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Master's thesis in Industrial Economics

Implementation and optimization of condition based maintenance on an offshore oil and gas installation controlled from onshore.

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Abstract

The demand for better maintenance solutions within the oil and gas industry is a trigger for this thesis, where Total E&P Norge approached with a new solution. They wanted a student to look into this task and discuss how to implement condition based maintenance compared to already planned processes. The task given was also to observe and then suggest processes to optimize the utility of condition monitoring and to apply continuous improvement to the implemented strategy.

Through observations, research, examples and talking to key people working with maintenance and condition monitoring at Total E&P Norge, knowledge and insight was achieved. With these, theory about different strategies, condition monitoring tools, processes and systems is presented to best analyze and establish suggestions to solutions. Condition monitoring is a key factor in the condition based maintenance strategy and must be used and managed correctly to achieve the expected effect.

One can basically condition monitor every equipment with all types of available tools and all its major failure modes, but the available tools to do so is quite expensive. The need for criticality analyses is a measure to achieve good results from the new maintenance strategy and keep costs as low as possible. These analyzes puts equipment into categorizes which inform the needed amount of condition monitoring. The overall reasons condition based maintenance is applied will be to achieve an increase in equipment reliability and availability and to reduce maintenance costs.

All these condition monitoring tools requires not only to be bought and installed, but there are also many disciplines to be taken into consideration. These tools generate a lot of information which must be gathered and analyzed. This may require highly sophisticated information technology and software. In general the increase of condition monitoring may result in changes in maintenance operations and management.

When starting the research, some results expectations were already made. Some of them were the implementation process should be straight forward and simple. The learning and optimization process was also considered to be the same. These expectations were quickly known to be false. The process may be straight forward, but it was not simple as expected. For a huge company to change some of their strategies and process would need a lot of backing from the top management.

In general people are quite conservative and are not so open to changes. New processes and new software requires courses and learning periods to make personnel operational to the required competence. Many issues will occur by implementing condition based maintenance, but the clue is to be a step ahead of these issues and make good solutions.

The thesis presents some issues and possible solutions, but every new process and strategy has its flaws, and require continuous improvement. This is why some measures have been recommended to best monitor the efficiency of both processes and strategies. There will always be the need for improvements, and to be able to do so, the implementation process should be solid and strict. If the information gathered and analyzed are not sufficient or not the required ones, the possibility for improvement is slightly halted. The research presents another maintenance strategy which is not meant to take over condition based maintenance. The aim is to work together with it, to both improve equipment's availability and optimize the utility of condition monitoring.

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Abbreviations and definitions

CBM	Condition Based Maintenance
CM	Condition Monitoring
CMIMS	Computerized Maintenance & Inspection Management System
FMECA	Failure Mode, Effects and Criticality Analysis
GMC	General Maintenance Contract
HSE	Health, Safety and Environment
IO	Integrated Operations
KPI	Key Performance Indicators
MTTR	Mean Time Too Repair
NDT	Non Destructive Testing
OOC	Onshore Operation Centre
OREDA	Offshore Reliability Data
P-F	Potential – Functional Failure
PI	Process Information
PM	Preventive Maintenance
RCM	Reliability Centered Maintenance
SCOTT	Scott Tablet
SMC	Special Maintenance Contract
TEPN	Total E&P Norge
VM	Visual Management

1 Introduction

Maintenance is a topic which has been an issue for a long time and will always be of high importance. Total E&P Norge came with an idea they are planning to implement for the Martin Linge field. They wanted someone to look into the idea and see how maintenance on an offshore topside platform controlled from onshore. This is a new way of thinking which may have many advantages, but can result in some issues related to organization and communication. To best get an overview of the baseline of the given problem, some research was done. First of all, there is a need of understanding the history of maintenance, identifying problems and define what this thesis should focus on. Since this is a large topic, some limitations are necessary to best manage to elaborate the given problem and define a suggestion to a possible solution.

1.1 Background

The meaning of maintenance has changed over many years and its function has also changed. It has evolved from a non-issue into a strategic concern. At first maintenance was only a necessary when something broke down and had to be fixed. There was no attention to availability, because equipment was supposed to fail at some point of time anyways. In the 1950's, after the second world war when the rebuilding of the industry in Japan and Germany, it became an increased intolerance for downtime because of the existing competitive market. Labor costs increased significantly leading to the use of more automation units and technology. Machinery ran at higher speed and wore out more rapidly. At some point breakdowns became too costly and measures began taking shape to extend the lifetime of equipment. This kind of thinking made maintenance a profit contributor and became more than just a necessary task. By establishing maintenance strategies and carefully implement them could actually result in a significant financial impact. Figure 1 shows an approximate maintenance strategy timeline together with the change in reliability starting from the 1930's and continues through 2010 and beyond. (Brown and Sondalini, u.d.)

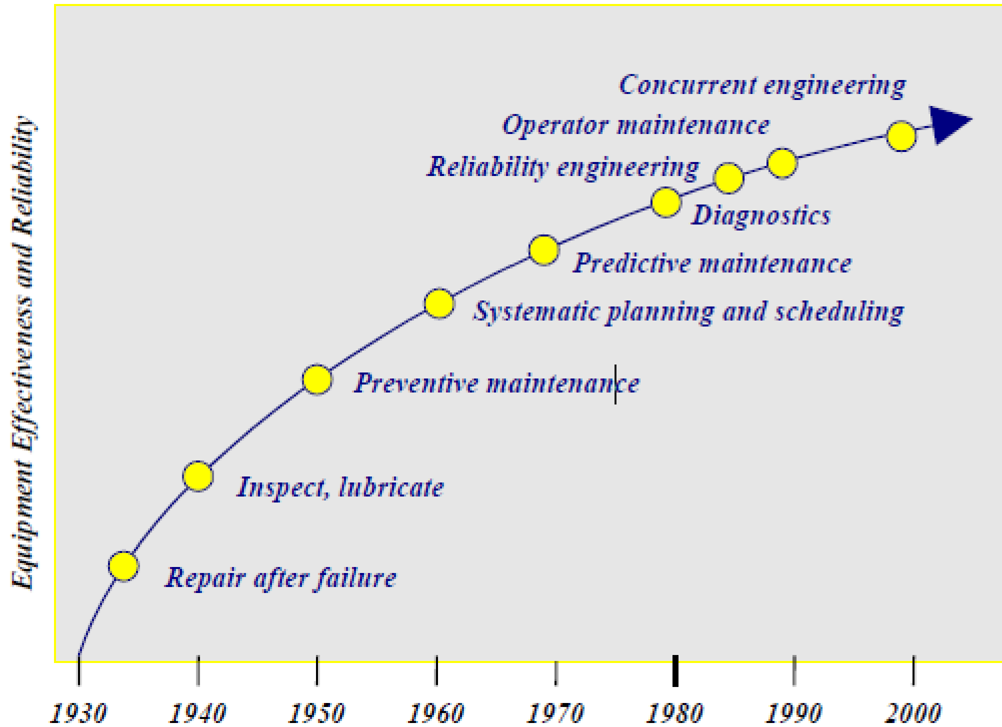


Figure 1 Maintenance strategy timeline and change in reliability (Shreve, 2003)

From this point the meaning and the benefit of maintenance changed drastically. Introducing the preventive maintenance strategy, which will be elaborated later in chapter 2.1, was one of the major changes before the year 2000. The idea was to repair the equipment before it actually broke down, so one could plan when to shut down, instead of it coming as a surprise. This was proven to be beneficial and was implemented in many lines of work. This strategy increased the reliability of equipment, but many of them were proven to be replaced too soon. One still had the advantage of knowing when the replacements occur, since they were planned, but the disadvantage of not knowing if it really is a need for replacements. By then looking on the condition of the equipment, one would know when a replacement is needed, increasing the utility and availability of the equipment. This line of thinking resulted in the condition based maintenance strategy which this thesis is based on. In just few years this topic has been integrated with new technology, processes and strategies.

1.2 Problem description

When contacting Total E&P Norge they had an issue which was about their project, called Martin Linge, which is an oil and gas platform in the North Sea. The problem description given was as followed:

"Total E&P Norge (TEPN) is operator of the Martin Linge field. Oil and gas production is expected to start in 2018 with a capacity of 100,000 barrels of oil equivalent per day (boe/d).

Total holds a 51% interest in the project. Its partners are Petoro (30%) and Statoil (19%).

The Martin Linge project in the Norwegian sector of the North Sea opens new doors for Total through technology innovations that reduce environmental impacts and enhance safety.

The development of this offshore oil and condensate gas field lying 115 m under water began in early 2012. It involves the construction of an integrated wellhead, production, utility and accommodations platform. Gas from the field will be exported to the UK via the FUKA gas pipeline. The Martin Linge installation will have a low permanent manning and be controlled from a dedicated onshore control room located at TEPN's offices in Dusavika, Stavanger. The installation will be powered from the Norwegian mainland grid via a 170-km subsea cable from Kollsnes west of Bergen.

The operation philosophy of Martin Linge is to a great extent based on new technology and extensive use of condition monitoring (CM) systems and tools for safe and cost efficient operations. The CM systems will play a centralized role in the planning and execution of maintenance activities. Maintenance will be performed in campaigns. Hence, well preplanned jobs are crucial for the success. This means that the onshore team will need to filter handle significant amount of information to be able to take the right decisions." (Oltedal, 2016)

The Martin Linge project is focusing on new technologies and condition monitoring. The plan is that a major part of all maintenance would be condition based maintenance to increase the availability and reliability of the equipment on the topside. Maintenance will be performed in campaigns, which will require a lot of preplanning to be successful. The installation will also be controlled from onshore. These plans and solutions may bring some new challenges and major changes in the organization. Also new procedures, technology and strategies are being implemented. In total, there is a need for new thinking to resolve the changes which are necessary for the implementation and optimization of condition based maintenance on an offshore oil and gas installation controlled from onshore**.**

1.3 Purpose and scope

The main objective for this thesis is to describe and establish processes which may make the implementation process of condition based maintenance on an offshore oil and gas installation controlled from onshore successful. As a part of the thesis, existing operational and maintenance philosophies for the Martin Linge project will be used as examples. These include objectives which will be used as milestones to discuss the success of the analysis.

Also there are sub-objectives of how to optimize the utilization of condition monitoring and improve the implementation process. Both of these are important to successfully implement and optimize condition based maintenance. Together with the other sub-objectives, they will become the answer to the main objective. The scope of this thesis will then be divided into a main objective and some sub-objectives given as followed:

1.3.1 Main objective

- **Implementation and optimization of condition based maintenance on an offshore oil and gas installation controlled from onshore.**

As mentioned, this is the main objective, but the process of implementation is an excessive one. To limit the extent of scope, sub-objectives is established which together will result in the answer of the main objective. Martin Linge will be used continuously as an example of the offshore oil and gas installation controlled from onshore, and is mention and compared to through this thesis.

1.3.2 Sub-objectives

- **Describe the CM tools to be used for Martin Linge.**

Some CM tools will be presented, where the focus will lay on the most common and likely to be used through discussion with key people within TEPN.

- **Describe how the CM tools best can be used in accordance with the Martin Linge maintenance philosophy, and how to identify possible methods to optimize the utilization of CM.**

The philosophy and possible methods will be presented and discussed.

- **Describe how to integrate the different CM tools into a common system and how to manage available data.**

Different systems, which are planned for Martin Linge, will be presented and discussed. Also methods to best manage the available data retrieved by the CM tools.

- **How to identify valid data from "normal noise".**

The incoming data will be used to monitor equipment. Procedures to detect abnormal data will be presented and elaborated.

- **Define a process for continuous improvement of CM.**

A process will be defined, included discussion of the importance of continuous improvement and its effect.

- **Propose relevant Key Performance Indicators (KPIs) that can be used for monitoring the efficiency of CBM.**

Relevant KPIs will be presented and why these are important will be elaborated. Methods to monitor efficiency and statuses will also be included.

The natural discussion is the benefits of the implementation of CBM and if the predicted result will be the finalized outcome. TEPN has already pursued with the new strategy, and then to see how best follow through with this strategy, right now and in the future, will be a major focus and will be elaborated. It is important to understand that this thesis presents suggestions to a solution and not a total completed solution. The answer of the main objective should indicate if the new strategy is doable and present methods and processes to optimize, maintain and improve the utility of CM.

1.4 Limitations

This thesis will present many methods to do different analyzes and different systems which will simplify the implementation process, but they will not move into the technical details and studies or include specific cost-benefit analyses to justify the results in the analysis. Technical problems within the described CM tools and systems will not be discussed where these are challenges that the operator have limited possibility to change. The mentioned CM tools covers only the main chosen tools to be used for the Martin Linge project. The installation analyzed has been limited to the topside and is then not including the subsea installation or the FSO (Floating, Storage & Offloading).

2 Condition monitoring and maintenance theory

“When do we need to do maintenance?” is a question that can generate interesting discussions, because there are more than one way to answer it. It depends on which type method you use, how you see the need for frequent maintenance, and what strategy you apply. The methods mentioned in this thesis are Preventive, Condition based, and corrective -maintenance. These are the main methods used in the Martin Linge Maintenance Philosophy, where the focus is on increasing the use of condition based maintenance, resulting by decreasing the man hours offshore. Figure 2 gives an overview over the different maintenance methods.

