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Writer: David Gusfre

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(Writer's signature)

Faculty supervisor: Professor Tore Markeset

External supervisor(s): Tom Svennevig, Rune Folstad

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PREFACE

This project was executed during the 4th semester, spring 2010, of the master education in Industrial Asset Management at the University of Stavanger.

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Stavanger, June 15, 2010

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LIST OF ABBREVIATIONS AND TERMS

AI	-	Artificial Intelligence
AI-ESTATE	-	AI Exchange and Service Tie to All Test Environments
AM	-	Asset Management
CBM	-	Condition Based Maintenance
CMMS	-	Computerized Maintenance Management System
DMC	-	Distributed Measurement and Control system
EPCI	-	Engineering, Procurement, Construction and Installation
FMECA	-	Failure Mode, Effects and Criticality Analysis
HSE	-	Health, Safety and Environment
ICT	-	Information and Communications Technology
IMS	-	Information Management Systems
IEEE	-	Institute of Electrical and Electronic Engineering
IRSME	-	Indian Railways Service of Mechanical Engineers
JIT	-	Just-In-Time
LAN	-	Local Area Network
MIMOSA	-	Machinery Information Management Open System Alliance
NCS	-	Norwegian Continental Shelf
NOK	-	Norwegian Kroner (Currency)
NIST	-	National Institute of Standards and Technology
OEM	-	Original Equipment Manufacturer
OLF	-	The Norwegian Oil Industry Association
OPEX	-	Operational Expenses
PM	-	Preventive Maintenance
PMP	-	Preventive Maintenance Process
RAM	-	Reliability, Availability and Maintainability (Analysis)
RBI	-	Risk Based Inspection
RCM	-	Reliability Centred Maintenance
SIL	-	Safety Integrity Level
TEDS	-	Transducer Electronic Data Sheet
WBS	-	Work Breakdown Structure

ABSTRACT

- Condition Based Maintenance within an Asset Management Framework

Description: The thesis shall describe how to implement Condition Based Maintenance within an Asset Management context. Asset Management (AM) is an area within Oil & Gas (O&G) Business with a large development potential in order to give companies added value in their operations. With the increased use of Integrated Operations concepts, a new approach for maintenance engineering is necessary. The asset performance is a result of the following four aspects:

- Design qualities
- Operational Support
- Maintenance support
- Management Functions

A framework/methodology is needed to handle the maintenance aspects properly in early design phases and EPCI phase. The early design phase is very important for influencing the maintenance qualities. The master study describes a theoretical framework with a main focus on the Maintenance Strategy in early design phase (Front End Loading) and subsequently Maintenance Engineering in the detail project phase (EPCI). Development of suitable Maintenance Engineering Methods to comply with Condition Based Maintenance strategies and Integrated Operations concepts is also an objective in the thesis.

1 INTRODUCTION AND BACKGROUND

This thesis is the final part of the master program “Industrial Asset Management” at the University of Stavanger. The thesis was given by Aker Offshore Partner in Stavanger and is written in co-operation with them and at their facility in Stavanger.

Condition based maintenance (CBM) is becoming an increasingly important field of work. Great potential savings and an increase in the levels of safety, effectiveness and efficiency are within reach, but many questions still stand unanswered with respect to its impact on the existing maintenance functions and how it best can be implemented to optimize that impact.

Mapping the transition to CBM requires all of the stakeholders to be involved, including financial, technical, human, and organizational. CBM will affect them all, and the level of preparation done prior to its implementation will only increase its chance of success and help combat any negative side effects.

This creates an interesting basis for a thesis where the implementation, effect and challenges of involving CBM in the existing calendar based preventive maintenance philosophy is in focus.

Thesis Objectives

The main objective for this thesis is to perform a study on the implementation of CBM in the O&G industry, the preparations needed for its implementation and the transition from a maintenance philosophy more focused on PM to a setting where PM and CBM exist together.

Subsequently, the impact of CBM on the existing maintenance regime will be addressed, as well as the technical features such as the ICT (Information and Communications Technology) solutions involved in the design of standards within the CMMS (Computerized Maintenance Management System) platform and the challenges involved in such operations.

Finally, a maintenance strategy development process based on an existing figure will be proposed.

Limitations

The thesis will not move into the many technical details and studies that could be involved, such as FMECA analyses of equipment, or specific cost-benefit analyses, because the focus is on the managerial part and the human and computer aspects. For example it is clear that extensive information and work is required from vendors with regards to operational statistics and failure modes (FMECA) connected to the new surveillance methods and equipment involved with CBM, but the technical approach into this problem will not be discussed. One chapter will, however, be focused on the challenges concerning the increasing computerization that comes with CBM, and advances in that technological area.

Methodology

To build a structure for this thesis, and involve the relevant information to be able to address the questions posted in the abstract and objectives, information was collected from internal Aker Solutions documents and presentations, academic journals from the University of Stavanger (UiS), magazines and articles and online databases. Also, discussions with relevant Aker Solutions employees with key knowledge on the subject have been frequent, and very useful.

1.1 Condition Based Maintenance offshore

At an offshore installation resources are limited. One does not always have the correct spare parts, the extra crew needed, the beds, or helicopter transport required to deal with problems as fast as one would want. They also cost more, compared with an onshore facility. Enabling operators to reduce the amount of resources and people needed offshore on a regular basis has been a focus since the birth of the industry, and as operators improved on the subject, possibilities opened up. Fibre cables from an offshore facility to an onshore facility where capable personnel assist the offshore personnel in problem detection and solving, has been a fact for some years. However, if we consider not only reducing the travel offshore and transport of equipment, and try to further reduce the costs associated with maintenance, the financial and safety benefits can be huge. Looking further into possibilities for not only remote surveillance, detection and processing of situations, but also problem solving, by remotely controlled or automatic equipment opens up many very interesting opportunities.

1.2 Integrated Operations

The OLF defines integrated operations (IO) as *“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”*. OLF (2006)

The use of information and communication technology is just as important with respect to IO as it is when addressing CBM. The core of IO is, as the name suggests, allowing several instances or processes to work together, integrating their efforts and reaching a higher level of efficiency. The development and use of IO and with it, a greater reliance on information management systems (i.e. CMMS) in the future will definitely walk hand in hand as they are both important parts of the production models and production philosophy today and more importantly, in the years to come. When addressing CBM later on in this thesis, one will try to show that aligning the maintenance strategy with CBM is a crucial part of the success of CBM. In the same way IO is dependent on people's commitment and understanding to deliver its potential. IO has the potential to increase production efficiency, but another major result is the improved HSE and cost savings. Allowing technical staff to stay onshore and to be available for the offshore crew for consults and problem handling not only saves money on offshore costs, salaries etc. but also decreases the number of people necessary offshore,

thereby removing them from the risk exposure. Figure 1-1 illustrates a work flow example of IO.

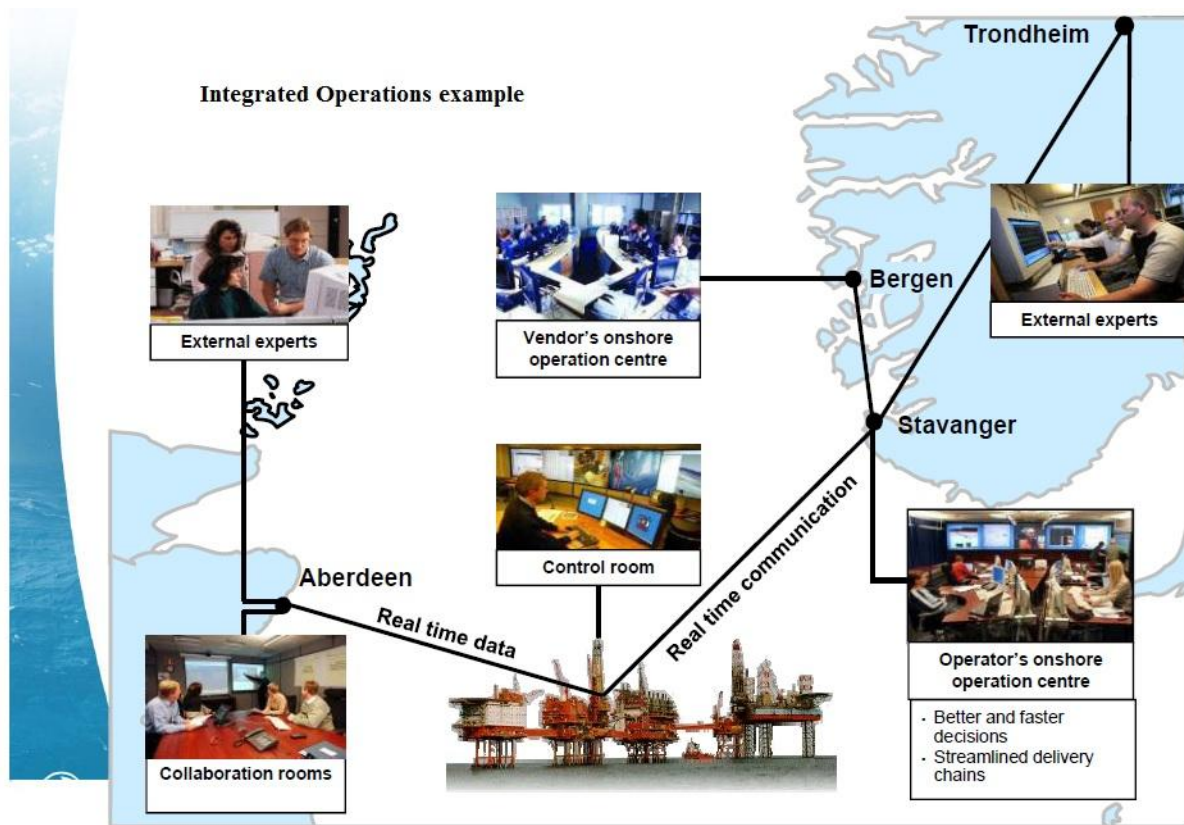


Figure 1-1: IO workflow example (Langeland, 2008)

The heart of the IO concept can be seen in figure 1-1, showing how the participants, with their individual operations, collaborate to achieve operational improvement and maximum utilization of the involved competence. It also allows input into the production to come from several locations and people, through computerized communications.

According to the OLF (Zachariassen, 2010a), IBM is the leading developer in this area with their "Center of Excellence" in Stavanger, Norway. Their solution is called the Integrated Information Framework (IIF), and is designed in cooperation with ABB, SKF, Statoil and Aker Solutions. This joint semantic platform as placed in between the production level, and the involved parties and, regardless of their different interface standards, enables them to access the same system and share information.

