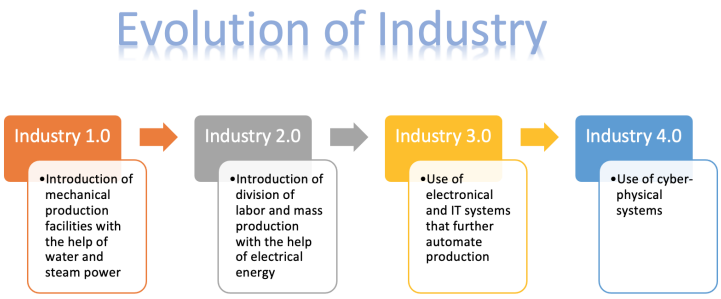

Figure 17: From industry 1.0 to 4.0

Embedded systems already play a central role in all of our lives. All devices used today have regulators, control and monitor functions, e.g ABS systems in cars, smart phone communication, and ordinary household devices. The embedded system are the intelligent central control unit at work in most of these devices. Control units typically operate as information-processing systems "embedded" within an "enclosing" product which "connect" with the outside world using actuators and sensors. This allows embedded systems to be increasingly interconnected with each other and the online world. [27] It is this evolution of embedded systems becoming connected to "the world" that creates the vision of a global "Internet of Things" and thus also the fourth industrial revolution.

7.1 Internet of things

The Internet of Things is a therm used to describe the phenomenon where electronics are connected to, and controlled via the internet. These electronics can be everything from the television, phone, heater, lights or a car. The ability to connect these "things" or devices to the internet is not what makes the phenomenon new or interesting, but rather the ability for the devices to talk with each other and exchange information.[10]

These devices generates a lot of information that is not valuable on its own, but when they are connected and processed by a automated system the full potential of "internet of things" becomes clear. Making it possible to analyse the information and creating an "action" to help someone with a particular task. [10]

7.2 Smart maintenance

One of the application areas of Industry 4.0 is maintenance in the form of self-learning and smart system that predicts failure, makes diagnosis and triggers maintenance actions. This type of maintenance systems have high demands on data access and data quality. [24] One way to ensure high amount of sensor data describing the condition of machines (etc.) is to make Cyber-Physical Systems (CPS) which integrates physical devices (i.e sensor) with software components. [41]

An overview of how the process of smart maintenance would be structured is shown below. The production plant represents the start and end point and is equipped with sensors and, as part of an Internet of Things implementation, is individually connected to the cloud and transfers data to subsequent services. Raw data gets processed in the cloud using pre-developed rules and filters before getting sent to the prediction model. A pretested prediction model is initiated and estimations are sent to a Decision Support System which reasons if, what and when actions should be triggered in order to prevent or correct a defect. Lastly, maintenance operators equipped with tablets receive maintenance instructions from the cloud, the sensors register the change and the cycle repeats. [41]

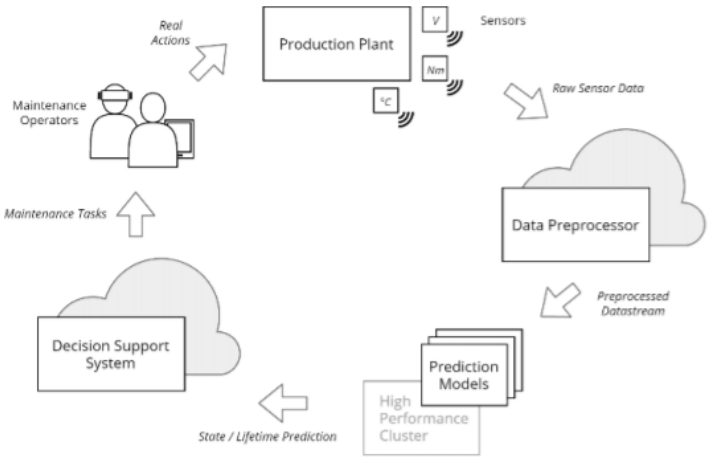

Figure 18: Smart maintenance lifecycle [41]

How a CPSs can contribute to many benefits when looking at maintenance can be demonstrated by looking at a CPS system developed in The Institute of Industrial Automation and Software Engineering (IAS) of the University of Stuttgart. A coffee machine was connected to the cyber world with the help of hardware add-ons and a microcontroller board was used as a gateway to the cloud (where the cloud was a local computer). A website and an Android app were created for operation of the CPS. [21]

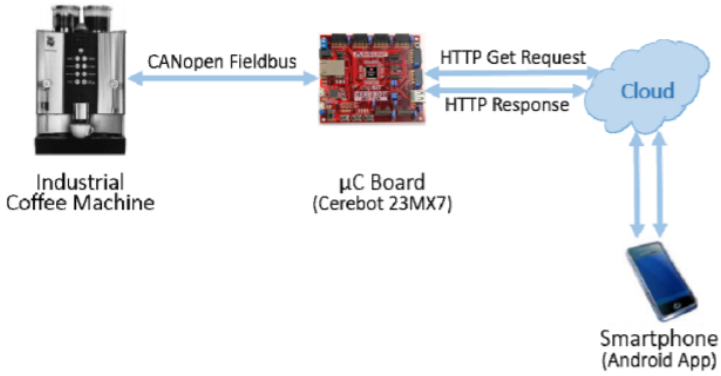

Figure 19: Modifying a coffee machine into a Cyber-Physical System (CPS) [21]