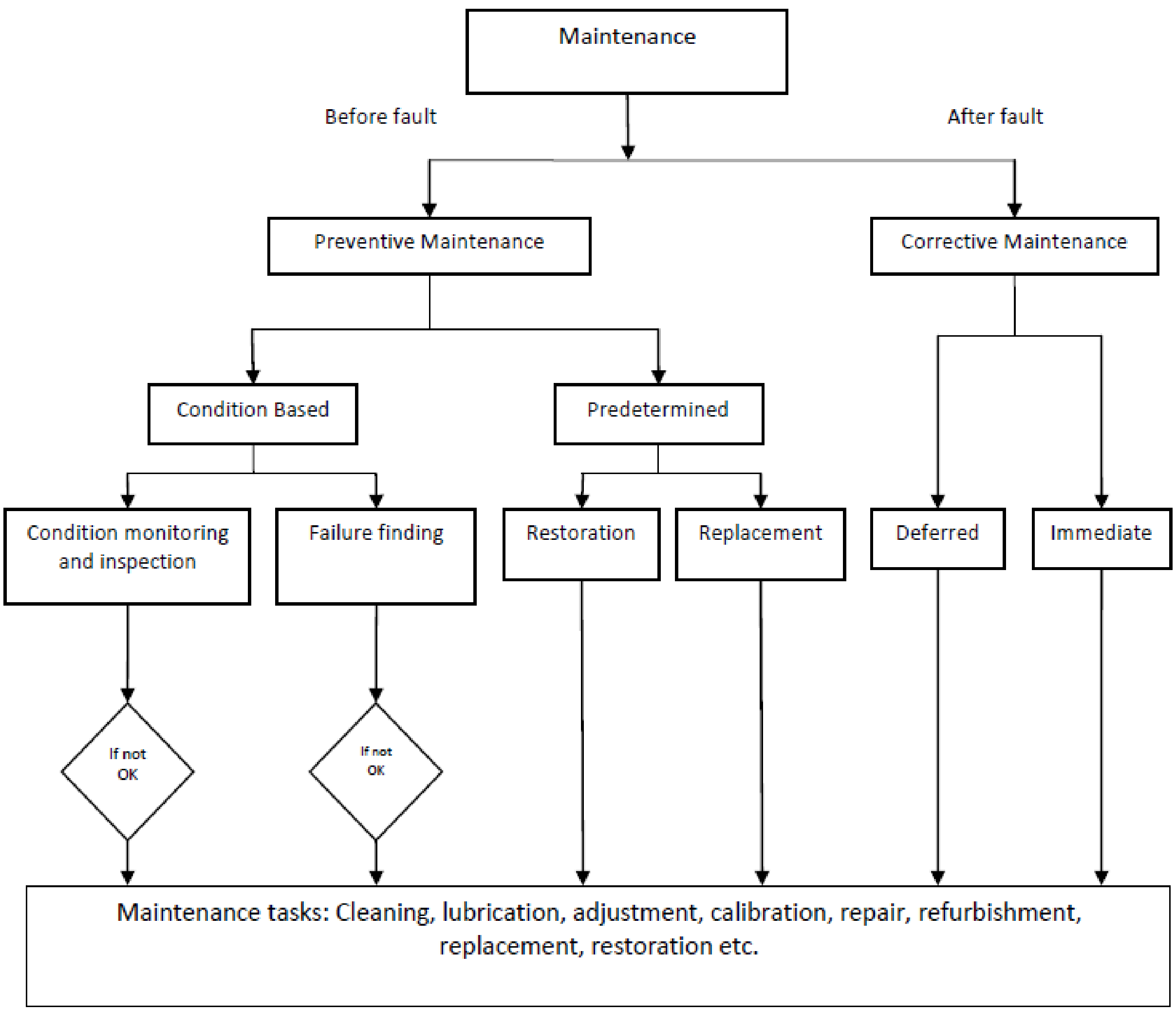


Figure 2 Maintenance methods (IEC 60300-2-11, 2009)

2.1 Preventive maintenance

Traditional preventive maintenance (PM), also known as time based, is the classic method of maintenance in the oil and gas industry. The main objective of this method is to have a fixed time based maintenance program to ensure crucial equipment from shutdown. To minimize downtime is one of the most important objectives for any production facility, since downtime is very costly. PM is also called calendar based because the date and time for maintenance is already planned ahead. This method makes it easy for the contractors, where a procedure is mostly fixed. By knowing when and what the tasks are, one can in good time plan and be ready to do the maintenance swiftly. Figure 3 shows an undefined result of performance with the use of calendar based PM. Most companies are using a Computerized Maintenance & Inspection Management System (CMIMS) which automatically generates new PM orders and sending them to contractors. Of course, this is based on that all the failure modes are known, which may not be the case. For economic point of view, the maintenance cost will be somewhat constant.

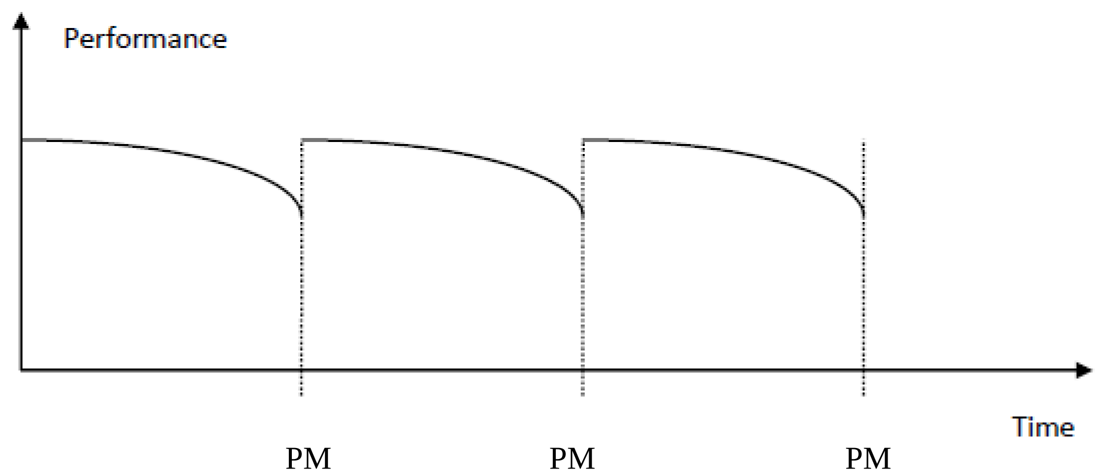


Figure 3 Curve of performance with PM (Heggeland, 2012)

This maintenance method also has its disadvantages. To periodically disassemble all critical equipment on the installation can be expensive and time consuming. Also the predicting the intervals between periodic inspections are difficult. If the program is so successful that no failures occur, it may be the interval is too short and money and production is being wasted. If the interval is too long, costly failures may still occur. Some PM is absolutely necessary. To give some examples; electronics, lifeboats, life rafts, fire extinguisher. (Shreve, 2003)

2.2 Condition based maintenance

When talking about the condition of equipment one often refer to the status of it. Is it working as it should? If it is, then there is no reason to do maintenance on it. Then the question is how we can monitor the condition of equipment, so we can know when it is not working as it should. That is when CBM comes in. The objective is to monitor equipment using various tools to estimate the condition, degradation and to predict when maintenance is needed. When an abnormally is detected, one will then plan and then send out a work order for maintenance. The monitoring tools are expensive, but in the long run it is an investment that will reduce maintenance cost and increase system availability and productivity if used wisely.

There are different tools to use for condition monitoring. Some of them are:

- Vibration monitoring
- Non Destructive Testing (NDT)
- Wear and Oil monitoring

Each type of monitoring fits to different equipment and acquires different parameters. To use an example, one would use vibration monitoring on rotating machinery to see if the equipment is rotating as it should. One could also use a NDT method called thermographic monitoring to see if abnormally heat is generated in the bearing areas.

The three basic activities in condition monitoring are measuring to create a relevant data basis, analysis of the data and making a decision based on the analysis. Which equipment and how intensive they are to be monitored is also a question, because by monitoring everything it will be too expensive. The equipment most crucial to the production line, and making the facility still producing would be prioritized. As mentioned earlier, the main objective is to minimize downtime of production.

It is common that variations in the measurements will occur due to various disturbances when monitoring equipment. By knowing this there is an expected variation in the measurement so the monitoring system won’t react on small variations. When condition parameters differ from expected values one can analyze and conclude with that equipment has an error. This can either be because of age related issues or internal/external direct/indirect problems. These variations can be termed as a failure (P) which is an event, but the machine still may have capability of performing its required functions. This is commonly called a potential failure. When the machine loses its ability to do its required function or it breaks down it is referred as a fault or functional failure. Figure 4 shows the curve from potential to functional failure, also known as the P-F curve. (Heggeland, 2012)

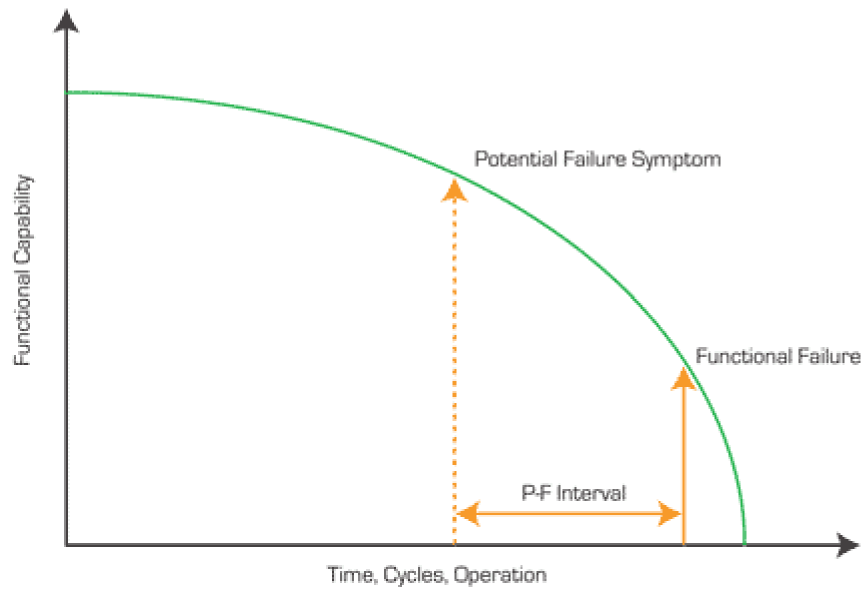


Figure 4 P-F Interval (Apelgren, u.d.)

For CBM to actually work, the P-F interval has to be long enough for condition monitoring task and actions taken to prevent functional failure. Otherwise CBM loses its purpose. CBM is not a substitute for PM, but more of a valuable addition to improve the time based maintenance. If one experience that potential failures occur at similar intervals over time, on one or more equipment, then PM will be more suited for them. (IAEA, 2007)

2.3 Corrective maintenance

Corrective maintenance is a reactive method where one does maintenance when a fault occurs. Equipment is simply allowed to operate until its performance isn't sufficient. Depending on the criticality of the fault one can decide if the maintenance should be performed immediately or at a later time. A lot of equipment is maintained this way, but corrective maintenance has several obvious disadvantages. Failures can happen at any time. There is little that can be done before the failure event to predict the tools, personnel, and replacement parts that may be required to repair the equipment. Also machines allowed to run to failure generally require more extensive repair. Some failures can be catastrophic, which may require total replacement of the machine. A catastrophic failure may also pose a safety problem for personnel. The added cost of lost production and the possible replacement can be excessive. Because of these disadvantages corrective maintenance is mostly used for non-crucial equipment or for redundant machinery. As a guideline for corrective maintenance, one would apply it if the repair cost is as high as or higher than its replacement cost, and representing no risk to safety, production, or product quality. (Shreve, 2003)

2.4 Proactive maintenance

The purpose of proactive maintenance is to find the failing root causes and try to eliminate them. An example is that one can improve the material in a bearing or on a shaft or switch them with better quality, where there is a lot of vibration and heat exchanged. Of course is it hard to eliminate root causes, but the idea is to learn from the equipment and improve it with time after knowing where and why faults occur. As mentioned, one need to learn from the equipment, and that is where condition monitoring comes in. This method of maintenance has the need for surveillance of the equipment behavior. It is crucial because new faults can occur at any time, and by implementing condition monitoring, these may be detected much faster.

2.5 Reliability-centered maintenance

Reliability-centered maintenance (RCM) may be defined as a process used to determine the maintenance requirements of any physical asset. It is a top-down approach that begins with establishing boundaries for the system and developing a critical equipment list. Equipment is deemed to be critical if it performs a function or if its failure mode can affect major damage to personnel safety, environment and production. RCM is one of the most common used maintenance analyses methods because of its success in increasing safety and effectiveness handling risks.

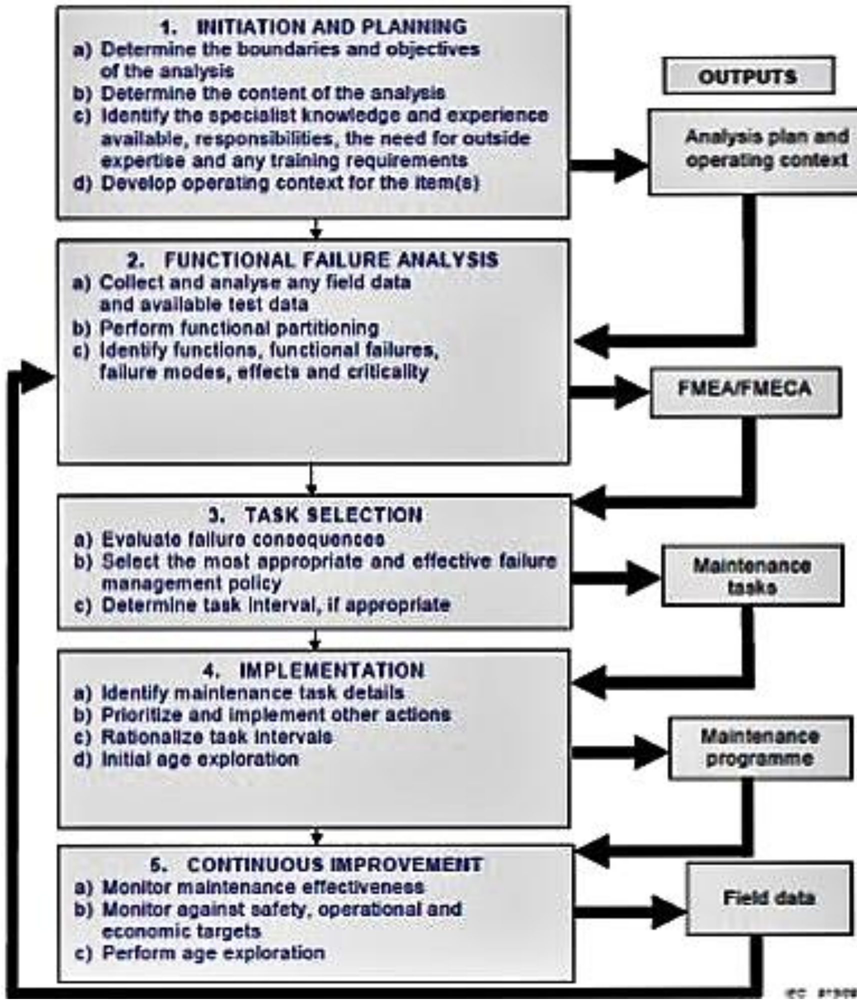


Figure 5 Example of a RCM process (IEC 60300-2-11, 2009)

The process and the various tasks in a RCM process is shown in figure 5. This method is often used on new and unfamiliar equipment to get to know the equipment better and from the acquired information develop maintenance programs. This process is time demanding matter and are then more commonly applied for maintenance optimization in operational phase rather than the project phase. (Heggeland, 2012)

RCM discovers that not every failure mode needs to be or can be addressed by a maintenance-based solution. If this is the case and a maintenance action is not available or is not cost effective, and the failure cannot be tolerated, then a design modification is recommended. If the failure can be tolerated, corrective maintenance may be applied. One of the objectives to the RCM process is to ensure a balanced mix of periodic and condition based maintenance. It is presumed that an optimal balance between PM and CBM is achieved through the establishment of a critical equipment list. This will be mentioned later in the chapter, but it is a necessity for implementing CBM. Time shows that plants that have used RCM typically report significant reductions in periodic maintenance and increased use of condition based maintenance. (Shreve, 2003)

2.6 The Maintenance philosophy of Martin Linge

The maintenance philosophy is a document which describes the wanted results and strategy of maintenance in the future for a project. In this thesis the Martin Linge project will be observed, which is having a greater investment in condition monitoring and is implementing CBM. The objective is to reduce long-term costs, and increase availability and reliability of the Martin Linge Asset. The maintenance philosophy is strict on following Company Rule (CR EXP 200 Maintenance Policy) and that the whole project is compliance with local, national and international laws. Through maintenance the philosophy wants to have sustained operation and performances. Other objectives are development, implementation and continuous improvement of a cost effective optimization system.