2 THE TRADITIONAL MAINTENANCE ENGINEERING PROCESS

As a basis for the thesis, the existing traditional maintenance engineering process along with the traditional preventive maintenance regime will be addressed in this chapter. This is to create a reference for development into CBM strategies, and also the challenges that come with its integration with CBM elements.

2.1 Typical Maintenance Management Process

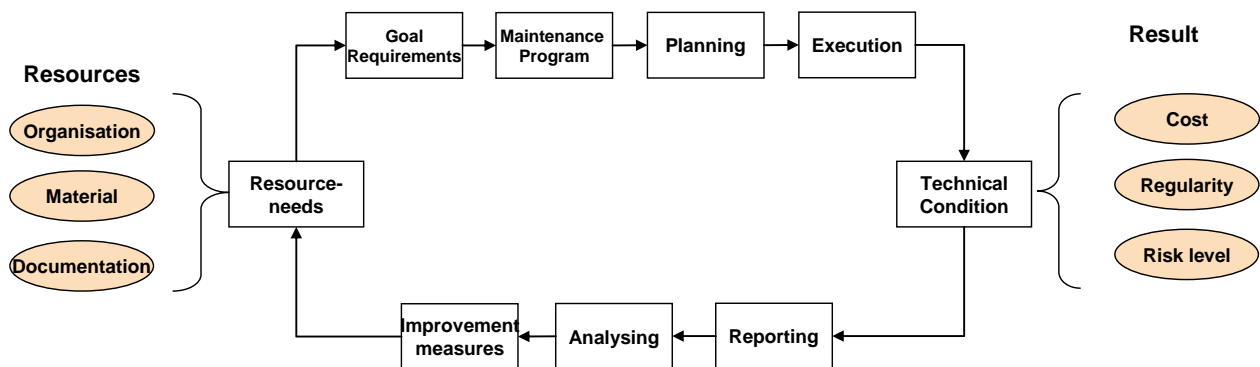


Figure 2-1: Maintenance Management process model (Øxnevad and Nielsen, 1997)

Figure 2-1 shows a typical maintenance management process and its components, from the resources, through the process loop, the feedback loop, and the ending results. A more thorough explanation follows in the next sections.

2.1.1 Resource needs

The resources are divided into three categories; organisation, material and documentation.

Organisation

The maintenance strategy is based on an organisation that is divided into three levels:

- | | |
|----------------------------------|---|
| 1 st line maintenance | Offshore personnel carrying out standard work and performing maintenance tasks of maximum one working day duration. |
| 2 nd line maintenance | Offshore personnel with special training on selected equipment, performing tasks exceeding one working day. |
| 3 rd line maintenance | Advanced equipment requiring specialized maintenance or tasks that will require several days to complete. |

Material

Criticality, availability and equipment constraints are the governing principles within the spare parts category. It is important to consider that space might constrain the option of redundant systems, and it will also impact any offshore storage of parts. Utilizing the RAM analysis will provide guidelines towards required spares and the location of those spares.

Documentation

All forms of documentation such as manuals, data sheets, equipment drawings etc. are crucial in supporting a complete and total maintenance program

2.1.2 Goals and requirements

Based on the resources available, the starting point for the maintenance strategy is to set goals and requirements for the project, making it possible to meet the maintenance and operational targets. Figure 2-2 shows how the goals and requirements are placed within maintenance engineering in the project phase. Examples of such goals and requirements are:

- Availability
- Maintainability
- Equipment selection
- Corrosion prevention
- Operability
- Material Handling
- Standardisation

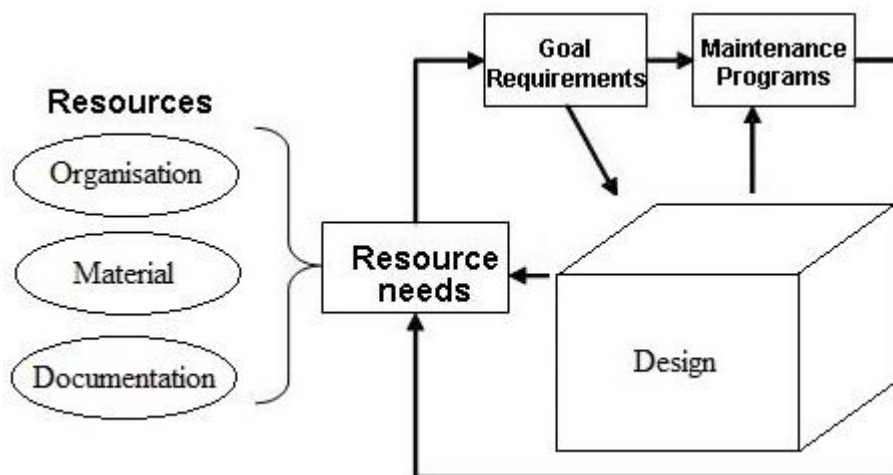


Figure 2-2: Resources, design and requirements relations (Aker Document 1, 2009)

2.1.3 Maintenance Program

The maintenance program shall ensure safe, financially optimal and efficient operation of the maintenance activities.

2.1.4 Planning and Execution

Based on the maintenance program, maintenance is planned and executed in accordance with operational statistics, time, cost, etc.

2.1.5 Technical Condition

The technical condition is the system or operational state achieved by the prior process segments. As the subcategories suggest, a certain level of regularity and risk level is achieved at a certain cost.

2.1.6 Reporting, Analysing and Improvement measures

To keep the maintenance program up to date, and operating efficiently one must be able to learn from completed maintenance, errors and experience. This is done by providing feedback from the achieved technical condition on operational statistics, efficiency of maintenance tasks, etc. and analysing this data to generate improvement measures. These measures are then fed into the needs section and the process repeats itself.

2.2 Traditional Maintenance Engineering

To be able to adapt and develop the maintenance engineering process to allow the changes that comes with CBM, and finally a joined strategy, one must first address the traditional process. Below is figure 2-3, illustrating a typical maintenance engineering work process, followed by the description of the main activities.

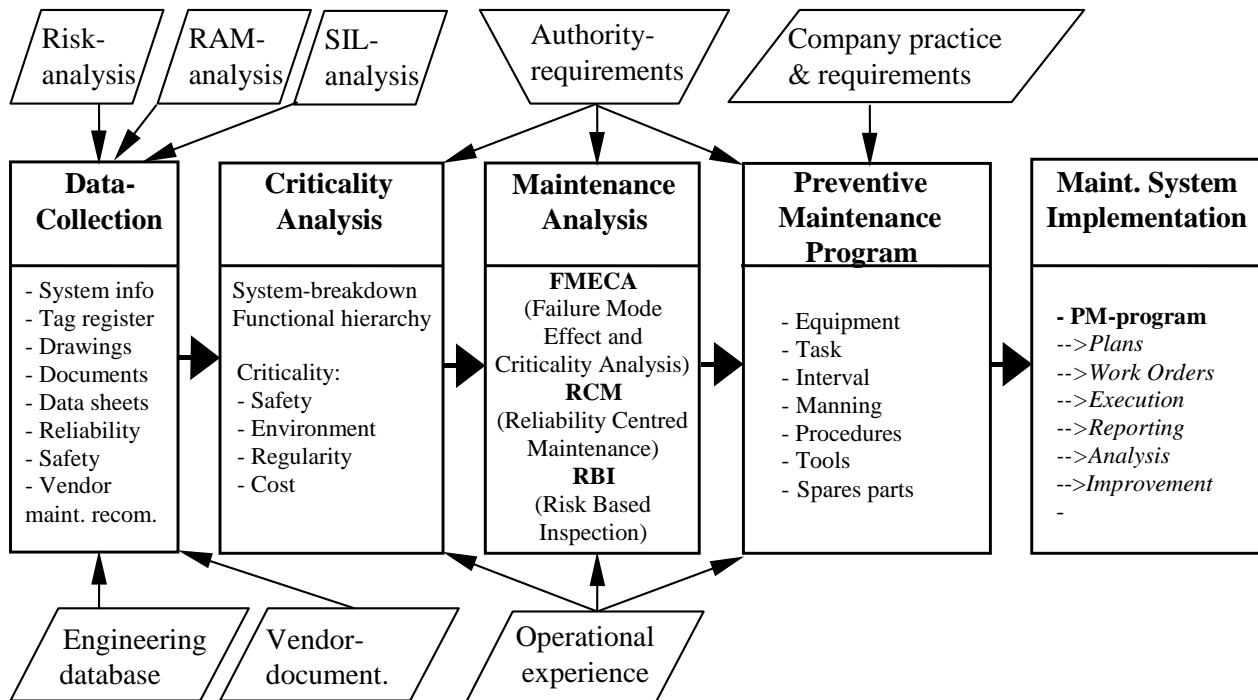


Figure 2-3: Maintenance Engineering Work Process (Aker Document 2, 2010)

2.2.1 Data Collection

Gathering data on components and system including all information needed to create a basis for evaluation is the first step of the process. In this step, receiving input from analyses done from implementations already made and resulting in improvements is also taken into account in the data collection process, as this is a repeating model. Other inputs also include risk analysis, Reliability Availability and Maintainability (RAM) analysis, and Safety Instrumented Function (SIL) analysis. Large amounts of the data is collected from existing engineering databases, either exclusive for the company to perform the gathering, or shared as a common database for a field, or group of installations. The vendor document input is basically the raw data of the components delivered by the vendor; generated effect, rotational speed, power requirements and so on.

2.2.2 Criticality Analysis

A criticality classification of all components involved is crucial to create a correct image of the system as a whole and its nature with respect to weaknesses and points of focus. The criticality of the component will be involved in defining the type of maintenance to be applied to it. A less important component may be chosen to run to failure, whereas a component vital to the process may be, when other factors such as cost, applicability etc. are also present, suitable for preventive maintenance. Knowledge of the criticality of any piece of hardware to be used is not only necessary to be able to operate a safe system; it is also required, legally, by the authority requirements. Criticality can be defined through addressing the function of the component in the system with respect to how its failures will affect the process and its reliability. An FMECA addressing the failure modes of the component along with their probabilities and effects (i.e. consequences) is also to be included.

NORSOK Z-008 recommends a matrix for evaluating consequence as shown in table 1.