This configuration makes the coffee machine more "smart" in various ways. It was for instance able to remote diagnose, update the software via the cloud and remembering customized customer settings chosen via the app. For the maintenance side this setup made it possible to remotely determine which component was defective or which ingredient had been used up, and then communicating via the app what spare parts or which ingredients are needed.[21]

7.3 Continuous monitoring

The term continuous monitoring describes the process where a machine or component is connected to sensors that continuously monitor predetermined parameters, such as temperature or vibration. The intention behind continuously monitoring of equipment is to analyse, detect and correct a problem before a breakdown occur. It is also possible to create maintenance reports and plan based on the data created from the sensors. [16]

It is important to have a good connection between the sensors and the main servers where the data is stored to have a well functioning system when utilizing continuously monitoring. The connection commonly used is the internet, which brings with it both advantages and disadvantages. The advantages are that it is possible for the main server to communicate with the sensors wherever they are in the world. The main disadvantage is that the internet coverage and capacity is not as well developed in large parts of the world. The best example is the worlds oceans which covers approximately 71 % of the worlds surface. Other examples can be in the flight industry, developing countries or large uninhabited areas such as the Sahara desert [40].

This is all about to change with the construction of the Starlink satellite constellation which will bring high-speed internet to every corner of the planet. [6]

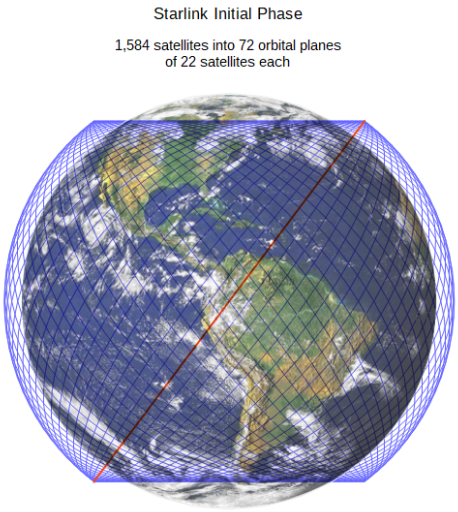

Figure 20: Starlink phase 1 [26]

The Starlink constellation is currently under construction as of spring 2021 and the first beta users gained access in certain areas of USA and Canada in October 2020. The first phase of starlink will not cover the poles and the most northern coverage will be 53 degrees north, meaning that Norway will not be covered in the first phase, as seen on Fig 20. The coverage north of 53 degree north will come at a later date [40].

The business model SpaceX uses with regard their product Starlink is that it will be easy to use for normal people. The Starlink kit will consist of an antenna to connect to the satellites, Wifi router, power supply, cables and a mounting tripod. The antenna is easy to mount and will align automatically to the satellites when connected to power. The user can use an app to get an overview of the sky to see if there are any obstructions and move the dish if necessary [40].

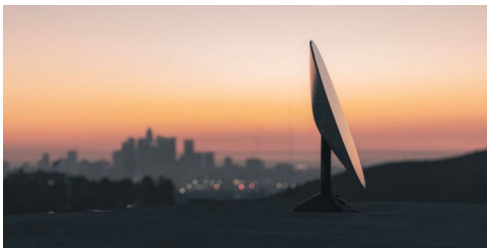

Figure 21: Starlink user terminal in front of Los Angeles [40]

SpaceX claims on their site that during beta testing users can expect to see data speeds vary from 50Mb/s to 150Mb/s and latency from 20ms to 40ms, and that there can be periods where there are no connection at all. They expect these numbers to get better when exiting the beta testing. [40]

7.4 Conclusion

One can imagine the impact CPSs can have on Maintenance Management if equipment continuously self-monitors its state, communicate deviations and triggers maintenance tasks with all necessary information ready to be handled by a technician. This is all doable with the evolution of industry 4.0 and the Internet of Things. If you add big data and machine learning the system is now able to predict failure and compute prognoses (smart maintenance). The technological advancement necessary for this revolution is already under construction as mentioned with Starlink which enables global Internet of Things in a much higher degree, all accumulating to a smart maintenance system being realized.

By having Industry 4.0 in mind Karsten Moholt AS can prepare and plan for the direction maintenance will take in the future, or set goals to pioneer the development. When developing the Maintenance Management team this chapter might give KM a pointer to what technology to invest in, what competence would be wise to have further down the line and how this team can evolve in order to perhaps be a supplier of new maintenance services following the upcoming industry revolution.