The maintenance and inspection contracting strategy is to divide the contract into three parts:

- MIEC (maintenance and inspection)
- GMC (Operational maintenance)
- SMC (Specific maintenance)

One contractor gets both MIEC and GMC to handle internally, but the SMC include many contracts for specific equipment, such as elevators, valves, pumps, compressors and electrical equipment.

The maintenance also include some principles, such as maintaining the availability of the Martin Linge Oil Production system to the target of 93,5% and Gas 94,5%, at a minimal cost while ensuring safe conditions. 21 days planned summer shutdowns every 4 year, together with St. Fergus. It is also said to include Maintenance engineering (ME) objectives at the beginning of the project. (Total E&P Norge, 2012)

2.6.1 Health, Safety and Environment

Health, safety and environment (HSE) is a central part in the maintenance philosophy of ML. Measures should be taken to make the personnel have a secure environment as possible to minimize the number of accidents. Reporting is essential to maintain a good work environment, but also to minimize the Mean Time To Repair (MTTR). With less time spent on repairs, the less exposure is there to personnel. (Total E&P Norge, 2012)

2.6.2 Manning

The manning philosophy is to minimize the work done offshore, and make the work offshore more efficient. When personnel are working offshore they are exposed to a higher risk environment. Also having people offshore is a cost issue, and by doing most of the work onshore, one can reduce costs. As the Maintenance Philosophy states:

"Offshore work will be moved onshore when possible."

It is also said to "Design for minimum offshore work," which is in line with the previous statement. (Total E&P Norge, 2012)

2.6.3 Maintenance strategy

As mentioned above, one of the objectives in the maintenance philosophy is to minimize the work done offshore. To achieve this objective the strategy is to decrease frequency of inspection and time based preventive maintenance (PM). With a higher degree of CBM, one can do most of the condition monitoring onshore. The objective is to make CBM, within 2 years, cover at least 60% of the performed maintenance hours. PM should cover 30% and 10% by CM. The 40% not going to be CBM is set because not all equipment on a topside platform is necessary to monitor. They may not be crucial to maintaining the production, or they can be designed out maintenance. To give an example, monitoring each and every bolt is ridicules, but one can ensure the reliability of the bolts by using high grade materials. (Total E&P Norge, 2012)

2.6.4 Campaigns

To do the maintenance as efficient as possible one must have an execution plan. Before sending people offshore, the maintenance philosophy states:

"The maintenance campaigns to be performed at the Martin Linge field have to be properly planned and prepared"

The statement tells us that work orders, planned hours, sufficient competence, spare parts and booking have to be set and ready before any campaign is to be sent out. This will minimize the MTTR. Urgent campaigns should be ready to go within 24-48 hours (depending on criticality).

Spares and tools packages are a measure the philosophy mentions to be an efficient way to immediately send out equipment offshore when needed. For each failure mode a “grab bag” is ready with the tools and spares needed.

Everything will be reported, such as;

- observations made
- reading and measurements
- tasks carried out
- spare parts used
- active maintenance time
- actual resources used
- testing and checkout

With this kind of reporting, the purpose will be to improve the “grab bags” and the whole procedure. This will be elaborated later in the thesis. As mentioned, campaign efficiency will decrease exposure and work hour’s offshore, again reducing costs. (Total E&P Norge, 2012)

2.7 Integrated Operations

The Integrated Operations (IO) concept is the use of information and communication technology to change work processes to reach better decisions, remote control equipment and processes, and to move functions and personnel onshore. These are based on right time information which is commonly available through monitoring of different disciplines. One of the objectives for IO is to work integrated together with vendors and service contractors. With IO there is a potential for improved HSE, increased production efficiency and decreased costs. By having most of the staff onshore instead of offshore the company can reduce overall offshore costs. The number of personnel necessary offshore may be reduced, which may result in reduced salary costs. The staff will be available for the offshore crew for consulting and problem handling. It also allows input into the production to come from several different locations and people, through computerized communications. (Gusfre, 2010)

2.8 Offshore Reliability Data

OREDA, which stands for Offshore Reliability Data, is a project organization sponsored by eight oil and gas companies. The projects main purpose is to collect and exchange reliability data among the participants. OREDA has established a massive databank with reliability and maintenance data for exploration and production equipment. It focuses on offshore subsea installations and topside equipment, but it also includes onshore equipment. The database contains data from 278 installations, 17 000 equipment units with 39 000 failure and 73 000 maintenance records. OREDA is also available for member companies and contractors working on their behalf. There has been a development of specialized OREDA software to make it simple to retrieve and analyze the current information. (Oreda, 2015)

2.9 Description of various condition monitoring tools

To apply CBM one would need tools to monitor the condition of the installed equipment running the production. These condition monitoring (CM) tools are quite expensive and one should then see the necessity of which parts are being monitored. By looking at the maintenance philosophy for Martin Linge, one should prioritize after what is most crucial to the system and the philosophy. HSE and production, as mentioned, is the two most important objectives.

There are many different types of CM tools and many ways to use them. To get an overlook over different methods to use for CM, one will make it more easily to get an understanding of the advantages and the disadvantages of implementing CBM.

2.9.1 Vibration monitoring

Vibration analysis is used to detect bearing damage, unbalance, misalignment etc. In its simplest form vibration can be considered to be the oscillation or repetitive motion of an object around its equilibrium position. Typical equipment which vibration monitoring is efficient is pumps, compressors, turbines, generators, etc.

"Vibration analysis has been proven to be the most successful predictive tool when used on rotating equipment, both increasing equipment availability and reliability. In order to maximize the finite life associated with rolling element bearings and optimize equipment production life, excessive wear caused by misalignment, unbalance and resonance must be minimized. The presence of trained vibration specialists with equipment to conduct analysis will form the basis of a strong

vibration program. Routine and consistently gathered narrow band vibration data is vital to analysis and trending of machinery health. Acceptance standards of rebuilt or newly installed equipment will be established and verified using vibration monitoring." (Shreve, 2003)

This type of monitoring is fast, sensible to changes and does not normally affect the operations of the equipment. It is also a reliable tool, where it has good repeatability. Then again, this type of tool need special education to handle and it detect ability is narrow. Usual parameters to get out of vibration monitoring tools using transducers, are amplitude, frequency, displacement, velocity and acceleration. Figure 6 is presenting the best way to measure the sensitivity to failure and what parameters to use, depending on the frequency of the monitored equipment.

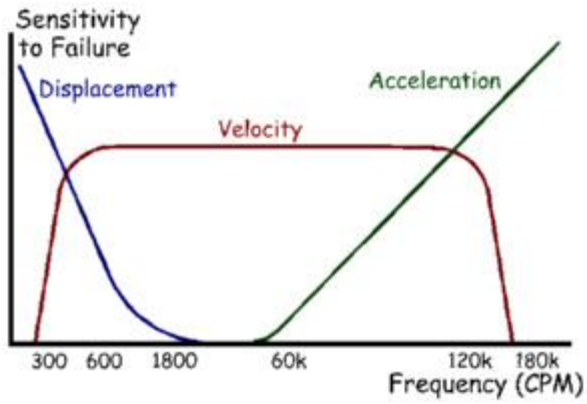


Figure 6 Sensitivity to failure (Monition, 1996-2016)

With a plot of the amplitude versus frequency on can get a represented view of the vibration signature and one would more easily analyze the status of the equipment. Most of the vibration based predictive maintenance programs use some form of signature analysis. The tools to be used to get these plot data is divided into three groups:

- Field analysis equipment (moveable diagnostic tool)
- Periodic monitoring (hand-held collector with analysis made in office)
- Continuous monitoring (permanent on-line)

2.9.2 Lubrication and wear monitoring

One of the most common factors that cause equipment failures are surface degradation. Corrosion and mechanical wear are common reason for this, and then lubrication is an important tool to reduce the surface degradation ratio. When there are contacts between surfaces in relative motion we then speak of tribology, which is a term that refers to design and operating dynamics of the bearing – lubrication – rotor support structure of machinery. It covers all aspects of friction, lubrication, and wear. This kind of monitoring can increase the reliability, the availability and also long-term costs of the equipment that is monitored.

Type of Wear	**Description**	**Comments**
1. Adhesive	Occurs when two surfaces are forced together under load, and then slid over each other	Increases with load and distance of sliding. Decreases with hardness of surface.
2. Abrasive	Occurs when sliding between two surfaces includes particles between the surfaces	Particles may “plough-in” (with softer surfaces) or may cause actual metal release from the surfaces (with harder surfaces)
3. Fatigue	Occurs when impacts between surfaces gradually cause fatigue damage to one or other of the surfaces	This may happen due to direct impact or from rolling and sliding producing a repeated alternating stress. The impacts may be due to cavitations
4. Tribochemical	Occurs due to the presence of a chemical in the oil or atmosphere which causes metal deterioration of the surfaces	The other three types of wear may also be involved

Table 1 Types of wear

To analyze the amount of wear one can use wear debris analysis. One must analyze the oil and then get the quantity of wear and the shapes of wear, telling us about the cause of the wear. Table 1 shows some of the most common types of wear and why they occur. This method is more accurate then the vibration monitoring, but then again more excessive. The quantity of wear will follow a bathtub curve, like in figure 7, where in stage 3, one need to have a plan ready to do maintenance on the equipment.

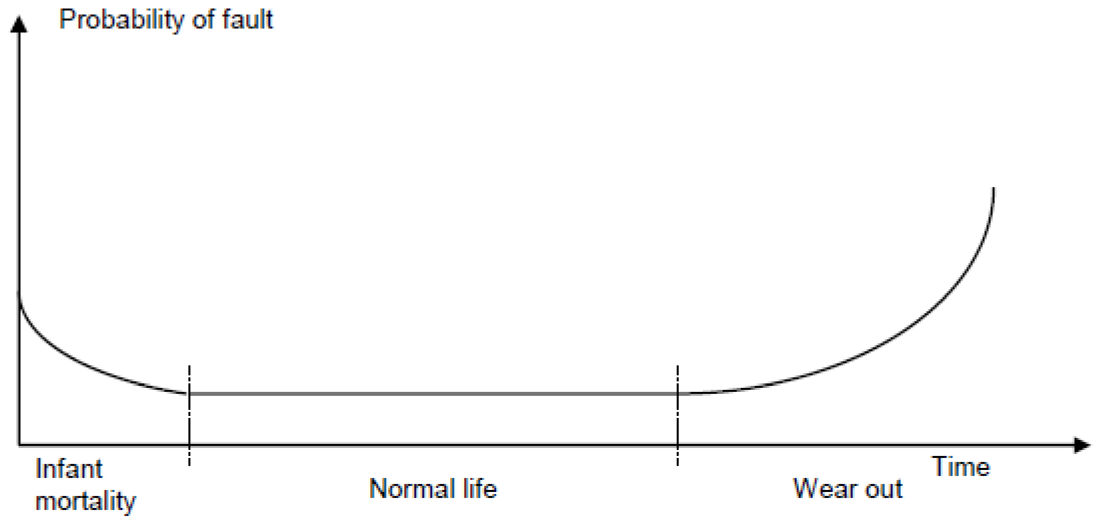


Figure 7 Bathtub curve (Heggeland, 2012)

As mentioned lubricants can slow down this process and increase the lifespan of equipment, but it is important to choose the right kind of lubricant. Table 2 gives a short overview of which type of lubrication based on different parameters.

“Select the lubricant oil that is thin enough to have a low internal friction yet heavy enough to separate the metal surfaces.” (Verma, 2015)

Viscosity	**Pressure**	**Speed**	**Temperature**
High	Heavier	Slower	Higher
Low	Lighter	Faster	Lower

Table 2 Lubricant viscosity

One way to do lubrication oil analysis is to check the viscosity. Viscosity is a measurable fluid condition and can then easily be monitored. It is the most critical physical property of oil. An increase in viscosity is more tolerable than a decrease in viscosity. There are limits of change in viscosity which lubricant vendors will provide. (Shreve, 2003)

2.9.3 Non-Invasive and Destructive Testing

Non-invasive testing together with Non-destructive Testing (NDT) is used to determine the integrity of a material, component, structure or quantitatively measure some characteristic of an object. There are many different types of these kind of testing, but in this thesis, some of the most common will be presented.

- Visual

This is the most basic and common inspection method performed by the operator offshore. Tools include fiberscopes, borescopes, magnifying glasses and mirrors. This method has a narrow detect ability, but it is cheap because there will always be operators on the platform.

- Acoustic Emission

Acoustic emission is defined as the science that deals with the generation, transmission, reception and effects of sound. It is the detectable structural or air-born sound that can manifest itself as a signal on mechanical objects. The pressure waves associated with leaking vapors or gasses, or the humming of electrical equipment. Acoustic monitoring can filter background noise which makes them more sensitive to small leaks than the human ear, and can detect low-level abnormal noises earlier than conventional techniques. They can also be used to identify the exact location of an anomaly. (IAEA, 2007)

- Thermography

Thermography, also called infrared, is used to detect unwanted temperatures from all kinds of equipment. There are three sources of thermal energy that can be detected from any object:

  - Emitted from an object
  - Transmitted by the object
  - Reflected from an object

Only the emitted energy is of importance for condition based maintenance. All objects around us emit heat or infrared electromagnetic energy which is invisible to the human eye. Objects above absolute zero temperature will emit energy. In order to see the energy being emitted, an infrared camera must be used. The camera detects the thermal energy and converts it to a visible image, which then allows the thermographer to analyze the image. This method is also very cost effective. The advantage of thermography allows one to quickly locate and monitor, in real time, both maintenance and production problems. Modern thermographic equipment can allow effective scanning and problem detection of very difficult problems. By being under NDT it may be performed with equipment in service at normal operating conditions. (Shreve, 2003)

- Working hours

From PM, working hours is an important factor to monitor with the use of counters. From analyses and experience, one is given a number of working hours before failure an equipment reach failure. When the number is getting closer, one simply plans maintenance. This method is cheap and effective, but it doesn't tell anything about the condition of the equipment. To monitor how many working hours is a crucial part, where one can use the achieved data to analyze, plan and improve maintenance. (Oltedal, 2016)

- Ultrasonic Emissions

Ultrasound is the use of sonic energy at frequencies exceeding the human audible range of 16 kHz. The ultrasonic energy is a form of mechanical energy excited by a piezoelectric, magnetostrictive methods, electromagnetic, acoustic transducers or laser. Mechanical shockwaves are transmitted from probes into material, producing an effect similar to striking an object with a hammer. The quantity of reflected energy is dependent upon the acoustic impedance between two materials.