Table 1: Consequence matrix (Norsok, Z-008)

Consequence	Health, safety & environment	Production	Costs
3: High	<ul style="list-style-type: none"> - Potential for serious personnel injuries - Render safety - Potential for fire 	Stop in production / significant reduced rate of production exceeding X hours (specify duration)	Substantial costs exceeding Y USD. (specify cost limits)
2: Medium	<ul style="list-style-type: none"> - Potential for injuries requiring medical treatment - Limited effect on safety systems - No potential for fire in classified areas 	Brief stop in production / reduced rate of production lasting less than X hours (specify duration) within a defined period of time	Moderate costs between Z-Y USD. (specify cost limits)
1: Low	<ul style="list-style-type: none"> - No potential for fire in classified areas 	No effect on production within a defined period of time	Insignificant cost less than Z USD. (specify cost limits)

Figure 2-4 shows a maintenance strategy development process used by two engineering companies developing maintenance strategies for O&G companies on the Norwegian Continental Shelf (Panesar et.al. 2008). It clearly show the important position of the criticality analysis, dividing the equipment into low, medium, high and very high categories, and how the further development of the maintenance solution is based on that classification.

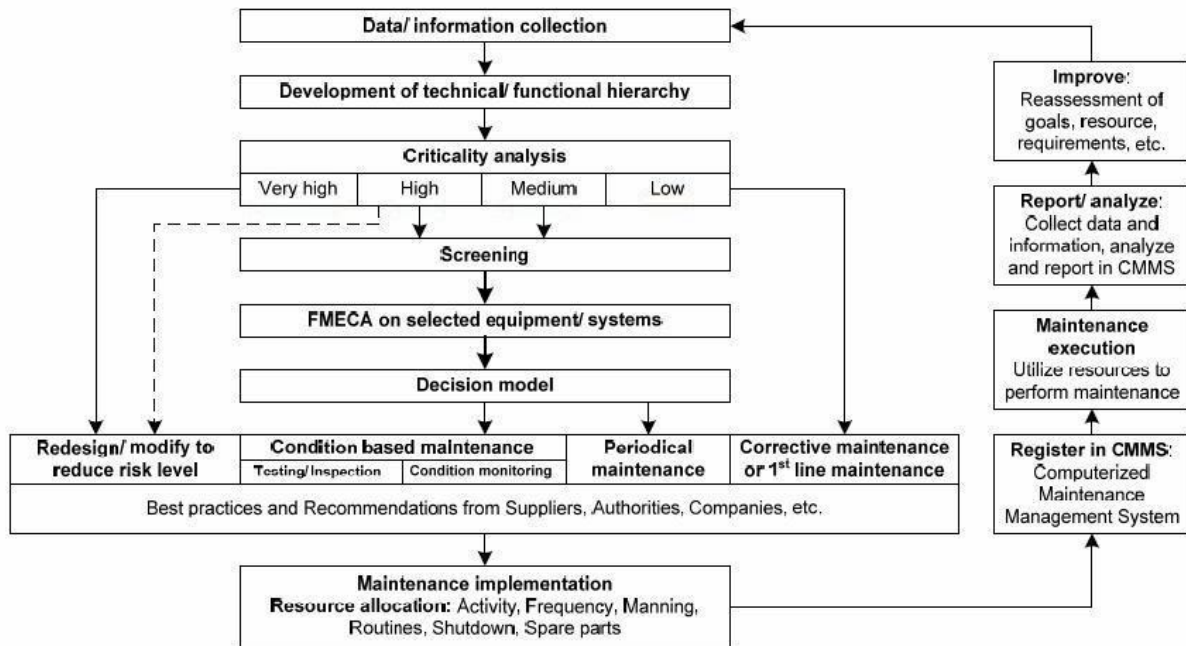


Figure 2-4: Maintenance Strategy Development Process (Kumar and Markeset, 2005)

2.2.3 Maintenance analysis

Completing a maintenance analysis is the next step of the process, involving methods such as Failure Mode Effect and Criticality analysis (FMECA), Risk Based Inspection (RBI) and Reliability Centred Maintenance (RCM). In this phase decisions are made as to what kind of maintenance the equipment will be allocated with.

“The Failure Modes and Effect Analysis is an analysis method used to reveal potential errors and predict the effect of failures in components in a system” (Aven et al., 2007). The method focuses on one component at a time and the effect that its failure will have on the system. The failure modes, their effects and the frequency of the failures are compiled in a diagram, resulting in a number score, showing what failures will be most critical to the system.

The Risk Based Inspection approach bases itself on a quantification of risk not only for the components individually, but for the system or facility as a whole (See Faber, 2002). This approach is risk based, and provides a platform for binding the inspection effort to the condition of the component, and also prioritizing these inspection efforts after the importance of the different components and the nature of the different ways of deterioration. It differs from the traditional inspection planning methods by quantifying the effects of inspections, better documenting, the ensuring of safety requirements, and focusing inspections towards the high risk components.

Moubray (1997) defines Reliability Centered Maintenance as “A process used to determine what must be done to ensure that any physical asset continues to do whatever its users want it to do in its present operating context”. As the quote implies, Reliability Centred Maintenance is centred towards maintaining the asset at hand in its desired state, efficiently and effectively. Dealing with failures and their respective modes, effects and consequences, proactive tasks and schedules, and the importance of commitment on all hierarchical levels, it sets out to achieve longer useful life of expensive items, greater maintenance cost-effectiveness and improved performance, while always keeping safety and environmental issues in mind.

2.2.4 Preventive Maintenance Program

The three prior main activities finally lead to the design of the preventive maintenance program, tailoring how the facility or system at hand will be kept in its desired state in a safe, economical and efficient way. An important input here is the company practice and requirements, because designing a maintenance program is of little or no use if it is not tailored to the company that is going to implement it. The social, human, safety and environmental factors are addressed with the same importance as hardware, software and financial issues. An important aspect involved in these considerations is the psychological aspect. Changes are big when they occur, and they often involve huge amounts of money, time and training. Therefore it is reasonable to address the fact that people must be convinced that CBM is something not be feared, but met with spirit, and eagerness. A clear top-down support of the process will help initiate the changes necessary for it to reach success.

2.2.5 Maintenance System Implementation

Finally, the model arrives at implementation of the designed preventive maintenance program. Optimally, this has led to a program designed to the system it is to maintain, with clear guidelines, standards and procedures for actions such as:

- Plans - Set standards for strategic operation and further development
- Work orders - Clear guidelines for where, what, how and when things are to be done
- Execution - Ensuring that the planned work is done in a way corresponding with the requirements and procedures of the maintenance system.
- Reporting - The establishing and continued feeding of a database consisting of the work executed and its results, so as to learn from previous incidents and increasing the reliability of preventing future incidents. A similar system, able to offer a financial stand point at a given time is also needed, for example based on a work breakdown structure (WBS) enabling the user to pinpoint financial cost to work processes, so that one can keep track of the advancement in the operation not only in time, equipment and so on, but also with respect to money.

- Analysis – Using the data from all parts of the maintenance process to increase understanding and efficiency, and to be better prepared for future challenges
- Improvement – Applying the knowledge gained from operations on all levels to continuously improve the process and keep it up to date.

3 GENERAL DESCRIPTION OF CONDITION BASED MAINTENANCE

A general description of today's maintenance practice would focus mainly on the predetermined and corrective maintenance approaches.

It is worth mentioning, since the CBM will coexist with, and not replace, calendar based maintenance, that any offshore facility with different types of equipment and systems will usually include a mixture of all of these maintenance philosophies. The figure below illustrates the strengths and weaknesses of the maintenance methods and shows how failure rate and maintenance philosophies are related.

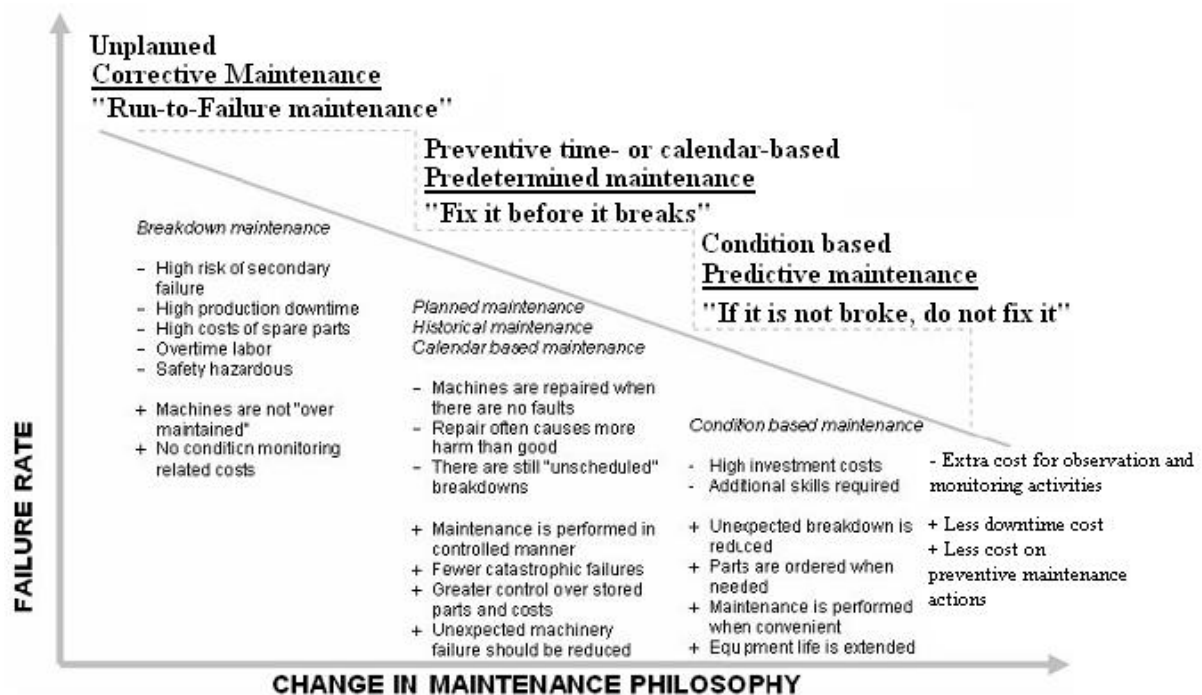


Figure 3-1: Maintenance methods relations (Adapted from Sethiya, 2005)

Corrective maintenance, or “run-to-failure maintenance”, implies that maintenance is carried out after a failure or breakdown has occurred. If a component is for example considered to be non critical or low critical and inexpensive to replace or repair, one might choose to leave it in operation until it fails.