8 Recommendations

One recommendation is for the top management to get acquainted with the ISO 55000 standards, define their objectives and start to implement this throughout the company. Asset Management is already used in Karsten Moholt AS but in a passive way. Integrating Asset Management on a larger scale will help to fully utilize their assets lifespans and help connect the team to the existing "red thread" in the company. However, this process starts with the top management in KM. It is recommended to map the company objectives, compare and make them coincide with the determined Asset Management objectives. Not everything in the ISO 55000 standard has to be required, some can be a guideline, like the leadership aspect.

As stated in Chapter 5.3, this is how we would recommend the team to look at the beginning. Some of the positions might need more than one person, but in general these positions need to be filled. In the beginning we would recommend only hiring a maintenance manager to get the team started. The manager needs to define the team's objectives, the work tasks for each role and make a implementation plan for the team into KM. A sales and marketing person should be the next one to be hired to start reaching out to clients and market the new service to old and new clients.

Another important step we recommend before starting the team is a market evaluation, something that has not been done in this thesis. This is important for understanding the market and to get a view of the market potential for a service like this. For example, KM's service employees that are in contact with existing clients can ask around to get a thought of what clients think a service like this should contain.

As discussed in Chapter 6.2 it is important to have competence in the field of World Class Maintenance and RCM. As a minimum requirement we would recommend the RCM expert and maintenance manager to be certified in these two fields. Of course, the RCM expert will have the proper education and experience as well. This would create a solid foundation competence wise and could help create a work environment where the maintenance manager and the RCM expert can be the first part of a specialist environment.

In Chapter 5.1 it is mentioned to make a self assessment inspection checklist. This is something we would recommend for the team to make. The process will be easier if the team knows beforehand what the problems in their clients organization is before they start their work. It will also save the clients money in travel expenses.

Computerized Maintenance Management System (CMMS)

The excel spreadsheet provided as an attachment to this thesis lays out many alternatives for RCM/Maintenance Management software. Many of these software have a free demo which gives Karsten Moholt AS the opportunity to test the programs without the cost. The simplicity, layout and the general ease of use has not been evaluated and this has been explicitly communicated by KM as being important. Therefore, we recommend that KM spends some time acquiring free demos and testing the different software to find what suits them best. However, the analysis in this thesis only covers a small portion of all the software out there. If KM find other relevant software we would recommend that the same procedure used in the analysis is used for the other software as well. This gives a clearer view of what the different software offer and a better comparison with the other software.

9 Discussion

It can be discussed how the circumstances would be different if the authors had been able to interview other people in KM, not only one top manager. Firstly, when it comes to how the Maintenance Management service could be set up in relation to the services that KM already provides, could be more accurate with multiple views from KM. Secondly, it is difficult to assess how cross department communication is done today and how the responsibilities of the complete package that KM can provide should be distributed between the department.

Moreover, we initially thought to find out what customers want from a service like this by actually talking to a existing or potential customer, but this was not possible as well. Its safe to say that this is very important in order to ensure that the service gets developed into something that the market actually needs.

With the inability to gather viewpoints from KM more information/data have been taken from the scientific literature, thus making the thesis more theoretical and subjective than first anticipated. However, this made the project less influenced by KM. In the end its all about the organizations objectives and what they want to achieve that will have the most influence on the team.

From the interview with Karsten Moholt AS five success criteria was mentioned, as listed in Chapter 3.2. With the recommendations presented in this thesis it might ensure that at least some of the success criteria will be achieved. For instance, the team will be in a position where they will be able to create a desired synergy effect to the rest of the departments in KM, in sync with the growth of the Maintenance Management team. The success criterion about having a positive impact on the environment will be difficult for us to discuss. However, one of the benefits of Asset Management is demonstrating social responsibility. By focusing on this point, it can help KM be more environmental focused thus helping their customers finding more environmental beneficial solutions.

Every company has different problems and it could therefore be important to emphasize to the clients the possibility to customize the service to their needs. Also, the services marketability will benefit immensely by using the Karsten Moholt AS name and reputation. We can assume that in the beginning it is prudent that the department from KM that is in contact with the clients can mention this new service. Over time, when KM wants to offer a complete maintenance package it will be natural for the Maintenance Management team to be the first point of contact with clients, as shown in Figure 13

10 Conclusion

Starting a new team is challenging no matter the circumstances, or field of work. By having Asset Management implemented on a larger scale in Karsten Moholt AS, many of the challenges with starting a team can be reduced. One specific work task for the team is to perform Reliability Centered Maintenance analysis, which has a strong scientific background for being effective. However, businesses know the advantages but nonetheless fail to adopt the methodology, mostly due to the process being complex and resource demanding. The expertise that KM brings to the customer in the form of a Maintenance Management team will be in a position to mitigate the disadvantages RCM analysis brings.

This thesis is one out of many ways to do so. The recommendations presented in the thesis are subjective and can work as a blueprint for how to put Karsten Moholt AS idea to life. Moreover, with the extensive literature review done before landing on recommendations we are confident that the recommended actions are applicable in this context. If KM implements a Maintenance Management team that is based on the principle of Asset Management and RCM, they can provide a service that complement the whole organization and follows the "read thread" in the business today, helping them and their clients.

List of Figures

List of Tables

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Appendix

- **Appendix 1-** CMMS alternatives