An airborne ultrasonic device can be an effective, integral part of the equipment utilized by the predictive maintenance program. Ultrasound detectors complement the infrared instruments for routine surveys of electrical equipment. While thermography allows technicians to detect light that the eye cannot see, ultrasound allows them to detect sounds that the ear cannot hear. Using ultrasonic instruments, the maintenance personnel may identify the presence of a problem in the equipment and pinpoint its source. Most equipment involves the use of headphones and filters which make the ultrasonic frequency range audible to the human ear. (Shreve, 2003)

- Radiographic

Radiographic testing is based on x-/gamma rays ability to pass through solid objects. If x-rays or gamma rays pass through a solid, dense, object such as metal, then holes and less dense material enclosed within the metal will attenuate less radiation than the metal itself, while more dense inclusions will attenuate more. It is a very good method for detecting volume defects, pores, cracks, corrosion and thickness changes. Some disadvantages of the radiographic testing are the radiation which is dangerous for the health of personnel. (Verma, 2015)

2.10 Criticality class levels and analyzes

With the operational philosophy in mind, TEPN have established different criticality class levels. These are made to categorize the equipment that is going to be used based on the important factors and objectives described in the philosophy.

Beneath are the different levels established and their definitions:

Criticality class levels	Definitions
V=Vital	Equipment the failure of which immediately causes a loss of production or decreases the level of safety. Vital equipment should operate on demand and maintenance should be designed to provide this level of reliability to avoid unacceptable exposure to hazards or major incidents. Corrective action on 24-hour basis Vital Equipment spares to be immediately available
C=Critical	Equipment the failure of which increases the risk of production loss, might affect the environment or is necessary for health and general welfare of personnel. Equipment which is in a duty/standby arrangement or more generally which requires more than one equipment failure before any significant loss of production. Equipment that requires urgent attention on failure, dependent on operational need and standby availability. Critical equipment spares shall be ordered on a priority basis, however long lead items, such as strategic or insurance spares, may be held
S=Secondary	Equipment the failure of which does not affect the production, safety or the environment and has limited commercial impact. Equipment does not require urgent attention on failure. Secondary equipment spares ordered as required.

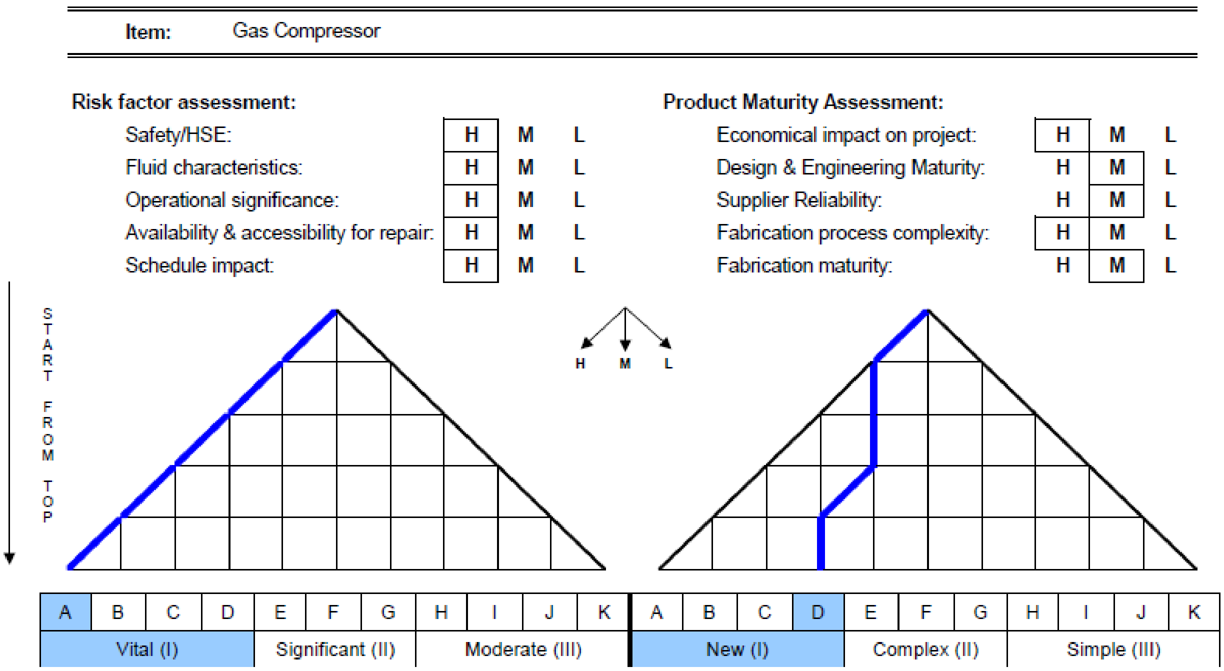
Table 3 Criticality class levels (Total E&P Norge, 2012)

The different criticality class levels require different types of condition monitoring. Vital class would need excessive condition monitoring of known failure modes, because the consequences of failure can result in unacceptable events and losses. The critical class would need a lot of condition monitoring too, but not in the same degree. By only monitoring the most common and most crucial failure modes, the equipment would be well covered in a cost-benefit point of view. Secondary class level equipment won’t need much condition monitoring, where the failure modes has a limited affect. A reason may be because of redundancy, and maybe because they are fixed through corrective maintenance. The maintenance philosophy states that only 10% of all maintenance should be corrective maintenance, so one would need to control and estimate if almost no condition monitoring on secondary class level equipment would exceed these 10%.

To categorize the equipment into these class levels, one is needed to do a criticality analysis. In the analysis one observe crucial factors for each component, like HSE, Production and Costs. The maintenance philosophy tells us which these are, but these three are often among them. For Martin Linge, HSE and Production are the most important. If a failure in a component drastically reduces the production, this one will automatically set in the criticality class level, vital.

Figure 8 shows an example of a class selection procedure, by using the criticality analysis. They first divide the factors into two main categories; Risk Factor assessment and Product Maturity Assessment. Under each category there are five factors that will decide the class depending on the criticality of each factor. When this is done, they then put the output into the Overall rating matrix. In this example, the rating is 1, because a gas compressor is obviously a very important component in the system, which is costly to lose and replace, and hazardous to the personnel and environment if a failure occurs.

There are many methods to do the criticality analysis, again depending on the maintenance philosophy of the project. Most of the equipment is a logic matter and are easily put in the vital class level, but to reduce costs, one would want to put as much as possible in the secondary class level. That is the main objective of the analysis; to maintain the production and safety high, while keeping the costs low.



Overall Rating

	Risk Factor		
Product Maturity	**Vital (I)**	**Significant (II)**	**Moderate (III)**
New (I)	*Rating 1*	*Rating 2*	*Rating 3*
Complex (II)	*Rating 2*	*Rating 3*	*Rating 4*
Simple (III)	*Rating 3*	*Rating 4*	*Rating 5*

Figure 8 Criticality analysis (Total E&P Norge, 2012)

2.11 Planned condition monitoring systems for maintenance

To gather, store and analyze the information acquired from the equipment which is monitored, there is a need for systems to manage these in an efficient matter. TEPN already have purchased and planned to use given systems as a part of their maintenance strategy. By using different types of counters, strategically placed, the plan is to acquire the right data and measurements to be shown on an interface when needed. Some of the systems which is planned to use, and which is going to be elaborated in this thesis are PI, Smart Signal, SAP and SCOTT.

2.11.1 SAP

SAP is a German multinational software corporation that makes enterprise software to manage business operations and customer relations. TEPN is planning to use different types of software to remotely monitor the equipment and communicate through SAP with contractors to plan maintenance orders. SAP is software commonly used by companies, and makes it a good tool to communicate data efficiently.

2.11.2 Process Information

Process Information, also called PI, is a system made to store and gather information. It is like a manifold with storage capabilities gathering historical data. Figure 9 shows how the CM-platform is for ML and one can see that PI is a central system binding all the other systems together. Previously it has been used for process analysis only, but is now implemented into CBM. To more efficiently analyze the different equipment and their streams of data, other systems are also implemented. Some are better to analyze vibrating equipment, and other is better to analyze temperature or flow. The implementation into the SAP system is doable where it already have been done something similar in Mexico by PEMEX. (Muro, 2007)

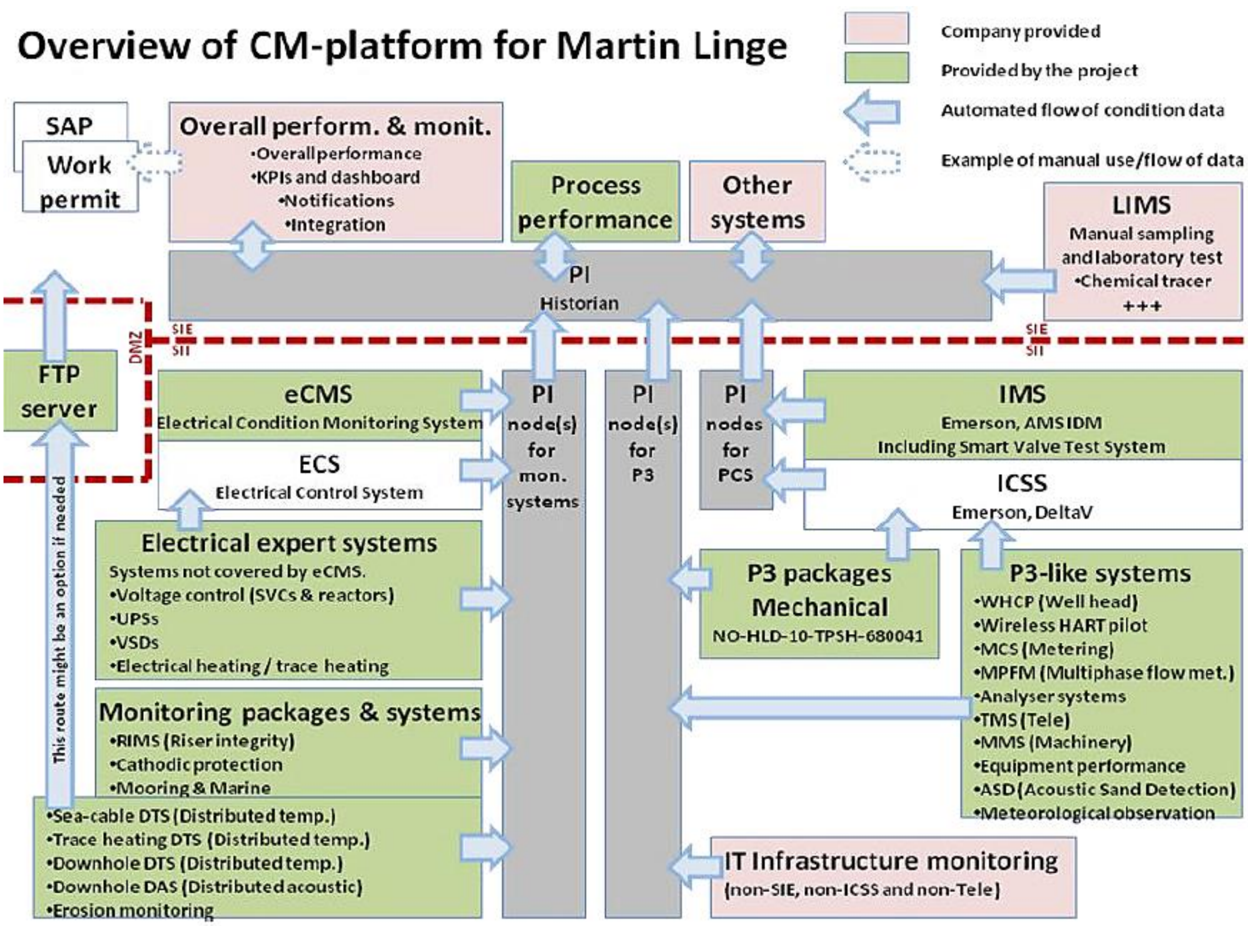


Figure 9 Overview of CM-platform for Martin Linge (Total E&P Norge, 2012)

2.11.3 Smart Signal

Smart Signal is a predictive analytics software, made by GE, which can identify what is going to fail, what is the apparent cause of the failure, and what is the priority of the impending failure. This system helps one do this automatically, continuously, and relentlessly, 24/7, for optimized asset performance management. "SmartSingal's predictive technology and SAP for Aerospace and Defense are complementary to one another and will provide companies with a unique competitive advantage," states Peter Goebbels, vice president industry business unit aerospace & defense, SAP AG. (Kerastas, 2003)

2.11.4 SCOTT

The personnel offshore have the need to have the necessary information available at any time, and with SCOTT this may be possible. SCOTT is a monitoring system made for portable equipment like a tablet. The software will get the information from PI and will merely be for visual purposes and not to adjust the monitored equipment. Then again SCOTT will be able to send maintenance order to SAP when an alarm or possible failure is noticed. Which parameters to be monitored and how often to update the information is a maintenance management issue. Rapid updates will possibly result in many unnecessary alarms, and vice versa. (Carpentier, 2016)

2.12 Key Performance Indicators and Visual Management

The term Key Performance Indicator, also known as KPI, is a quantifiable measurement which help an organization to define and measure progress of their goals. When an organization have done a solid analysis of what the mission is, who the stakeholders are, and which goals to achieve, there is need for a simple way to measure and monitor objective progress, and that is where KPIs come into the picture. Depending on the organization, the KPIs designation will differ. A business may have a KPI over the percentage of its income that comes for return customers and a school may have KPI on graduation rates of its students. (Reh, 2015)

Visual management (VM) is the process of displaying information such as KPIs that relate to production output, efficiency and quality. By displaying data on the facilities, personnel have a better overview to see which equipment is and isn't meeting the wanted expectations. It provides a better easy access monitoring of performance and the possibility to determine, in real-time, areas that may need improvement. The result would be a drive to increase efficiency, quality and uptime. (Red Lion, 2015)

3 Methodology

The thesis involves relevant information which is gathered through different means. The information will be used to make the planned analysis's, which in involves literature studies, internal TEPN documentation, academic journals from the University of Stavanger (UiS) and discussions with external supervisor and other employees with key knowledge on the subject. This gives an understanding of ways to do CM, the different maintenance strategies, and the TEPN goals and philosophy which is planned for ML.

To carry out the given objectives, the operational and maintenance philosophy was used as a ground basis of what TEPN want to achieve through the ML project. Their plan was to implement CBM, and to see if the planned processes and goals are achievable and which improvements that can be applied. By using observations and discussions one gets an overview of which processes are more questionable then others. This method of analysis was the most effective where the qualitative information earlier gave useful results.

Through meeting activities and benchmarking, the qualitative information was getting more reliable where these gave a real-time look into the planned, executed and improved processes. Some quantitative information was also required from the book OREDA, which was used to analyze future equipment behavior.

4 Implementation of condition based maintenance

When implementing new processes there is often some obstacles and with CBM these will also present themselves. To give an overview over what is important to consider, some guidelines will be presented. The process is not to go from traditional time-based (calendar and/or run hour) maintenance to CBM, but to find a suitable mix to optimize availability, reliability, and decrease cost and working hours offshore. This mix will evolve and improve over time, and is elaborated in chapters 5 and 6. New technology has enabled the CBM to get at larger part in the maintenance strategy, where CBM requires new systems, tools and equipment to be beneficial to the organization.

4.1 Necessary conditions for implementation

To successfully implement a process, some conditions may be necessary. The need for culture changes and change management are typical ones. It requires commitment from all personnel including management. The staff must commit to the process and its new technologies. They also need to trust the training and the technology, which the management must commit to procure. All groups in the organization have to be on board and take ownership to achieve success. Management can reinforce the expectations and must maintain the commitment throughout the organization.