Predetermined maintenance, i.e. Calendar based maintenance, implying to “fix it before it breaks” applies operational statistics, historical data, and previous experiences to predict when maintenance is needed, e.g. maintenance scheduled every 6 months on a component. But unexpected breakdowns will still occur, as we trust our statistics as the base of execution.

Predictive maintenance, or condition based maintenance, suggests the ability to decide when to perform maintenance based on the status of the component. The field of CBM is currently

undergoing huge developments, as technology is finally catching up with the needs of the industry. With CBM the maintenance needs is based not on a set schedule, but on the actual state of the component. By monitoring factors such as temperature, vibration, noise or lubrication oil quality, maintenance will not only be done exactly when it is needed, but failures can be, theoretically, avoided completely by noticing the signs of impending break down, and acting upon them.

Though CBM represent remarkable potential with respect to increasing production, two factors must be fulfilled before CBM is a valid option. Firstly, the implementation of CBM must be financially beneficial. All of the other factors will not matter if there is no money to be made (i.e. saved) by using it. Secondly, it must be technically applicable. The necessary resources, equipment, and circumstances must exist for CBM to be able to perform on the expected level.

The effort in form of money, time, equipment, training, trust and manpower needed to achieve such a degree of predictive maintenance is a big part of the focus in this thesis. The transition to be made into CBM will undoubtedly be an easier one if the necessary work is done in advance. The next section describes eight selection points for a possible CBM maintenance choice.

3.1 Decision Criteria for selecting a Condition Based Maintenance Strategy

These eight points represent a basis for deciding if a component is suitable for CBM, and they all present a “Go/No go” decision point. The points are as follows; the detection of a condition, a suitable P-F interval, a certain degree of precision or sensitivity when it comes to measuring, the skills needed to respond to condition based, and not calendar based maintenance activities, a reasonable cost-benefit scenario, appropriate physical and mechanical surroundings, known applicability and effectiveness and finally, trigger levels.

3.1.1 Condition being detected

The status of the component and its nature during operation must be understood, so that its initial status, supported by the data from monitored/measured values will allow us to interpret when failure will happen, and to assist us in choosing an appropriate CM technique. Such a choice may be that a gas turbine shall be outfitted with an on-line vibration monitor, sampling the vibration level each ten seconds or so, and that at a certain level of vibration, predetermined actions must be taken.

3.1.2 P-F Interval

This theory is based on the fact that most failures do not occur instantaneously, but has a point of “initiation” followed by a period of deterioration leading to failure/breakdown. This will not only enable us to act before failure/breakdown, but also to not act until it is necessary, based on time, money and risk. If an expensive component, say a gas turbine, can be run an additional eight, twelve or 24 months before any intervention is carried out, time and money is saved. And any replacement or service can be more efficiently carried out because the interval provides us with time to plan ahead, knowing that action has to be taken. Additionally, any negative effects that the breakdown would have had on the system as a whole can be prepared for or avoided.

The process, shown in figure 3-2, shows how the deterioration of the component can be followed over time from where failure starts to occur, to the point where we can find out that it *is* failing, and on to the point of failure/breakdown. The input needed to create such a graph can come in many forms, for example an increasing amount of particles in lubricating oil, or the deteriorating insulation in a furnace creating hot spots, as well as vibrations in a piece of machinery revealing imminent bearing failure. However, time or stress cycles are classic examples. If we are able to detect and act on an anomaly within the time from P to F, then actions can be taken to prevent breakdown or minimize the effects of that breakdown. Our condition monitoring tasks will be designed to detect any potential failure.

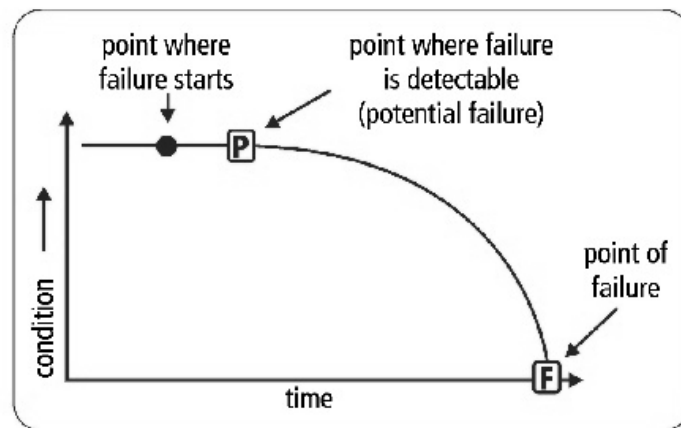


Figure 3-2: Illustration of the P-F interval (Troyer, XXXX)

For different components, the time from potential failure to functional failure can be seconds, or they can be years. If we are to act upon the input from such an interval, a reasonable interval must be chosen between warning and failure enabling us to do what is considered best at that time. Should the interval prove too short for maintenance actions to be taken, perhaps a shut down can be initiated, reducing the impact on the system.

Sethiya (2005) suggests setting a checking interval equal to half the P-F interval, unless reasons to do otherwise exist. This ensures detection before failure, as well as providing us with at least half the interval to act upon the problem. Of course, this is a choice more suitable for a PM regime. With the ways of monitoring to be addressed later (i.e. on-line sensors and computerized systems), any practical interval can be chosen, and in many cases one will want to monitor the equipment constantly since it does not represent an increased cost of any kind.

Sources of potential information when determining the interval:

- Manufacturer's recommendations
- Published information such as RCM analysis
- Historical data (if available)

When an interval is set, factors may indicate that it should be reduced even more, these are important factors defining the situation in which we are placed if and when the component starts to deteriorate:

- If we are not supplied with enough time to take corrective action
- If the operators have low confidence in the estimate of the interval
- If the risk of failure/severity of failure is very high

On a further note, defining limits within the data received from monitoring to automatically involve the operator or a third party (e.g. the vendor) to evaluate the state of operation, can be beneficial since there is no reason to monitor an operation that is constantly within its limits and operating as desired.

3.1.3 Measurement Precision / Sensitivity

The potential precision with which sampling or measurement can be carried out will affect the choice of the CM technique as it defines the input we receive, because the input is meant to present an image of the components condition. The presence of money and resources will no doubt play an important part in the choosing of the monitoring technique, as more advanced equipment is expected to cost more. Comparing ultrasonic testing to the skills of the human senses, for example, it is clear that ultrasonic testing will provide a higher level of precision than that of a human factor. However, it also requires more equipment, costs more, and requires additional competence.

3.1.4 Skills

It is important to mention that whether equipment is subjected to PM or CBM the maintenance tasks done, will be the same. The difference, however, lies in how the maintenance is "triggered". The fact that one will not have a scheduled, calendar-based system for when maintenance is to be done will lead to different challenges for the people involved in this work and the way they utilize their skills. More focus will be placed on appropriate responses to the current situation or failure, and with timing and efficiency. In future maintenance systems, the "trigger" action will occur onshore, which requires the people onshore which one might call the "digital engineers", to possess the skills to evaluate the problem the specialized competence to interpret it. Subsequently, the personnel offshore must to be able to perform the maintenance actions. This subject shall be further discussed under client involvement.

3.1.5 Resources vs. Risk

Maintenance is an investment along with manpower, equipment and facilities, and must be treated with the same economical foundation as any other expense. Risk is defined as a combination of the likelihood of an event taking place, and the effect that that event has. Consider a facility where a gas turbine fails two times per year causing NOK 200,000 in lost production and expenses per failure. Another machine may fail four times per year causing a loss of production and expenses of NOK 100,000 per failure. The financial risk run by keeping these two machines in operation is equal. If the price of implementing and maintaining a CM task is equal to, or higher than the cost of dealing with the equipment failures, implementing the task might not be financially smart.

3.1.6 Environment, location and portability

Physical considerations when performing maintenance must also be considered. Equipment or systems under pressure, in extreme temperature surroundings or any hazardous environment will not only demand more planning and precautions but may also be a reason for not implementing the considered technique. Space for sampling/monitoring, and the equipment needed to do so must also be considered. The opposite can also be the case; if human intervention is not possible, perhaps a sensor can be fitted.

3.1.7 CBM Task applicability and effectiveness

The question of applicability and effectiveness is most likely one of the biggest in this thesis along with the financial aspect. The transition to CBM must be reasonable one, with positive effects on all levels, financial, HSE and so on. These are the points suggested to address to evaluate if CBM is, in fact, applicable and effective:

Detectable failure through measurable parameters: A parameter able to inform us of the component's status must exist. This parameter must be able to indicate the equipment's deterioration and maintenance personnel must be able to define limits, showing when corrective actions must be taken.

A consistent P-F interval: The P-F interval must be of a consistent, repeating and trustworthy nature, so that we can fully rely on it to inform us of the components status. This will also ensure that corrective actions are not taken too early or too late, thereby ruining the wanted effect of the CBM process.

Practical response interval: Earlier in the text, an interval of half the P-F interval has been mentioned. However, the techniques in CBM, such as active sensors on a network (mentioned in chapter 5) can allow us to monitor constantly, thereby reducing the importance of a suitable interval. The fact still stands though, that we must be able to notice and act upon the data received from the sensors. The data sampled from the sensors must be stored, along with an accompanying trend, as they both represent important information with respect to setting a diagnosis. Figure 3-3 shows how a potential comparison between the maintenance situations given by the two systems.

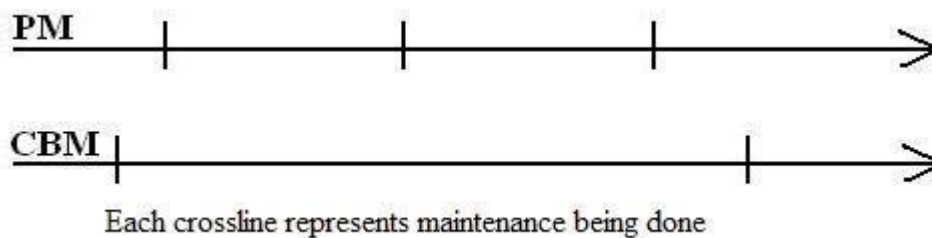


Figure 3-3: A suggested comparison between the numbers of maintenance actions done over a period of time.

The major weakness of PM is that maintenance is rarely done exactly when it is needed, but mostly it is done either too late or too early, as shown in figure 3-4.

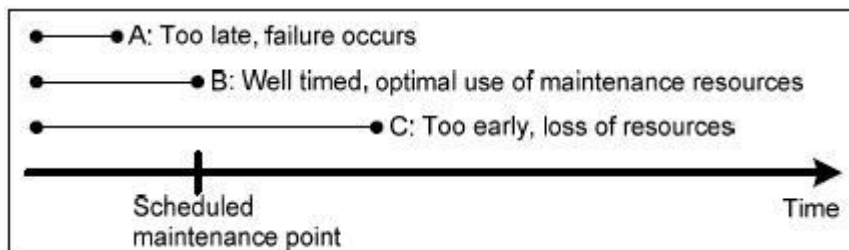


Figure 3-4: Timing of scheduled maintenance with respect to failures (Markeset, 2008)

Failure probability reduction: The interval of the measurement task being carried out (i.e. the sampling/measurement) must be so that the overall risk of failure is reduced. A definition of what the acceptable risk is must be predefined.

Cost-efficiency: As with the example with the two machines where even though one failed less than the other, the final cost was still the same, the implementation of CBM must lead to a reduction of costs associated with maintaining the component.

3.1.8 Trigger levels

In ensuring the effectiveness and applicability of the tasks to be implemented, trigger limits must be set to clearly define when actions are to be taken, to avoid a difficult to follow, underperforming system. These trigger limits will be an important part of the final output process because of the strict hierarchical and technical structure that will be needed to respond to the failure modes received from the system. If the degradation of a component has passed a limit, for example, the system notifies the operator in charge of that section (defined by a hierarchy). This operator is presented with the situation, and ways to solve it, with the accompanying time and resource needs, and can then make a final decision on the next actions to be taken.

4 MAPPING THE TRANSITION FROM PM TO PM+CBM

When addressing the changes needed to utilize CBM in an offshore setting one must underline the fact that the PM regime will not be replaced by CBM. What is a more reasonable aim is to focus on their coexistence. There will always be equipment where there will be no gain in neither cost nor production levels or safety by applying CBM. At the same time, some components will greatly benefit from such a strategy.

The subchapters under this heading address three important points with respect to the transition to be made in the offshore maintenance regime.

First, the effect the implementation of CBM will have on the existing work processes, and the challenges associated with it, along with the roles of the vendors and operators.

Second, the particular considerations needed with respect to maintenance being done when needed, and not on a schedulable date, putting more strain on an already challenged logistics system offshore.

Third, a proposed strategy development process scheme more directed towards CBM, based on figure 2-4, the Maintenance Engineering Work Process, will be proposed.

4.1 How CBM will affect the work processes

The work processes already present and integrated with the existing corrective / preventive maintenance systems will be affected in many ways by the coming CBM systems. The following points of attention are listed below. Also, the roles of vendor and operator are addressed.

4.1.1 Assumptions for implementation

Certain points of focus stand out when addressing the implementation of CBM elements in the maintenance regime. The authority requirements will most likely be raised with respect to the higher level of automation expected with the CBM system, but complying with these requirements will also be made easier by its availability and maintainability. Dealing with the criticality of the components, and also certain points within preparing for the transition will also be addressed.

Authority Requirements

The fact that we are moving towards a more automated maintenance system in the sense that it can be retrieving, processing and recommending actions by itself, will probably impact the level of safety demanded by the authorities. Total trust in the automated systems must be present, and must also be documented so as to assure the authorities of its safe operation.

The requirements set by the authorities will of course be followed in a regime containing both CBM and PM as well as in a PM-only regime. But in a CBM+PM regime, the task of following them will be made easier by e.g. the high level of availability and re-programmability that the system offers, and the detailed, accurate and live status of the components in the system.

Criticality Analysis

In the preventive maintenance process the criticality analysis was used as a filter to decide whether to redesign/modify to reduce risk level, or recommend for condition based, periodical or corrective –maintenance (see figure 2-4). A lot of attention has been put to the amount of work related to performing FMECA and RCM analysis, and that is why it simply cannot be set as a point in the process, when dealing with CBM. Performing the analyses on all components/systems would cripple the process, and lead to no progress. A split process is therefore suggested, consisting of first prioritizing the components, before any analysis is done, and then, if the necessary conditions are present, to perform an analysis. However, with the amount of equipment that will be put through this process, it will still represent a bottleneck. That is why increased support from vendors will be required. The vendors will themselves be required to supply the buyer with FMECA results for their equipment as well as the standard information package. If and when the prioritizing reveals a component with a high level of criticality to the system, and with failure modes that are not clear enough, a more extensive analysis should be performed.

Maintenance Analysis

The three following points are deemed vital under the assumptions for implementation of CBM. A measurable condition and the necessary equipment are technical aspects, but the idea of a contractual obligation and the possibility within it aim for a more managerial perspective.

Measurable condition / degradation: Reasonably consistent values or statistics for the component which can be measured and analysed to give an impression of its status must exist. These must be based on FMECA / RCM analyses done by the vendor.

Necessary equipment / software: As the measurable values are defined and present, instruments for recording, transmitting, and processing them must be available.

Contractual obligations: Vendors generate profit by providing service solutions and spare parts. Arranging so that the vendor has access to the CBM system to provide input and give advice to the operation of the equipment they have provided, may lead them to offer a higher level of reliability, and a better performance statistic for their equipment. And most importantly, it may lead to reducing the number of service visits needed, while still providing the same guarantees.

At the other end of the process, the purchaser of the equipment, i.e. the operator cannot leave the responsibility up to the vendor. They will be required to obtain and maintain a certain level of knowledge of the existing CBM techniques in use to ensure that they do not acquire equipment unknown to them, and to be able to decide whether the equipment is suitable to their purpose or not.

The final maintenance analysis shall lead to the component either being confirmed for CBM or dropped from the process and scheduled for preventive / predictive maintenance.

Preparations

The term preparations involve many things on a large and small scale, involving macro- and micro management such as warranties, responsibilities, competence, regulatory demands, strategy development, adaptation, willingness and trust, and these are addressed later on in the sections “Supplier Involvement” and “Client Involvement”. Some points, however, apply for the entire industry such as willingness to change. As in any industry heavily affected by rules and regulations, change involves a great effort by all parties. This will to implement must come from the top-down, that is, managers must create an environment where employees know that change will come, making it a point of focus throughout the company. The people involved must be convinced of the benefits of CBM and the improvements it brings, as well as the challenges involved with such change.

On the more technical side, the most important preparation action to be done is probably a cost-benefit analysis. This represents a thorough analysis of the resources involved with the implementation and what is to be (potentially) gained from it. The accuracy of the analysis depends on how accurately the costs and benefits have been estimated. Another interesting point within the cost-benefit analysis is that it relies heavily on previous projects as a basis for estimation, and with CBM, past projects might not be existing, or their differences may be great, making the analysis harder to perform accurately. On a positive note, the analysis removes any non-technical input in the equation, such as “positive thinking” or personal interest from participants or investors, leaving the numbers to speak for themselves.

4.1.2 Vendor Involvement

Many new aspects will come into play with the implementation of CBM, and this also applies for the vendors. In the oil industry today, if you were to purchase a gas turbine from a vendor, it would come with detailed operational statistics, and failure data related to preventive / predetermined maintenance including for example vibration analyses and recommended time limits for operation as well as expected maintenance tasks with accompanying time perspectives. All this information is given to you from the vendor, because the vendors know their own product best. They will have some operational experience from their own tests and from already installed equipment (i.e. they have received operational data from the operator).

Most importantly they have watched probably dozens of their products from cradle to grave, and gained much needed experiences from their lifetime.

The same kind of involvement, and involvement exceeding the prior mentioned will be required for CBM to be a success. New ways and new equipment will be used to monitor the components, and the vendors able to supply their customers with detailed solutions and data specifically for CBM, will no doubt be preferred by the industry. The following points are noteworthy with respect to supplier involvement:

Failure modes (FMECA)

As part of the package expected from the vendor, a complete FMECA on the selected equipment should be supplied to the customer. If CBM is chosen for a component system by a contractor and recommended to the operator, it would represent an immense task to the contractor, if they were to complete these analyses on their own. They will of course have employees with experience with similar components, and though the innovation with respect to CBM lies with the surveillance procedures and monitoring equipment, the technical specifications of the equipment remains standardised.

Supplier recommendations / opportunities

When dealing with the transition into CBM, it would be a pointless approach for the operator wanting to implement CBM to simply make the decision, and then start preparing. The weight of the innovation needed in this transition lies with the vendors. Subsequently, what the vendor can recommend, and the opportunities that exist for them to supply what is needed will be the “make or break” point, and will also define the level of competitiveness between the vendors. In a business as rigid and conservative as the O&G business, one can expect a challenge in the willingness of the vendors to comply with the needs of the operator. For example with offshore gas turbines, the maintenance schedules and actions are close to written in stone, and a vendor might tell you that no other system of maintenance than the scheduled preventive / predetermined will be “allowed” or recommended, and that the warranty for the equipment cannot be upheld if other options are considered. The aspect of warranties is addressed in the next section.

Warranties

Any company producing equipment will most likely have a warranty policy stating how long they will be held responsible for the performance of their equipment, and under which conditions. The same applies for the O&G industry. An example of such a statement, from a manufacturer of acoustic underwater equipment, EdgeTech ORE Offshore, is included below:

“ORE Offshore warrants its products against defects in material and workmanship for a period of one (1) year from the date of delivery. During this period, on satisfactory proof of such defects, any unit, which becomes inoperative, may be returned, prepaid, for repair or

replacement at the option of ORE. No returns will be accepted unless prior authorization has been received and a job number assigned by ORE.

This warranty applies only to the original purchaser and only if equipment has been installed and operated in accordance with published operations and service manuals, or in a manner approved by ORE Offshore or its representatives.

No other warranty is express or implied and in no event shall ORE be responsible for collateral or consequential damages.” (ORE Offshore website)

The points stated in this warranty are similar to many others, containing a time period, such as one year, service agreements, and legal regulations. The interesting part with respect to implementing CBM is:

“This warranty applies only to the original purchaser and only if equipment has been installed and operated in accordance with published operations and service manuals, or in a manner approved by ORE Offshore or its representatives”.

This statement underlines the importance of the vendor’s involvement. They will not guarantee or support their product if the equipment is not maintained as they have instructed. The change from a PM to a CBM method will affect the nature of the maintenance of the equipment and the vendor must be aware of this and choose to support the change. No operator will approve the equipment for use, if the vendors warranty fails to apply with their current maintenance system.

There is also the issue of a vendor requesting to be responsible for their equipment only if they have access to monitor it themselves, which can be an option through a CMMS for CBM. But a concern throughout the O&G industry is that if the vendors is left to manage the equipment on their own, the temptation of scheduling offshore trips more often than necessary to make more money, may prove too big.