One of the reasons why many CBM efforts have not been successful is the lack of a well-defined implementation strategy. When new technology is acquired and new procedures are established, it has to be implemented into to the affected parts of the organization. Change management is important for the implementation because the organization may experience large changes in the process. The implementation strategy should include all of the organizations planned activities and factors which are needed to complete the CBM implementation process. These may include technical aspects, work processes, management aspects, training, and responsibilities.

4.2 Benefits of controlling oil & gas installation onshore

All of the oil & gas installation in the North Sea are controlled from offshore on the installation itself or from a neighboring installation. In the last years a new strategy has emerged to move the control function to an onshore location. This has an effect of the offshore manning requirements and subsequently operation and maintenance costs. The new strategy also includes that the offshore installation will not only be controlled from onshore, but also will get its power from an onshore power facility. The benefit from this is that the installation offshore now has no need for local power generation and will eliminate a lot of vital classed equipment such as gas turbine driven generators, which decreases total CM tools, and maintenance costs. There will of course be the use of CM tools on the onshore power sub-station, but as this is located onshore this will normally be cheaper to install, operate and maintain. These changes in operating strategies make the implementation of CBM more likely to succeed and achieve its true potential.

4.3 Process guideline and further analyzes

Figure 10 shows a guideline to implement CBM. It has to pass through all of the levels and one often initiate with a cost/benefit analysis, which tells us if it is profitable to implement. Since this is getting implemented more and more into the oil and gas industry, this is the case and many of these levels already have been carried out, and some are in the process of execution. The Martin Linge project is at this phase, and has come far in the implementation process. It will be exciting to then see the continued process, but also to see what results they have achieved.

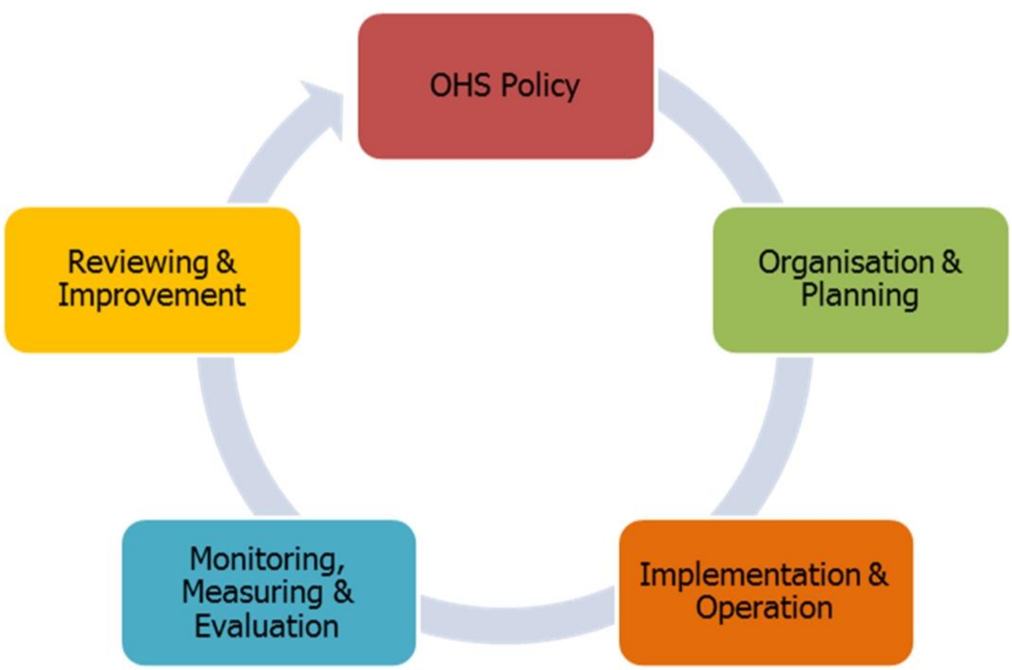


Figure 10 Implementing CBM (CBM HSE, 2013)

In the next chapters there will be a focus on the continued process. In figure 10 this will be equivalent to the posts “Monitoring, Measuring & Evaluation” and “Reviewing & Improvement”. The Martin Linge project will be used as an example in this thesis to see if the wanted utility, out of their planned processes, is achieved and how they measure these so the possibility for continuous improvement is available.

5 Optimization of the utility of condition monitoring

To optimize the utility of CM there are many methods where some will be elaborated in this chapter. A major one would be to know where to use, and when to use CM. To decide this, one would need some historical data to observe the lifetime cycle of the different equipment. If the variation in time between potential failures is large one would need to apply CBM and then increase the utility of CM. Then again if the variation is small or there is redundancy, there would not be need for CBM, because one can already predict when equipment needs maintenance. Then it would be more efficient to use PM on this equipment. The issue here is that one can't know for sure if the CM is sufficient or unnecessary until some historical data is received. From the company delivering the equipment, one should then get a data sheet like the handbook Offshore Reliability Data (OREDA) with given information as, expected lifetime cycle of the equipment, the variation of this cycle and which failure modes that may occur. It is important to point out that this information is not accurate, but may be used as guidelines in the startup phase.

5.1 Example: Closed Drain System

To analyze how to optimize the utility of CM one can look closer to one of the many systems on a topside platform. The system chosen in this thesis is the closed drain system where mainly hydrocarbons are running through. This system also goes by the name of hazardous drain system because of the hydrocarbon gases. A closed drain system is as a separator system, but it is used to acquire the spill from the regular separation process and retrieve more oil and gas from it. The system in figure 11 is an example of a closed drain system from the Martin Linge project and is used to do part of the analysis. The figure is only a cutout of it. To view the whole system, look at Appendix.

There are 3 separators in the main separator system which will send their spill to the closed drain system. As mentioned, this system works as a separator and have the same purpose. The resulting oil and gas will be sent back to the 3rd and last stage separator.

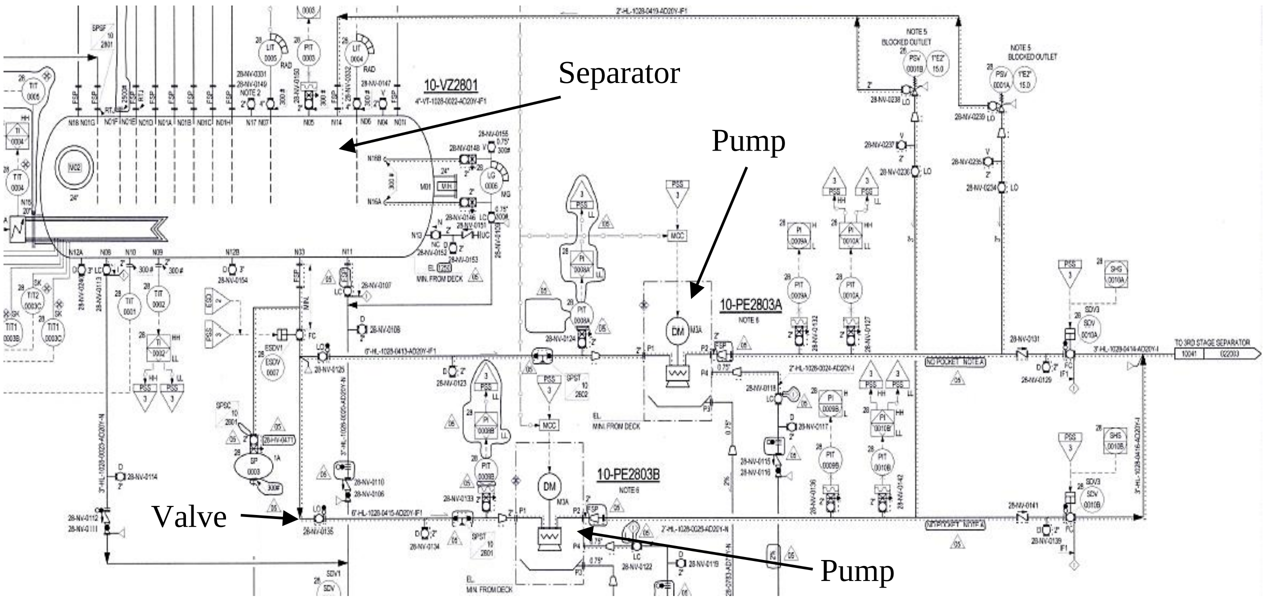


Figure 11 Closed drained system (Total E&P Norge, 2012)

5.1.1 The procurement process

With the spill entering the low pressurized closed drain system, and entering the separator, the system will start heating up the liquid to flush out the gas in the separator. The oil will then be separated from the water and pumped through dedicated pumps to the 3rd stage separator.

5.1.2 Recommended strategy for maintenance

Pressure, temperature, volume and wall thickness are the main parameters in this system. The system itself has been given the low criticality class level secondary because it will not have any major effect on production or HSE except for loss of containment. If the system is down, the drained liquid is stored in the separator, and if the stored amount exceeds a given volume, the gas will be flared. The remaining liquid will be stored. This means that corrective maintenance may be the most economical strategy for the system, which includes the separator, pumps, piping and valves. The parameters which are most important for maintenance are current liquid volume in the separator, and the wall thicknesses. Corrosion and erosion can decrease the wall thickness, and it may happen in every part of this system. This is normally a slow degradation process. The use of calendar-based inspection by an operator offshore, as a part of their routine, with a handheld ultrasonic equipment, will then be the most efficient solution where the wall thickness is designed with margins. The minimum wall thickness should already be established by the vendor and including an estimated “need for maintenance” margins given through a safety factor. With this information it is possible to do CBM on this system.

There are two dedicated screw pumps in this system which is pumping the oil to the 3rd stage separator. The pumps are not working simultaneously to give it redundancy by the use of a sparing strategy. The main parameters for the pumps should be working hours and in/out pressure. By monitoring the pressure on both sides of the pumps one will be able to follow the performance of the pumps, and a decreased performance will indicate the need for maintenance. Because of the redundancy one can have one of the pumps run till it fails and then switch instantly to the second one. The period to failure can be long, and having the redundant equipment just in stand-by can be damaging. By using a 4-2 active period one would use both pumps where the primary pump will be on 4 days/weeks/months and 2 off. When the primary pump fails, the reliability of the other pump is much higher, and then run for twice as much working hours then it already have been through. This gives the possibility to apply corrective maintenance on the pumps without any major disadvantages.

The valves in this system are both manual valves and automatic valves. The automatic valves should have in/out pressure, torque and actuating time monitored to see if they operate as supposed to. To have corrosion inspection will also be necessary, but may be applied to the operator routine. One can also monitor working hours for the valves, but is not a necessary measure. Similar to the pumps, if there is an error, it will not be crucial to any major attributes because of the storage capabilities of the separator. There are a number of valves in the system, which should be standardized. This may result in a simple process to switch valves or to do maintenance when necessary. The manual valves can also be pressure monitored and maintenance will mostly be proactive open/close maintenance done by operators in their routines.

5.2 Systems in general

In the example presented, corrective maintenance strategy is sufficient because it has low to none consequences for production or HSE. The maintenance philosophy of Martin Linge states that only 10% of all maintenance is going to be corrective. To meet the philosophy one will in general need to focus more on CBM, resulting in increasing the utility of CM. There has been made a criticality analysis for all of the equipment, but to also do this with the systems may be an idea. Depending on the criticality analysis of the system one can see which maintenance strategy to use. In the example, the system is deemed secondary, since it is not crucial for operations. In this case CBM may not acquire the wanted potential of CM. The criticality analysis is then an important factor in the optimization process of the utility of CM. One can make a maintenance selection sheet to decide which strategy to use depending on the criticality given in figure 12:

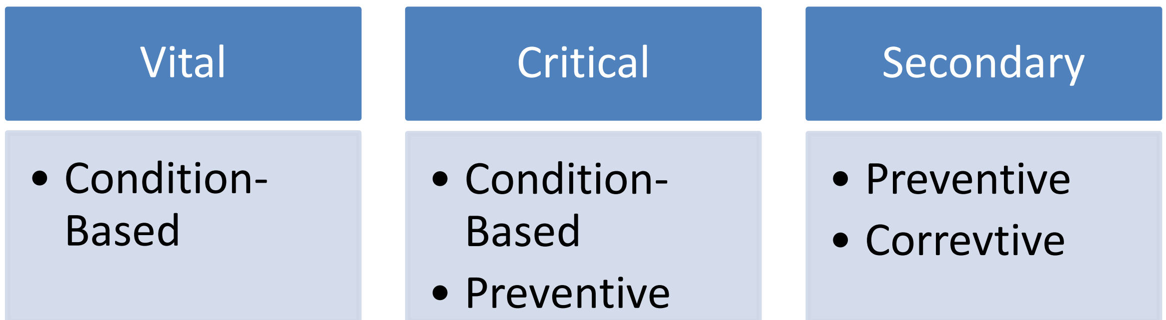


Figure 12 Maintenance selection sheet

When a system is vital, one should mainly use CBM to both fulfill the maintenance and the operational philosophy of Martin Linge. As mentioned one cannot know the equipment life span right away, so one should use CM to retrieve data and use PM to the point one know the equipment well enough to trust it and the CM tools. This is to minimize possible accidents and downtime in the start phase. What is to be recommended, in the light of the given philosophy, is then to take safe measures within PM and have short intervals, and to increase the intervals in time. By doing the opposite one will take the risk of equipment failing before planned maintenance. Of course this will give one a milestone and much faster find the limits of the equipment. Then again, it may result in major accidents and downtime.

5.3 Organization strategy

With equipment criticality classed and factors acquired to best monitor each, one is still missing something. How should an operator organize themselves to best integrate CBM, because the procedure is a different one from the traditional PM. The maintenance philosophy states that maintenance should be done through campaigns. Then there will be a need for procedures to simplify this process and an organizational structure to best strengthen them. These questions should be answered as soon as possible when a fault is detected:

- What is wrong?

- What is its criticality class level?
- Do we need to fix it?
- Who can fix it?
- When can it be fixed?
- Why did it go wrong?

The two first questions should be answered instantly. The other four is dependent on the maintenance contractors. If one already has a contract and communication established this would make the process much faster.

5.3.1 Organizational structure

Since the installation is controlled from onshore, a new organization structure should be applied to best integrate the new strategy. One would divide the organization into three cross-functional teams named, the offshore platform team, onshore support team, and the campaign team.