Considering these before mentioned points, the vendor must be prepared and willing to implement CBM, and the operator must be able to correctly receive and control their services. Also, though CBM will allow a more dynamic relation to the maintenance of the systems, clear and concise guidelines must be present, to keep the service arrangement on track, and within limits, both financial and operational.

Cost benefit of CBM vs. traditional PM

As with just about any other point of action in the business, nothing will be done if it does not ultimately lead to savings or improvement. The biggest costs include equipment and installation costs, and also running costs (see Homstuen (2009)). The benefits with respect to the implementation are increased availability and reduced needs for inspection and

maintenance. All of the benefits listed here contribute to saving money; increased availability means less downtime, reduced needs for intervention means less downtime as well as less work needed, and increased reliability leads to all the before mentioned benefits.

4.1.3 Operator Involvement

As with the vendor, there are certain roles with respect to the operator that stands out in the transition process towards CBM. These points are addressed in this subchapter and are as follows: *strategy adaptation, complying with authority and regulatory requirements, and an operator's role as the employer.*

Strategy Adaptation

When agreeing upon implementation of a CBM maintenance scheme, the operator must follow through with respect to focusing technical, human, and financial resources towards obtaining and pursuing the strategy chosen by the vendor and the contractor. A *service reception strategy* (Kumar and Markeset, 2005) is suggested to control and to manage the services that are to be received and how to receive them. This *service reception strategy* must coincide with the operations and maintenance strategy employed in the company. It must also be in relation with the service delivery strategies of the various manufacturers that the company is involved with. If it does not, the gaps between them will undoubtedly lead to shortcomings for all parties involved. Figure 4-1 on the next page shows the outline of the strategy alignment principle.

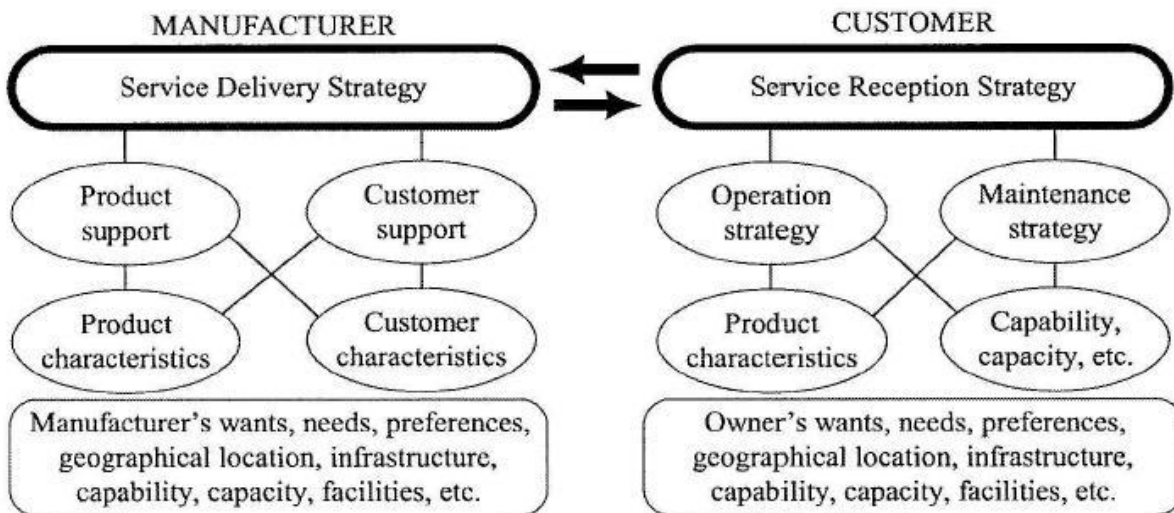


Figure 4-1: Relations between manufacturer and customer strategies (Kumar and Markeset, 2005)

Operational Responsibilities, Competence, Capacity and Challenges

As discussed earlier, the implementation of CBM on any level will require a will and ability to pursue it from all the involved parties, and as mentioned in the warranty section, there are clearly defined rules with regards to responsibility on all levels. The operator, as the purchaser of the system / solution retains much of the operational responsibilities of the production. These operational responsibilities are directly linked to the competence needed to tend to the maintenance needs, the capacity of said competence, and the challenges that the operator faces in the process. Neither the vendor, nor the contractor can be held responsible for incidents occurred because the operator did not have the skill to manage the system. So either by internal training or acquiring, or by outsourcing these tasks, the operator must make itself able to do so. Of course, this scenario requires that the operator encourages the vendor to be a part of the process at a later time, seeking the vendor's knowledge. An interesting aspect in this context is the possibility of granting the vendor access to the CBM system so that they can assist the operator, and that this possibly can lead to a "health-care contract" between vendor and the operator, where complying with the operational responsibilities is made an easier and less demanding task. This is not only recommended because IO allows such a scenario, but also because of the clear advantages that are gained with it.

Complying with Authority and Regulatory Requirements

Compliance with authority and regulatory requirements will be an important aspect as always, and the requirements should be addressed before the implementation of CBM occurs, as well as during operation, so that both parties are aware of the changes, and the effects they will have on the requirements. In many cases upholding these requirements may be made easier by the benefits mentioned in the "authority requirements" section under the "assumptions for implementation" heading.

The purchaser of the solution / system will face some aspects of the upholding of the regulations, as the operator of the equipment. It must be operated within the limits set by the vendor so as to achieve the high HSE and reliability it was designed for. At this point, a "health care contract" between the vendor and the operator, meaning a more active involvement by the vendor to aid the operator in operational challenges, made possible by the computerized CBM regime proposed in this thesis, will positively affect the safe operation of the equipment.

The Operators role as the employer

The further implementation of IO concepts, and with it CBM, aims at redefining and reducing manning offshore, and also the ability to move some of the competence to onshore installations (See Zachariassen, 2010a). As a natural result of this, the employees, represented by labour unions and other similar organizations fear for their jobs and the overall development of not only moving, but also removing workplaces. The possibility of not only

onshore control, meaning less jobs offshore, but also input from locations in other countries or continents leading to jobs being removed from the NCS and gained elsewhere worries the labour unions (Zachariassen, 2010b). Terje Nustad, head of the labour organization SAFE feels that moving the competence onshore will only work as long as the operators can recruit from personnel with offshore experience and that if this is not done, the result will have negative effects on the production. This is another important aspect of the kind of change that CBM will bring with it.

4.2 Offshore Considerations with respect to CBM

One could not attempt to address the subject of maintenance, and the changes that CBM will imply, without addressing the circumstances of offshore facilities. Though the major guidelines for CBM will apply whether on- or offshore, there are considerations which will greatly differentiate the offshore process from the onshore.

4.2.1 Storage

Space is a critical issue offshore, and the spare part storage space one might have access to onshore, will be greatly reduced offshore. One does not simply transport equipment offshore and place it on a rig “just in case”. For that, the transport and the construction price per square meter is too high. CBM will allow maintenance to be done when it is actually needed, but if the parts, or people (to be addressed later), are not present, maintenance cannot take place. This is another reason as to why the CBM process must contain all thinkable failures, and needed equipment, prior to the failure occurring, so that the things needed for the maintenance to take place can be present when needed. One must decide what spares to be kept offshore, and what not to keep offshore. Also, means of transport, and the time it will take from the decision being made that maintenance is required until it is actually possible, if the needed parts are onshore at the time.

4.2.2 Transport

An offshore facility is accessible either by ship or by helicopter, and as such, these are the only possible means of transport for both crew and equipment, and while the helicopter is the fastest it can by no means compete with the carrying capacity of any seagoing vessel. One must also consider the high cost of a helicopter transport. This implies another issue with regards to spare parts; if the part is onshore one must arrange for its transport offshore, given of course that the weather allows such a transport to take place. The size of the part is also vital as it will decide how fast it can be received. Helicopter transports to facilities on the Norwegian continental shelf are close to daily, and at bigger facilities, several per day.

4.2.3 Accommodations

The benefits of road connection and even surrounding hotels that an onshore facility might have do not exist for an offshore rig. The size of the accommodations section is set from

construction, and is in many cases a go / no go point for possibilities for offshore work. For offshore equipment to undergo maintenance by people outside of the operational crew, beds must be available and is as important as transport or storage. If there is no room for the people needed to do the maintenance to sleep, the job might be reduced to something done in a day, and not requiring beds. However, PTIL (Petroleum Safety Authority in Norway) regulates the transport section offshore to ensure, among other things, maximum safety for the people working there. Because of this it might not be as easy as just "reducing" the job so that beds are not necessary, because then you subject the people to two flights that day. Not spending one or several nights offshore solves the problem of accommodations, but creates new challenges with the amount of work that can possibly be done, and the fact that those people must be transported to and from the rig, on the same day. A concern within the O&G industry has been the trend towards a link between the operational expense (OPEX) of the rig and the number of beds available, meaning that if there are beds available they will be utilized resulting in more work being done, increasing the OPEX of the facility. CBM will, over time, require less people to be offshore, hopefully reducing the OPEX.

Ultimately, offshore maintenance requires attention to many more and perhaps not so easily seen aspects, than the same actions taken onshore, especially when dealing with actions that are not set by a calendar, as the case is with CBM.

4.3 Proposed Maintenance Strategy Development Process

The maintenance strategy development process flow chart, shown earlier in figure 2-4, gives a good example of the decision and the work needed to develop a maintenance strategy. However, there are certain parts of it that might hinder an effective and efficient co-development where PM and CBM are in focus.

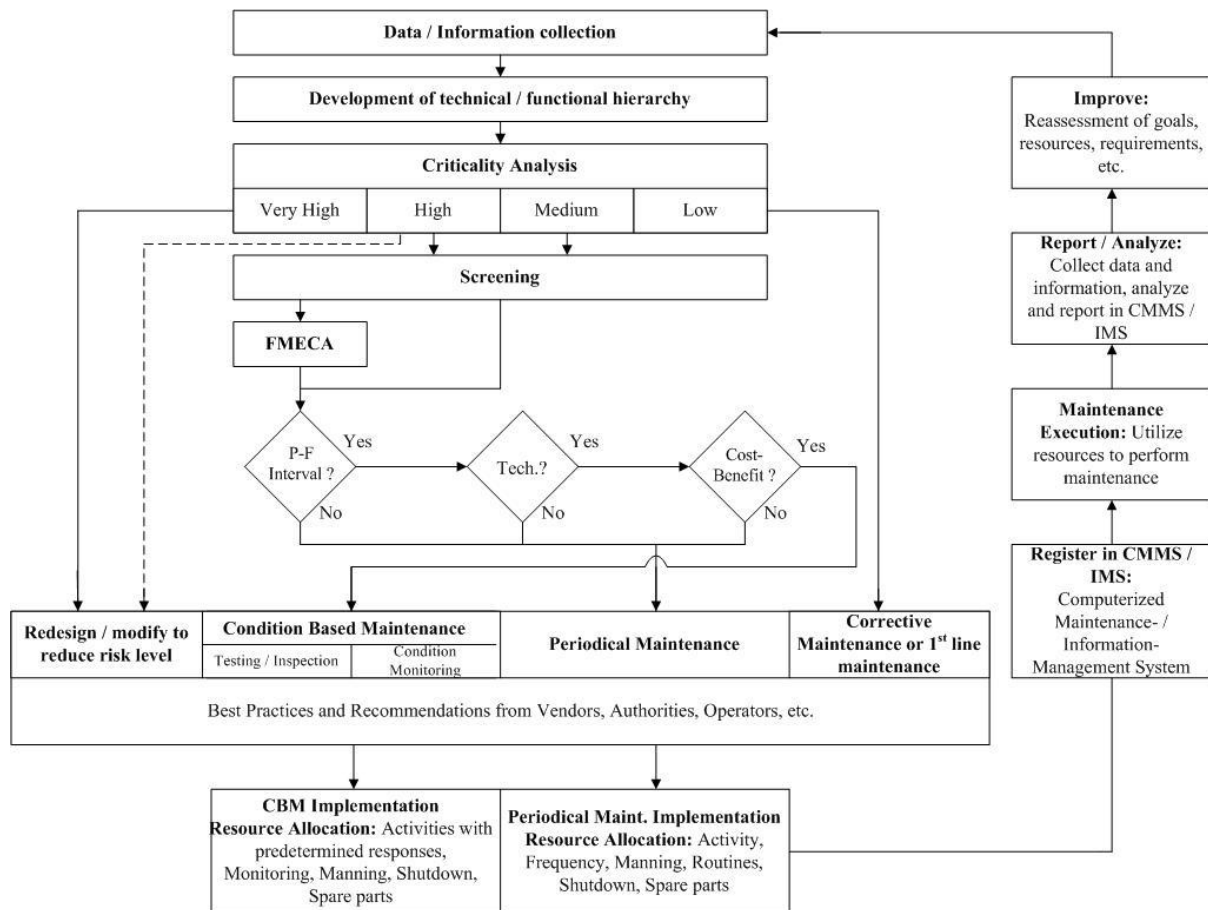


Figure 4-2: Re-engineered Maintenance Strategy Development Process (Based on figure 2-4, Kumar and Markeset, 2005)

The changes that have been made from the original process are:

FMECA

The screening process of the original chart lead to FMECA being carried out for selected equipment. We now take it one step further, by reducing the position of the FMECA process. As discussed earlier in the thesis, FMECA is a time and resource consuming process, and with the amount of equipment (old and new) needed with respect to CBM it would represent a bottle-neck in the flow chart if carried out when not needed. This suggests that FMECA should come as part of an information package from the vendor, reducing the need for it to be done later on. The FMECA process is included in the flow chart still, because most likely

there will be instances where the failure modes and effects of a piece of equipment will be less distinct and concise, and in these situations it will be beneficial to be able to further go into an FMECA analysis.

The equipment not selected for FMECA will join the ones that have gone through it, as shown in the figure, as they all have to pass through the subsequent decision gates.

Decision Gates

As a replacement for the "Decision Model" in the original figure, three decision gates related to the possibility of a CBM scheme has been included.

The thought was originally to put the Cost-Benefit aspect first, however after discussing the matter with the thesis supervisors, it was decided to put the interval issue first. This is because if there is not a practical interval and if the required technical surroundings are not present, there will be no CBM implementation, and no need for a costly Cost-Benefit analysis. Also, if the time and technical issues are present, they will both affect the Cost-Benefit outcome, as the equipment needed for the monitoring will be a major part of the investment.

Therefore, the first gate is the one related to time. The development and occurrence of a failure or reduction in operational potential must occur within time limits enabling us to react to it, find a solution and to set it into action. If this is not possible, the implementation of CBM will be futile, since it will not give us a chance to profit from the condition information of the equipment.

The second gate is titled "Technical", and addresses the required sensors needed to monitor the components / systems, as well as hardware and software to transmit and treat the operational information. We also need people with the correct competence for all levels of the maintenance scheme.

The third and final gate to be passed is the Cost-Benefit analysis. If gates one and two, a practical interval and the required technical surroundings are present, they will both be taken into account when the Cost-Benefit analysis is done. The result should ultimately decide whether we are to proceed with CBM or direct the process towards periodical maintenance

Should a component or system not return with positive results from any of these decision gates it is directed towards periodical maintenance as shown in the figure.

CBM Implementation

The CBM "path" in the flow chart has been given its own implementation section. The underlying points are adapted from the periodical maintenance implementation section in the following way;

Activity, frequency and routines have been replaced by activities with predetermined responses. This is because frequency will not exist within CBM as it did within PM. The component condition now states when maintenance is done, not the calendar. Routines and activity is now represented by activities with predetermined responses, meaning that failure modes are to be reacted to with responses involving procedures, routines, spare parts, manning etc., that are defined as a part of the engineering of the maintenance system. This is a key element of the performance of the CBM system and must be a focus point from the early design stage of the system to ensure success.

Finally, a change has been made in the feedback loop in the figure. Where it originally said CMMS, IMS (Information Management System) has been added. This is done to underline the fact that in the technical information system to manage CBM, handling the maintenance information is one of the most important functions. Including IMS into the loop makes it cover more of the actual practice.

Monitoring

This point has been added because the monitoring actions with the surrounding software and hardware issues is vital to how the condition of the component will be able to define the maintenance actions. The condition not being transmitted, or transmitted in a faulty way due to monitoring failure, can lead to undesired events and even the loss of human lives.

Shutdown, Manning and Spare parts

Shutdown and manning are included relatively unchanged but a few comments are required:

As shutdown is an activity not only done when the system is undergoing maintenance, but also to prevent possible failure or accidents, it is worth mentioning that shutdown can be a reaction to the monitoring in the CBM system; if the reaction time given by the set interval in the monitoring section is too short, shutdown may be the way to go to avoid accidents.

Manning is a vital part of both implementation processes, but where the people involved had a calendar to check for when work was to be done, the implementation of CBM will no doubt affect the reaction time, and requirements in terms of involvement and location of the competence needed (i.e. onshore facilities) of the crew set to perform maintenance.

Spare parts is a huge investment in both maintenance schemes, but will in CBM be more tied to the activities with predetermined responses, and must be treated as a less rigid process, with respect to purchasing, availability and storage, than is the case with PM.

5 ICT AND INFORMATION MANAGEMENT

In the middle of the 90`s the National Institute of Standards and Technology (NIST) and the Institute of Electrical and Electronic Engineering (IEEE) started working together to create a standardized network interface to support smart sensors (see Sethiya, 2005). The thought was to allow the sensors to communicate together like computers on a local area network (LAN). One of the biggest advantages with this type of system is that many sensors can be connected through the same cable, and sensors can be disconnected without affecting other sensors. Figure 5-1 shows how communication is suggested to flow between parties in an open system CBM design.

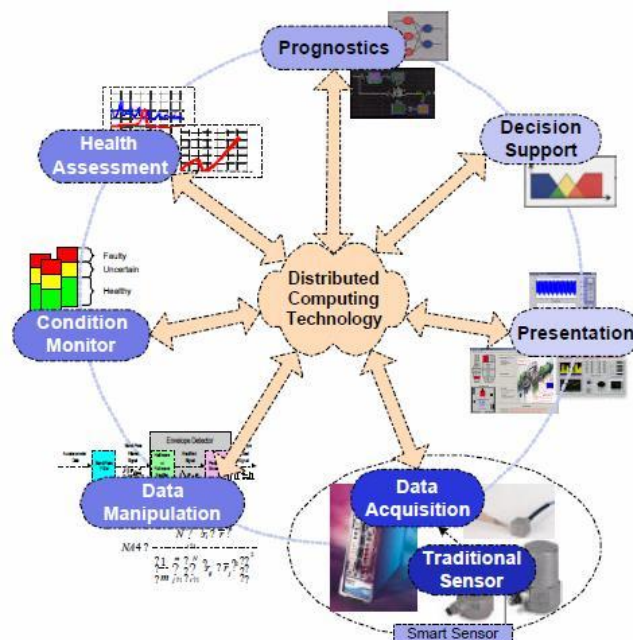


Figure 5-1: Data flow within an open system CBM design (Lebold et.al. 2002)

5.1 Network / Interface determination

As not only different types of data but also, on a general basis, more data will be sent between sensors and receivers a standard must be set for the network and communication system to ensure compliance with all parties. This system is often referred to as the distributed measurement and control system (DMC). The operator faces problems with integrating all the needed components from different vendors, which is why a standard is needed. There is also a need for standards for the software used to operate the sensors and supply their data to the correct recipient.

The OSA-CBM is short for Open System Architecture for Condition Based Maintenance and is a standard for moving information in a CBM-system (MIMOSA website).

This tool provides a framework for defining the inputs and outputs of components, and also the “roads” the information will take within the system. The MIMOSA organization (Machinery Information Management Open System Alliance) list benefits of the OSA-CBM system as:

Cost Savings: Vendors and operators will save time on not having to create new solutions to comply with each other, and because the standard is broken into blocks or section, one does not rely on a single vendor to supply all the equipment to ensure compatibility.

Specialization: Because of the block structure for integrating equipment from different vendors, the vendors are not constrained by having to supply a complete package, but can instead specialize on one or more of the blocks, allowing for more innovation and higher quality equipment. It also reduces the chance of some vendors being left out because a big vendor can deliver the entire system.

Competition: Because of the specialization achieved using the OSA-CBM standard, constructive competition on a solutions level and not a total solution level will create a better environment for innovation.

Cooperation: The standard defines the interface between the blocks, allowing for communication between them even though they may be developed by different vendors, creating a genuine platform for cooperation and learning.