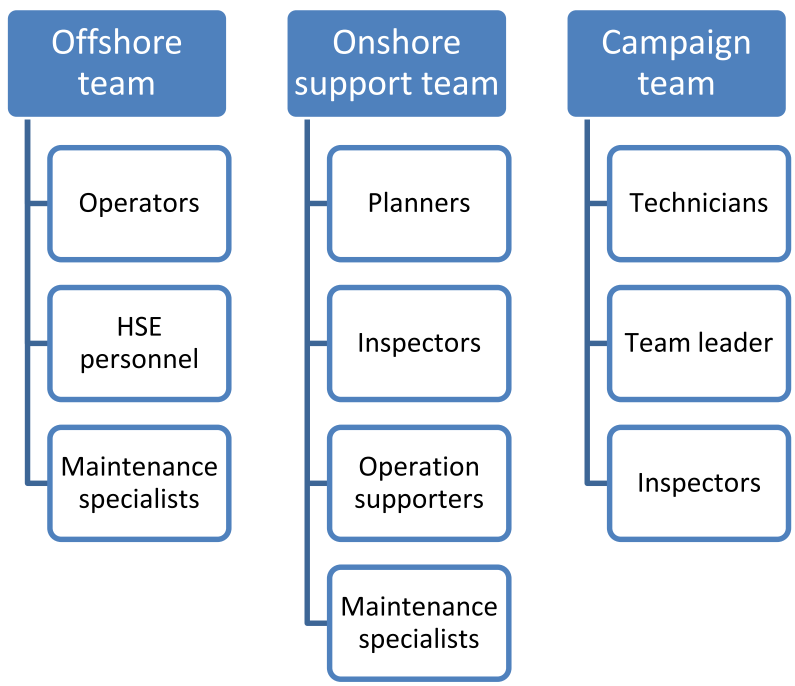


Figure 13 Overview over preferred personnel in each team

Figure 13 gives a hierarchal view over which personnel that should be included in each team. Both the offshore platform team and the onshore support team should mainly be employees of the operating company and some from a maintenance service contractor. The campaign team should be the opposite, meaning mainly contractor personnel. This would result in a relocation of many offshore personnel to work onshore instead. One of the reasons campaigns are used, is to eliminate the need for flexibility of the offshore personnel. If the criticality of a fault is secondary, then it will be set to the next campaign, if possible, instead of the maintenance done by those offshore. There would of course be the need for good communication between the different teams for this structure to work properly. The use of personnel permanent offshore and onshore, hired by contractors will ease the communication between the offshore platform and the incoming campaign, resulting in maintenance with decreased MTTR and reduced down-t

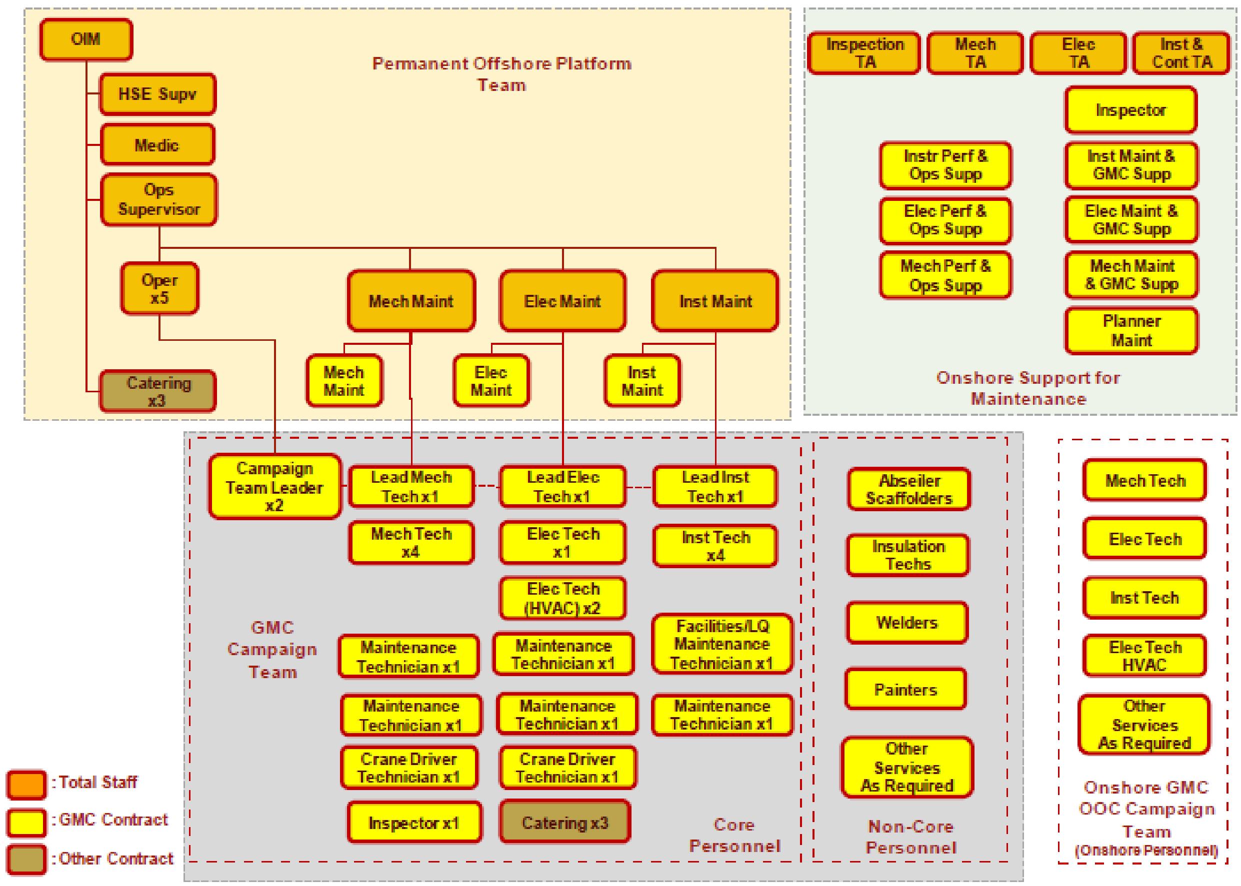


Figure 14 Planned organization chart for Martin Linge (Total E&P Norge, 2012)

To compare the team overview presented in figure 13 to what TEPN have planned would be interesting. Discussion and research led to figure 14 which show the planned organization chart for maintenance for Martin Linge. The idea is mainly the same to some extent, to divide the organization into three teams. One of the differences is the two-divided campaign team, which may have a positive effect on the MTTR. The color represents if the personnel works in TEPN or hired by contractors. There is a permanent offshore platform team which is mainly manned with TEPN staff, and a campaign team mainly manned by the General Maintenance Contract (GMC). This way Total won't need the expertise from the contractor before planning a campaign. The onshore team is also manned by the GMC, but won't need the whole support team until planned campaign starts. This follows the manning strategy given in the maintenance philosophy for Martin Linge, but by having few personnel offshore halts their flexibility since they already have their tasks and stations. One of the reasons campaigns are used is to eliminate the need for flexibility of the offshore personnel. If the criticality of a fault is secondary, then it will be set to the next campaign, if possible, instead of the maintenance done by those offshore.

5.3.2 Procedures for detected errors

As soon as an error is detected, one should go through a procedure to efficiently get an overview over which changes are needed to be performed. Figure 15 gives a brief example of a procedure given the fact that the GMC already know the equipment, and how to do maintenance.

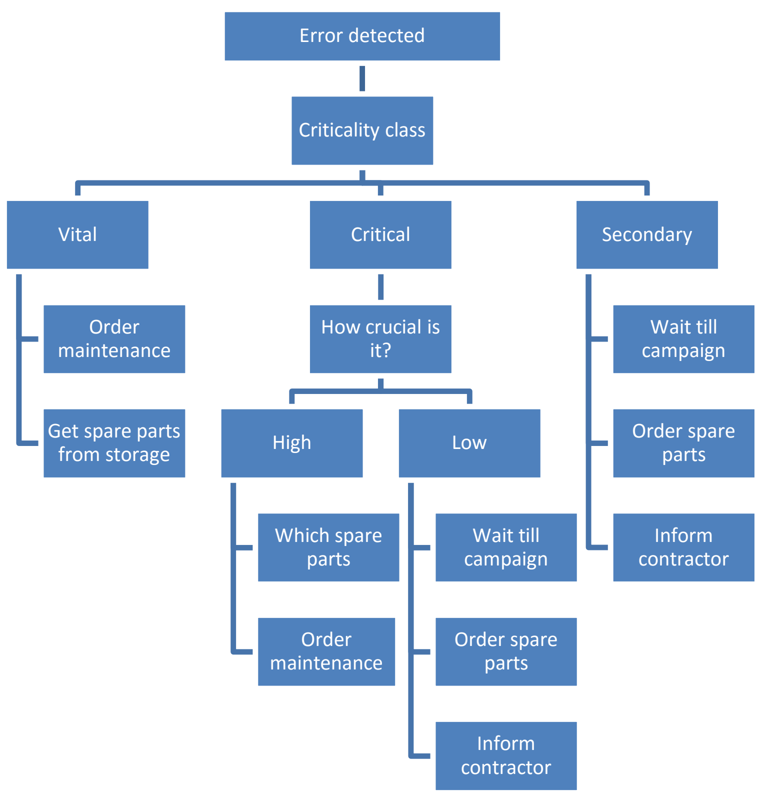


Figure 15 Procedure for detected errors

Having one procedure for all equipment wouldn't be sufficient. Procedures would vary over which kind of equipment it is and what the failure modes it might have. If the failure mode is high frequency vibration or high temperature, one could reduce effect by not having the equipment on full throttle to increase the time before failure, etc. These various procedures should be set into the common system already installed at the company. For TEPN the system is SAP, where all maintenance are planned and sent from, to the contractors. If this is done properly the maintenance planning would go swiftly, and reduce the planning period. To make reliable procedures one would first need to know the equipment and get experience over time. Continuously improvement of the procedures is essential for the planned strategy to work properly.

To have spare parts ready and available for replacement is an important matter that will decrease the time from planned to finished maintenance. The maintenance philosophy for Martin Linge states that the contractors are in charge to supply spare parts, but if the spare parts should be stored or not is up to the operating company. The general strategy for TEPN is to store spare parts split between offshore and onshore warehouses, but store offshore spares for vital and critical equipment except heavy or large spares. To manage all the spare parts and have control on what is ordered or in storage it is planned to use SAP. Through this program one can monitor the inventory, and know if the upcoming campaign has the needed parts. As part of the procedures the spare parts strategy should also have continuously improvement, since the storage costs could be reduced by having more spare parts stored onshore instead of offshore or by minimizing the amount of spare parts in general.

5.4 Integration of condition monitoring tools in a common system

To get the procedures more efficient, it is planned to have all CM tools sending data to the same system that already are implemented in the rest of the organization. There may be a problem with the conversion of data from the tools to the used system. By using few systems, one would minimize cost of software and training. Figure 16 is a simplified hierarchy of figure 9 in sub-chapter 2.11.2 about PI. The information retrieved is collected, stored, analyzed and directed to the contractor. With few systems, the reliability of the systems may decrease. An alternative would to mitigate the risk into different systems and software, resulting in an increased reliability of the systems.

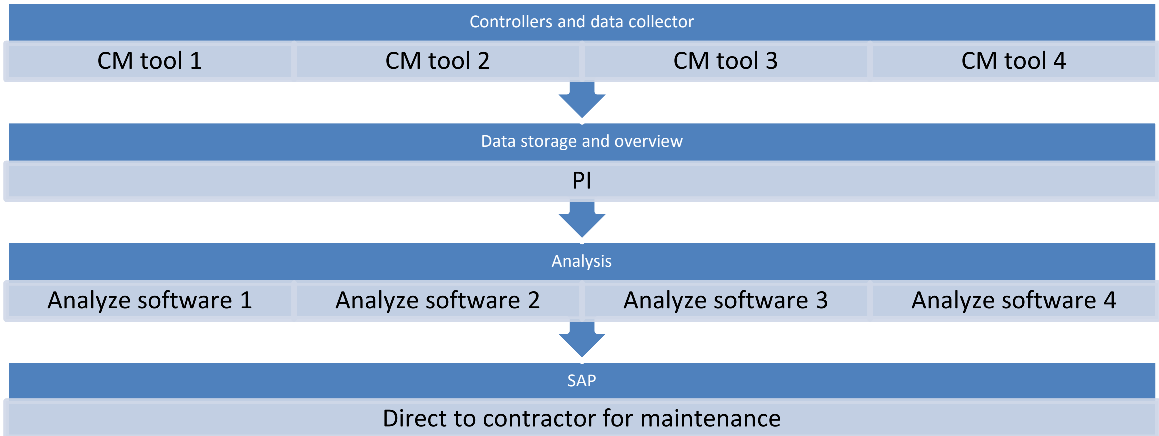


Figure 16 Hierarchy of planned systems and software

5.5 Detection strategy

With all the CM tools installed and the onshore operating centre (OOC) receiving data, one should have a strategy to detect possible failures. The received data will be plotted into a chart like figure 17, so one can view the condition of the equipment. There will be a lot of variations, which can give false signals. One should then have an upper caution level (UCL) and a lower caution level (LCL). If these limits are exceeded, one should be warned. It doesn't mean that a failure has occurred, but it might become one. The warning would say to be cautious, but not to act. Then there could be one more level called the action level (AL). When data reaches this limit, actions should be initiated.

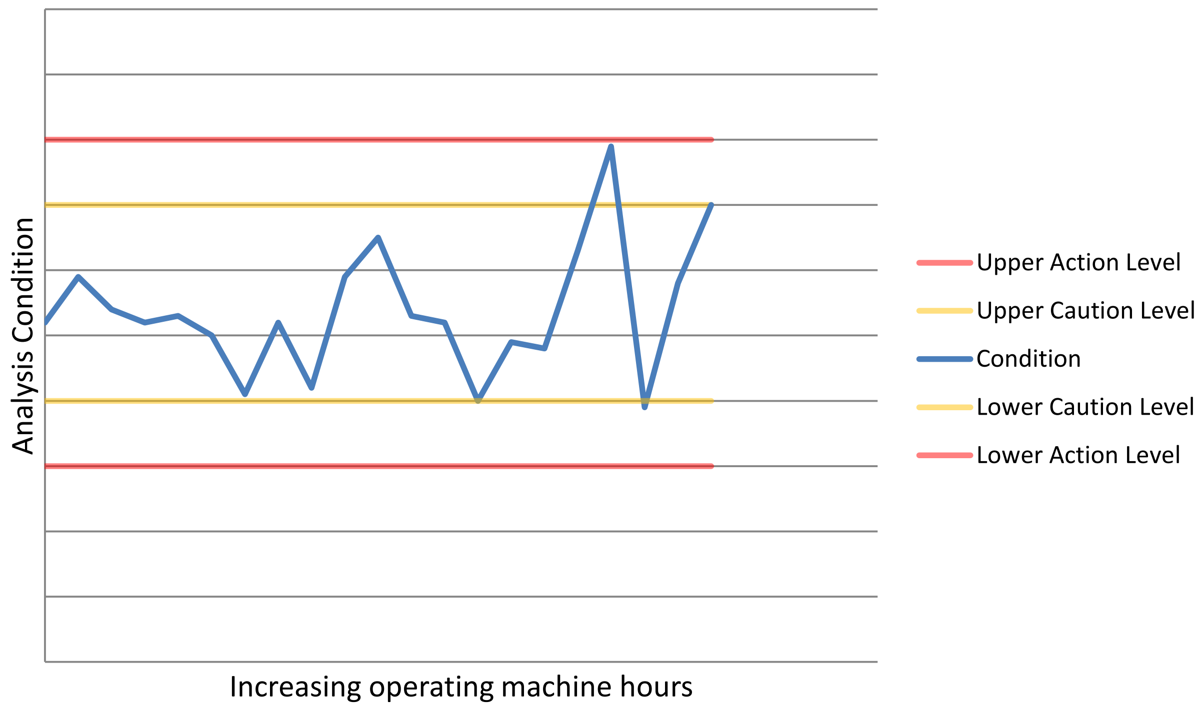


Figure 17 Condition analysis chart

How reliable these limits are, can and must be evaluated. Maybe the levels are too high or too low, but one can't be sure after some time and experience with the equipment and tools. The objective is to have as little downtime as possible, and then it is crucial to not be exposed to extensive failures. To have a low caution level, and low action level will result in too many warnings and too much maintenance. To start with a high caution level can also be a mistake where it probably will result in a lot of corrective maintenance. By starting with a medium action level the result will be a more cautious behavior, but not acting instantaneously on warnings. After getting to know the equipment and its behavior, one will probably exceed or lower the limit.

5.6 Standardized Reporting

When an error is detected there will be a need to report it. The report should include where, when and why the error occurred and how it was fixed. This is the information needed to take an assessment to see if this is a known error or an abnormal event. To make it easy for everyone to extract the information from the report, it should then be a standard reporting system. The standard report should have a simple layout and be easily available for both personnel writing a report or searching for a previous one. With this kind of system, one will achieve a better overview of all errors that has occurred and can then be easily presented to management or for other purposes.

5.7 Contracting issues from condition based maintenance

The contracting strategy has a big influence on cost and is an important issue to have in mind when implementing CBM. When one is moving from PM to CBM, it will have a negative effect on the contractors doing the maintenance. They will lose their fixed maintenance schedules, income and amount of working hours. The contractors must of course follow what the customers want, but at what cost? A natural result of customers implementing CBM will be increased fixed cost to the contractors, since the amount of work to be done by the contractors may vary. In the long run the wanted result will be less maintenance then with PM, and it will be in total a lower maintenance costs for the customer. The process to make contracts that will have this result will be necessary, and to discuss with different contractors to get the best contractor from an economical point of view. Then again is cheap necessarily the same as good enough? It depends of course. One must consider that this is false and realize that in the short run, such a contract will be good, but in the long run notice that maintenance cost and production losses increase because of a not well performed maintenance. In the planning phase of the project one may have a contractor that is analyzing what to be monitored and a recommendation of how often the equipment should go through maintenance. If the same contractor is doing the maintenance in the operation phase, they will of course recommend a lot of maintenance to be done. By awarding the maintenance contract to different contractors, it may have none, or give the opposite effect. To win the contract they could decrease the recommended amount of maintenance. This may result in reduced maintenance costs. Other compensation schemes can be evaluated. For instance the contractor can be compensated based on system availability.

6 Continuous improvement of condition monitoring

As mentioned, one of the reasons condition monitoring is implemented is because to increase both reliability and availability, and decrease the long-term maintenance costs. With Martin Linge being a new installation with new equipment, one can predict equipment habits, but not be entirely sure. A part of the optimizing process is then to do continuous improvement of the CM system, and the CBM strategy. To locate the need for improvement, one would then need to measure progress and compare it to the planned goals for the implementation. Continuous improvement has also shown its effect on maintenance strategies through time. Figure 18 shows how reliability and performance increase with the different strategies. How one may apply continuous improvement will in this chapter be elaborated and presented.

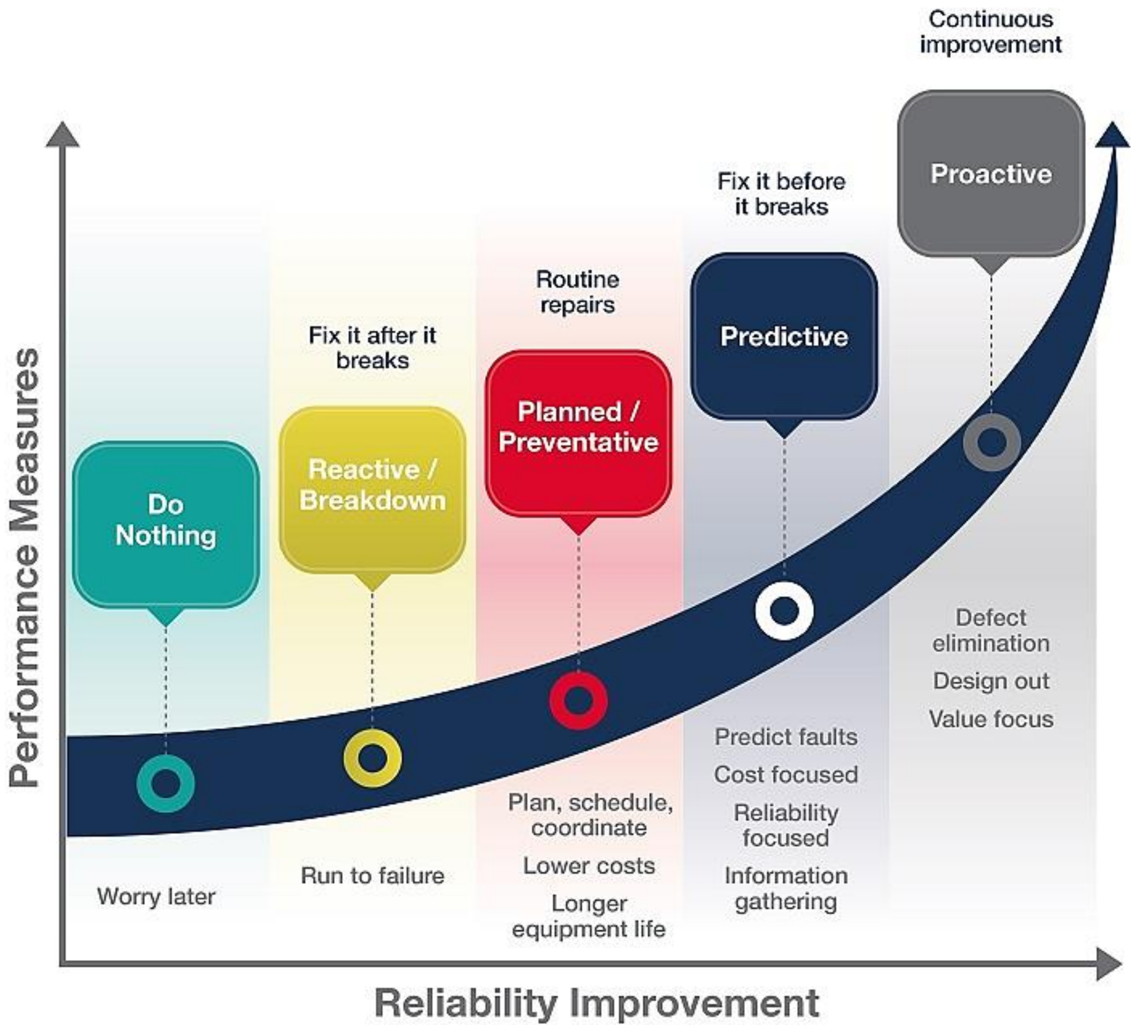


Figure 18 Maintenance strategy performance measures (Gales, 2015)

6.1 Monitoring the efficiency of Condition Based Maintenance

To monitor the efficiency of CBM, one can evaluate the implemented maintenance strategy and make improvements if necessary. Some tools that may be used for efficiency monitoring are Key Performance Indicators and then implement the tools into Visual Management, which will be presented and discussed further.

6.1.1 Using Key Performance Indicators

As mention earlier Key Performance Indicator, also known as KPI, is a quantifiable measurement which help an organization to define and measure progress of their goals. With the use of the maintenance theory for Martin Linge some goals have been extracted to be used as examples. How these goals could be monitored will be elaborated.

In the maintenance philosophy of ML, it is said to achieve a total of all work orders to be 60% CBM or more. To measure this, each work order can be stamped as the given maintenance strategy. Then at specific intervals see if this is matching the philosophy. If it during six months only have a work order rate of 20% CBM, improvements have to be made to achieve the given overall goal of the philosophy.

Another KPI important in the eye of the maintenance philosophy is a HSE indicator telling us the number of recordable incidents. This should be done manually, by reporting the incidents and getting them registered. The target number is of course 0 incidents. If an incident occurs, it should not be tolerated. A proactive solution needs to be established so it won’t happen again. This KPI may be presented monthly to get the best results. If it is presented yearly showing 4 incidents, but 3 of them have the same origin, 2 of them could have been stopped.

To monitor the availability of the installation would also be an important indicator because one of the objectives for ML is to reduce the amount of downtime. It will be monitored by calculating the percent of availability, which is the hours the facility is available to run divided by the total hours in the reporting time period. The percentage will start at 100% and then decrease when downtime occurs. This KPI doesn’t give any specific information of why the downtime occurs, but gives an overall view which can be compared to other installation and then see if CBM is increasing the availability or not. Some downtime will be planned, so one would reach for a percentage of around 95%. (Red Lion, 2015)

Since most of the maintenance is planned to be done through campaigns, one should monitor the number of them. The main objective about this measure is to decrease the number of trips going offshore. If the number of campaigns exceeds the number on a non-campaign based installation, something is not working as it should. This KPI should be measured by dividing the actual with estimated number of campaigns. If it exceeds the amount of estimated, then some need for improvement is necessary.

Not only the number of campaigns is important, but also how much of the planned campaigned was completed. A campaign completion ratio should be a preferable KPI to monitor these. This indicator can tell us if the campaign is overloaded or not. If it is 50%, one should reduce the amount of work orders per campaign, and if it is 100% one should increase the amount of work orders. To best improve and get the wanted effect out of the campaigns, this KPI is necessary. (Svennevig, 2016)

These KPIs should be checked continuously and if a KPI is not meeting its expectations some process should be defined to make improvements. Figure 19 is a simple straight forward process which includes: What is wrong, how and should we fix it. If the answer is yes, do the implementation, and monitor the results. For this process to be most effectively, the KPIs must be easy accessible for monitoring. A method for monitoring these KPIs will be elaborated in the next sub-chapter talking about visual management.

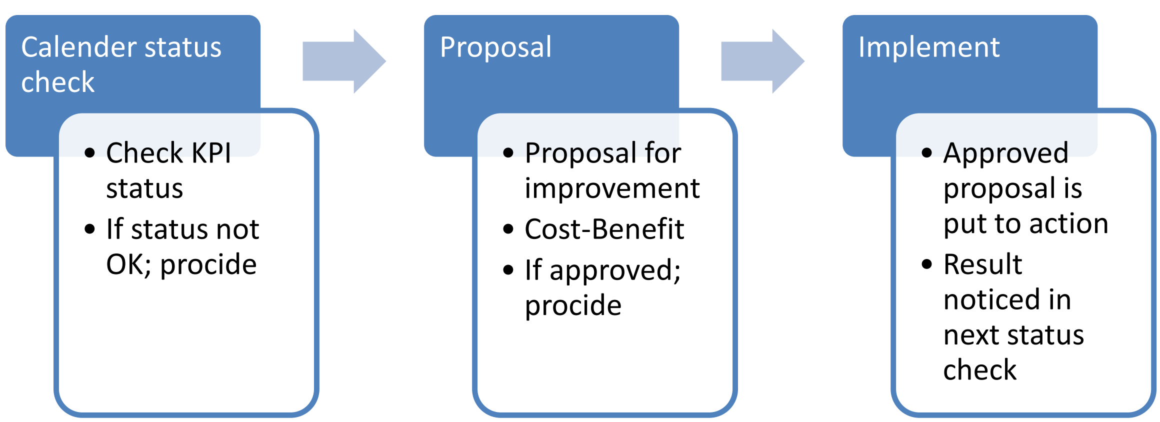


Figure 19 Continuous improvement process through KPI's

6.1.2 Implementation of Visual Management

The process of implementing VM would not be fast and not meet many obstacles. Basically it just makes everything more available. Easy analyzing data and colors presents if there is a need for change or not. How one would set up the visual interface is another question. It should be an easy access interface and not too much unnecessary details.

			KPI's		
	CBM work orders	HSE - Incidents	Availability	Campaign rate	Campaign completion rate
Facility Review 1	33	0	100	70	75
Facility Review 2	68	0	94	110	100
Facility Review 3	56	1	96	100	85
Facility Review 4	62	0	89	65	92
Key:					
Green	>=60	0	90-100	<100	86-99,9
Yellow	50-59	0 (no yellow)	80-89	100	80-85 and 100
Red	<49	>=1	<80	>100	<80

Table 4 KPI-chart

Table 4 is an example of how one can build a KPI chart displaying the current statuses. The KPIs used in this example are the ones mentioned in the previous sub-chapter. Let's say that the reviews are monthly and that the numbers are a result of reports and data. To analyze the different KPIs one may just look at given lights. When percent of CBM work orders are 33 percent, this is not acceptable. Changes are made and review 2 reveals a positive effect, where 68% of all work orders where through CBM. When talking about HSE, there should be a zero-tolerance for incidents, and as shown, the light says red when an incident occurs. The availability starts at 100, but slightly decrease, which can be a result of necessary maintenance in the start phase. The same happens from review 3 till 4.

When looking at the campaign rate, one may see good start where one has only 70 percent of estimated campaigns which is a good thing related to costs. Then there is a major increase to 110 percent in review 2. This may be a result of CM tools detecting a lot of faults; hence the high number of CBM work-orders. The need to mitigate the work over many campaigns may be the cause. Their completion ratio tells another story. In the first review there is planned too much work for the campaigns, but increases to 100% completion rate in the next review. One may look at this as good, but may be result of reducing the amount planned work too drastically. When the rate reaches 100%, it becomes both green and yellow, because there may be time wasted on the campaign which could be used. Then one would increase the amount of planned work slightly to best improve the efficiency of the campaigns.

As mention, these KPIs and this chart is only an example, but to have colors just describing the status is great when simplifying data and implementing VM. These KPIs will be monitored, but to have them handheld too would be an advantage. The handheld SCOTT which TEPN is planning to use may be the answer. It may be used by the operators offshore for reading condition on equipment, but also for project managers who need to access KPI conditions quickly when in a meeting.

6.2 Condition monitoring of systems

When talking about condition monitoring, it is difficult to measure if it fulfills the wanted goals with KPI's. One could instead preferably use them to measure wanted functionality of the equipment which it is monitoring. By using VM and a program to manage the systems one can easily find where the problem is. Every platform installation is divided into 10 systems, and each system has 10 sub-systems. To use the same system as mentioned in 4.1, the closed drain system, it is now something not going as planned and an alarm will occur. You don't know which system, but 20 has a red light on it, see table 5.

00	10	20	30	40
50	60	70	80	90

Table 5 Topside installation systems

By clicking on 20 on the screen in front of you, you then come into a similar matrix, but this time you may select from the sub-systems in system 20. Number 28 has a red light, which will direct you to the wanted system where the alarm got initiated, see table 6. Sub-system 28 is the closed drain system.

20	21	22	23	24
25	26	27	28	29

Table 6 Topside installation sub-systems

By just knowing that something is not going as planned in the closed drain system doesn't tell us much, because this only tells us where the problem is, but not what it is. By entering sub-systems, a map of the closed drain system should present itself, showing which monitoring tool is detecting the error. Let's say that the pump isn't producing the wanted flow. Then the first question is; Why? This question is for the contractors to answer. You now know which system, sub-system, equipment, and the failure mode of the equipment. This makes the job for the contractor easier and they can then faster get a diagnostic, followed by a solution to the error. (Svennevig, 2016)

6.3 The use of proactive maintenance

With some experience with the equipment, one may see the need for proactive maintenance. The main objective is to find common failure modes and design them out. This is resulting in an increase in reliability of the equipment. The ability to design out is related to the degree of technology which is acquired and exists. A new alloy and a new type of lubrication may have drastically changes in the equipment behavior. Proactive maintenance is the equivalent to continuous improvement. New failure modes may also occur which may result in the need for more conditions to be monitored. The importance of being updated in the marked of technology is crucial, and also to contribute with competence when new solutions are discovered.

CM is as important in proactive maintenance as in CBM, and works well together, but focuses on different objectives. As figure 20 presents, there are two zones which respectively CM increases the reliability, "The life extension zone", and then increases the availability, "The failure elimination zone". CBM are important parts of the first zone, but in time one would implement the proactive together with CBM. By eliminating possible failure modes CBM will become more beneficial where the elimination decreases possible conditions to occur, which may result in less maintenance costs. (Brown, 2016)

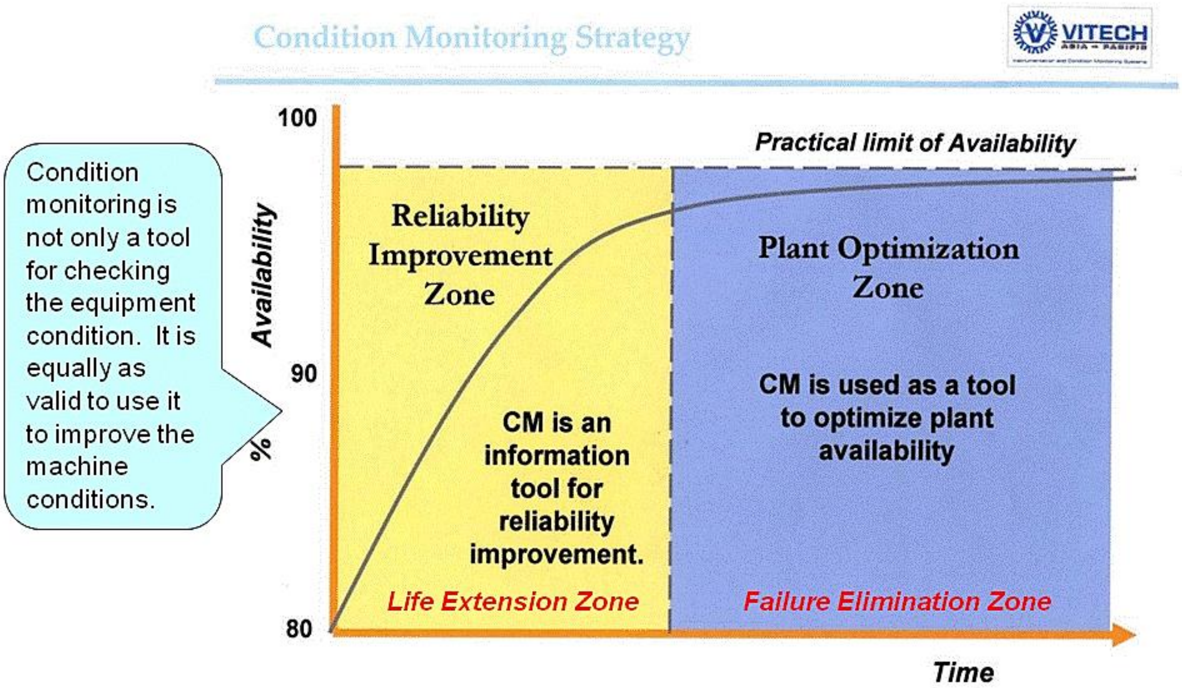


Figure 20 Condition monitoring improvement zones (Brown, 2016)

7 Conclusion

With an increased focus on CM and CBM in the oil and gas industry a challenge was presented by TEPN. They planned to implement major parts of all maintenance into being CBM to increase availability and reliability of the equipment on their topside platform of the Martin Linge field. New procedures, technology and strategies are being implemented, which resulted in this thesis where the purpose was to observe, describe and establish processes, strategies and methods to make the implementation process successful including the optimized use of these.

The implementation process and how to optimize the utility is presented. Continuous improvement is also elaborated since it is important to maintain or increase the utility of CM. To back the suggested methods and processes, theory about different CM tools and maintenance strategies are included. By talking to key personnel in the field of maintenance and CM in TEPN observations were made. These observations were used as examples throughout the thesis, but were mostly used to ask why, how and what else. Even with the experience, as a large company has, it could often be hard to move towards new processes, technologies and solutions. The possibility of many old processes and methods were to be expected.

The main objective of the thesis was in the introduction divided into sub-objectives to best limit the scope and to best answer the presented main objective. One of them was to describe the CM tools to be used for Martin Linge. It is important to remember the fact that there exist many different tools, but only some are elaborated because of the limitations made. The CM tools which are being recommended are also presented. As mention these are vibration, lubrication and wear, and NDT. NDT is covering many tools, but the ones elaborated is visual, acoustic, thermography, working hours, ultrasonic and radiography. Without sufficient covering of the known failure modes, CM loses its purpose and CBM is not working as it is supposed to.

To understand the covering needed and what is the sufficient one, we have to look in the philosophy and goals of the project. HSE and production rates are in the operational philosophy of Martin Linge the most important factors. Since some of the equipment on the topside have larger influence on these two factors, the main focus need to be on them. This is why a criticality class analysis is recommended to first understand the possible behavior of the equipment used, but also to categorize the needed amount of CM. To purchase, install and maintain CM is expensive. So the goal is to not monitor more then what is required.

To identify which equipment to monitor and how much they should be covered is a major part in optimizing the utility of CM. The major goal of the maintenance philosophy of Martin Linge is to achieve that 60% of all maintenance should be CBM. In the topsides systems in general CBM should be the prioritized maintenance strategy in as many systems as possible. To use a criticality class analysis on the systems together with the already established analysis for each equipment, one can apply the levels vital, critical and secondary to decide which maintenance strategy is sufficient. As mentioned one should prioritize the use of CBM, so both vital and critical should mainly apply it. Since CBM requires historical data and equipment experience PM should be used in the start phase of production to avoid major accidents.

To best implement CBM and optimize the utility of CM, the organizational structure has to evolve. The IO and campaigns has different need then the common method where the platform is controlled from offshore and maintenance is done when detected. To then divide the organization into three teams; offshore, onshore and campaign, is a good strategy. The campaign team should also be divided into two teams; offshore and onshore. The campaigns will be filled with low crucial maintenance tasks gathered until the time when it is needed, or when a high crucial maintenance task occurs. For each error detected, contractors should be notified as soon as possible so that spare parts can be ordered and ready for the next campaign. It is also important to report these events, both the errors and the campaigns. With a standardized report layout this process will get simplified when making the reports, but also when extracting information from them. The campaigns will be done by a contractor and this new strategy may put them in an uncertain situation. They will go from a fixed to a flexible work amount which results in an uncertain income. This is an issue and the result of implementing CBM may be an increase in fixed costs. Some contract strategies may be applied to establish the optimized contract, where one strategy would be to compensate the contractor based on system availability.

The benefits of the new strategy, implementing CBM and IO, may be the decrease in offshore manning and long-term maintenance costs. This is because the requirement of offshore manning is not the same, and it is cheaper to have personnel work onshore then offshore. Since Martin Linge gets its power from an onshore power facility, some vital classed equipment such as gas turbines will not be needed and may result in a simpler implementation process, and decreased total CM tools and maintenance costs. The changes in operating strategies may be the success measure for implementing CBM.

To gather, control, analyze and display all the incoming data from the CM tools some systems have to be integrated. Software planned to be used in the Martin Linge project is presented as SAP, PI, Smart Signal and SCOTT. There are many different software which could be used instead, but the main purpose is to allocate the possibility for integration of the already elaborated software. The possibility exists where sources say that the software is working along each other. The hierarchy of the planned systems and software is efficient, but it is relying a lot on the PI software which store data and displays it. In the case of updates, configurations or hacking, the ability to monitor the equipment may be insufficient. Increasing the amount of programs may be a solution, but will most likely increase cost resulted by training, licenses and human failures. The recommended solution would be making procedures for necessary shutdowns of software. One could increase the number of inspections done by the operators offshore when systems are down.

A lot of data will be gathered into the database with the integrated CM tools. Most of the data will vary, but have no consequences for the performance, which can give false signals. The process should be that no data is shown until it exceeds established warning limits. To have a caution and action limits will be smart so one can observe the behavior of the subjected equipment. Like mentioning P-F curve, this process may help establishing and improve it. The levels may also be subjected to continuous improvement to increase reliability and availability of the equipment.

Continuous improvement is essential for the implementation of CBM and optimizing the utility of CM. To locate the need for improvement, one would need to measure progress and compare it to the planned goals. To measure the progress, KPIs is a suitable tool. The thesis proposes KPIs to measure amount of work orders to be CBM, number of recordable incidents, availability of the installation, number of campaigns and campaign completion ratio. Several KPIs should be established, but to limit the scope to how to use KPIs to do continuous improvement only a few where presented. The established continuous improvement process is straight forward and says that the KPIs should be check time-based and if it doesn’t meet the wanted outcome something needs to be done. A proposal for improvement is established and seen if it cost-beneficial before approving it to be implemented. To calendar check the statuses of the KPIs VM could be used to simplify the extraction process. The same can be used for monitoring system statuses. Instead of measuring the progress through wanted goals, one can measure the wanted functionality of the systems. Then one can see which equipment is not performing as it should. By also including measurement from CM tools on the equipment one may extract a failure mode. When knowing which equipment is not performing and why, the contractor can easily get a diagnostic, followed by a solution.

When some experience with the equipment is achieved some measures to improve common faults could include changing material or design of the subjected equipment. This is called the design-out method and is a part proactive maintenance strategy. New material and new types of lubrication may have drastically changes in the equipment behavior and may resulting in the reduction or near elimination of a failure mode. This method and strategy is closely related to the degree of technology which is acquired and exists. It is then important to be updated continuously in the marked and also to contribute with competence if necessary.

The research done is important to allocate possible changes, issues and compromises that may occur when implementing CBM to a topside oil and gas platform controlled from onshore and optimizing the utility of CM. In addition the thesis presents a method and strategy for continuous improvement, which is not only important in the oil and gas industry, but in almost every industry and life in general. To implement CBM is just a small part of the process to get the wanted effect out of the strategy, which this thesis presents. The implementation process also requires a futuristic view, and the ability to look for long-term goals. Implementing CBM on a topside oil and gas platform is a long process in itself, but with and industry and technology moving more and more subsea, new issues may appear and new solutions would be necessary to sufficiently monitor the condition of the equipment subsea to be able to apply CBM there as well.

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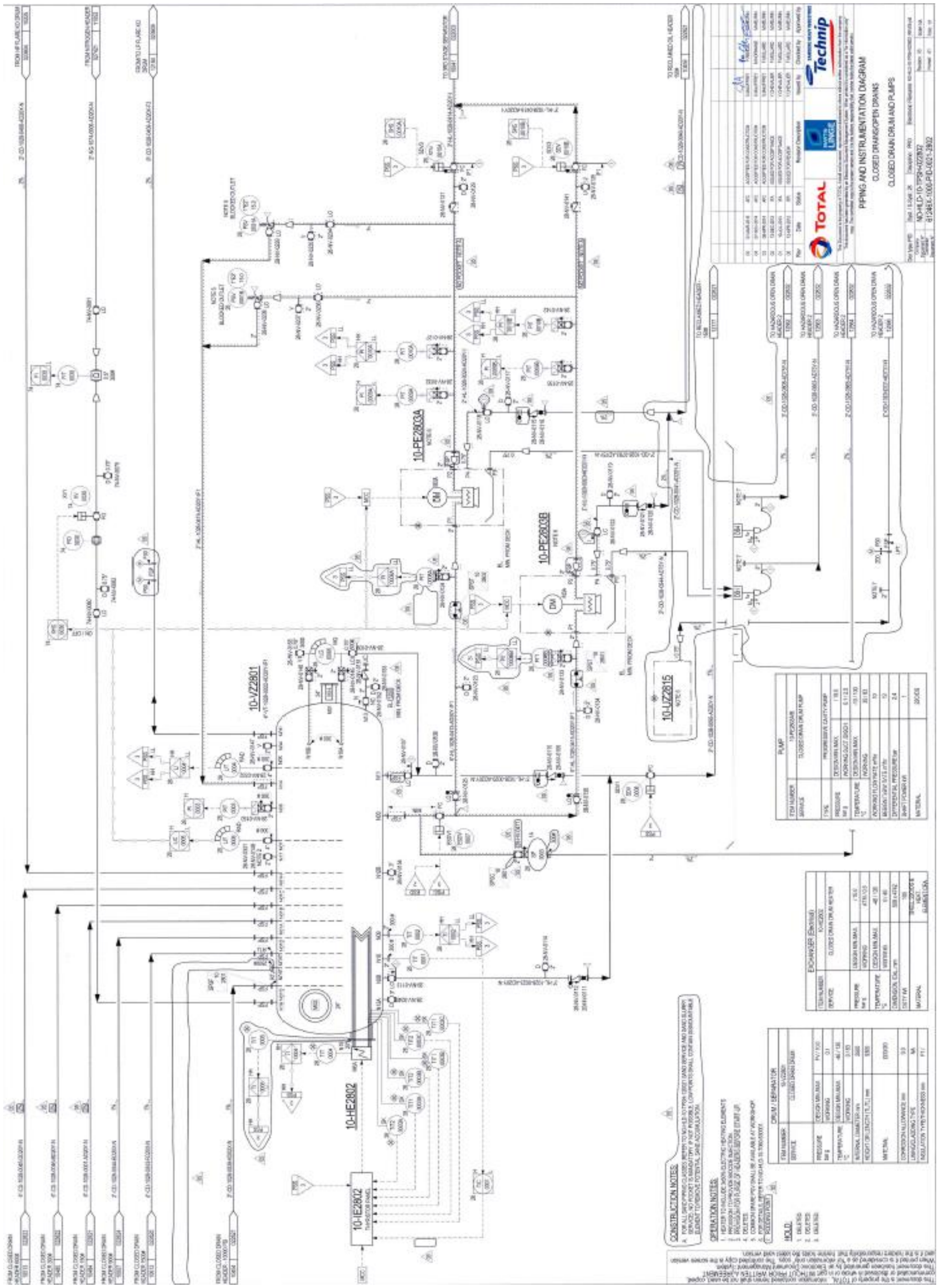
Appendix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10-PE2803A
10-PE2803B
10-HE2802
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CONSTRUCTION NOTES
OPERATION NOTES
HOLD
TOTAL
Technip
PIPING AND INSTRUMENTATION DIAGRAM
CLOSED DRAINS/OPEN DRAINS
CLOSED DRAIN DRUM AND PUMPS