5.2 The OSA-CBM model

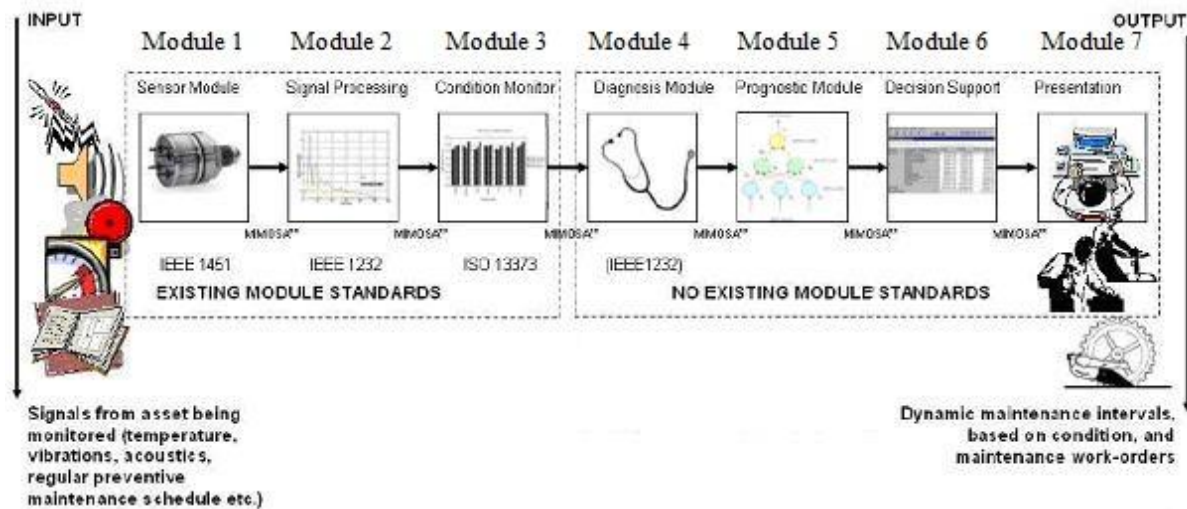


Figure 5-2: The OSA-CBM model with its seven modules (Adapted from Sethiya, 2005)

The OSA-CBM (Open System Architecture for Condition Based Maintenance) standard separates the CBM system into seven modules, as shown in figure 5-2. Lebold et.al (2002) has described these modules in their analytic paper "*OSA-CBM architecture development*". In the figure, they are separated into two sections, the first containing the three sections where standards exist, and the second containing the last four, where no standards exist. Though the data is treated by each module, the final module can access each of the others individually, as shown in figure 5-3

Module 1: Sensor Module / Data acquisition

This first module represents the software used to access the digital sensors or transducers, both for programming and acquiring data. Physically, it will consist of a server recording and manipulating the raw operational data from the equipment.

Module 2: Signal Processing / Manipulation

The primary function is to receives data from the sensors and process it to the request from the condition monitoring module.

Module 3: Condition Monitor

The condition monitor module will receive operational data and compare it to set operational limits and values and output condition indicators such as low or high level.

Module 4: Diagnostics module / Health Assessment

Assesses the health of the connected system or subsystem and, by comparing it to former trends, in the history of the system, maintenance records and operational status

Module 5: Prognostics

The primary function of the prognostics module is to project the expected health of the system into the future based on the received data, trends and former history. Also, an output of expected remaining operational time shall be generated.

Module 6: Decision Support

The decision support module is to provide recommendations and alternatives based on information received from the prior modules including operational statistics, objectives, mission profiles and resource constraints. The recommendations will concern maintenance actions and schedules, as well as modifying equipment configurations and settings to ensure that operational goals are met.

Module 7: Presentation / Human Interface

The presentation module will transmit results from the former modules such as health assessments, diagnosis and prognostics and also recommendations from the decision support module to the user creating a scenario with multiple options and actions. See the figure below for a graphic display.

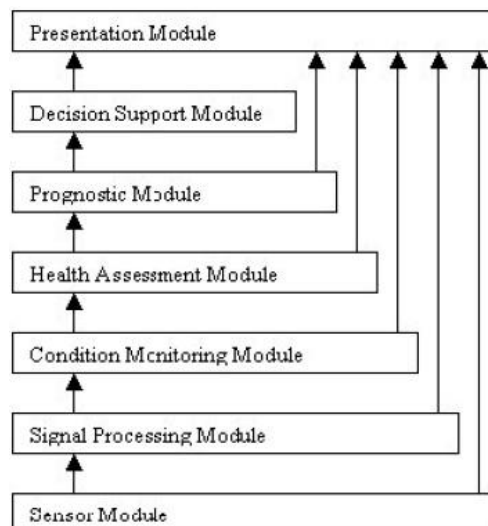


Figure 5-3: The information flow of the OSA-CBM model (Sethiya, 2005)

5.3 Existing standards

In figure 5-2, IEEE and ISO standards are proposed in relation to communication between the modules. A more in-depth explanation of the standards follows:

IEEE 1451 is a set of standards for interfacing between smart transducers in a network developed by the IEEE instrumentation and Measurement Society's Sensor Technology Technical Committee (see Wikipedia Online). One of the key elements for this standard is the definition of TEDS (Transducer Electronic Data Sheet) for each transducer. The TEDS is a memory device connected to the sensor enabling it to store identification, correction, and calibration data, as well as manufacturer-related information.

IEEE 1232 is a standard for Artificial Intelligence Exchange and Service Tie to All Test Environments (AI-ESTATE). "AI-ESTATE is a set of specifications for data interchange and standard services for the test and diagnostic environment. Its purpose is to standardize interfaces between functional elements of an intelligent diagnostic recipient and representations of diagnostic knowledge and data for use by such diagnostic recipients. Formal information models are defined to form the basis for a format to facilitate exchange of persistent diagnostic information between two recipients, and also to provide a formal typing system for diagnostic services. This standard then defines the services to manipulate diagnostic information and to control a diagnostic recipient." (Thomson Reuters Online)

It is worth mentioning that the IEEE 1232 standard is also mentioned as a possibility for layer four, Diagnostics module / Health Assessment.

ISO 13373 is titled "Condition monitoring and diagnostics of machines – Vibration monitoring" and it provides general guidelines for measuring machine vibration in a condition monitoring setting. It contains recommendations for the following: Robichaud (2008)

- Measurement methods and parameters
- Transducer selection, location, and attachment
- Data collection
- Machine operating conditions
- Vibration monitoring systems
- Signal conditioning systems
- Interfaces with data processing systems
- Continuous and periodic monitoring

These standards are fitting for their placement in figure 5-2, and having addressed the issue of trust and competition, the fact that they come from such internationally renowned instances as ISO and IEEE will help towards the standardization process. The last four layers represent technology not yet available, and with no suggested standards, but with the growth that IMS systems and computers have had over the years, such technology will no doubt be developed in the years to come.

5.4 Data and Security Issues

The interface chosen for communication between technical and human aspects must provide a functional platform for the users. That being said, another obvious important issue with the ever more extensive use of computer systems for not only communication, but eventually the control of production systems, is security.

Computer crime is a valid threat to such computerization, and must be taken into account. And even though bigger companies such as Statoil or Hydro are better protected as they know that they are exposed, (Gram, 2010) such eventualities must be addressed when designing these systems. If the production on an offshore rig is controlled via such a system, attacks by hackers, threatening the production would be catastrophic. Norwegian industries spend between five and six billion NOK yearly on research and innovation (Gram, 2010) to better face this threat, leaving no doubt as to the importance and cost of these activities.

Remote input and possibly control of production involves risk not only with respect to computer systems, but environmentally and financially as well. The level of access from third parties must be regulated to ensure a high level of security as well as accessibility and efficiency.

5.5 SmartConnect – An Example

Mechanical engineer Kenneth Innes, working for Shell, was in June of 2008 awarded the Royal Academy of Engineering's Silver Medal. (Shell website) The reason for this award was that he led the development of a new online monitoring system, called SmartConnect, able to continuously monitor pumps, compressors and turbines, and with that, optimizing both the maintenance actions and the operational performance of the equipment. He worked with Shell colleagues all over the world to map the most frequent kind of errors, and to utilize the data that was collected routinely by the plant control systems to monitor the operation of the equipment. The software was tested on the Nelson production platform in the UK, where it revealed equipment problems at an early stage, enabling actions to be taken before failure occurred. Shell's Global Discipline Head for Rotating Equipment, Wim Hardeveld, was quoted making the following statement:

“Ken's real innovation has been in combining knowledge and technology from a number of traditionally separate disciplines...”

“...SmartConnect can optimize the production process by 1 - 3 percent, so, on a typical platform producing 50-100 thousand barrels of oil a day, this could equate to over \$100,000 each day in increased revenue.”

The work performed by Innes is very interesting, especially with the software's ability to reveal equipment problems at an early stage, which is one of the desired outcomes from the application of CBM and a key to its successful improvements of the production. Another interesting point is the potential, though theoretical, optimization of the production by 1 to 3 percent, revealing that such "smart" software can have a major impact not only operationally, but also financially.

6 DISCUSSION AND CONCLUDING REMARKS

Today's vs. future CBM regime

Though CBM exists in use today, it is at a very modest extent, and the future extended use and commitment toward CBM in the O&G industry will no doubt lead to enhanced performance on all levels. The application of CBM has so far been limited to heavy rotating machinery due to many things such as existing extensive operational data and experience with this equipment, easing the implementation of CBM and leading to improvements in operation and cost. In the future, CBM will expand to less important / expensive pieces of machinery as the basis for CBM offshore is already laid and will develop further. When developing the maintenance regime of the future, one must not focus merely on the expansion of CBM, but the coexistence of both CBM and PM together and their continued involvement as a total maintenance regime. A key element for the future development and use of CBM in the offshore sector is a greater involvement of the vendors, suggested through contractual obligations, not only guaranteeing an improved technical support situation but encouraging growth through a joined focus on making CBM work, and making it better.

In the maintenance section today, generic concepts for both the engineering and operation of PM systems exist. They can be found in most maintenance departments in the companies in the sector, and are often shown in flow charts and engineering sketches. From a PM point of view the major difference to CBM is no doubt the removal of the "maintenance calendar" and subsequently, the dynamics of a CBM system. An interesting point for the future is how, and to what extent and advantage such generic concepts will be used in a CBM setting.

Relation to IO

The concept of integrated operations forms the basis for CBM. A suitable metaphor might be to view IO as a motor highway, and CBM as the vehicles driving on it. The sharing of information, data and competence that IO allows is vital for CBM to be able to perform, meaning that if there is no IO, there can be no CBM. The future development of both is connected and will no doubt affect each other both in design and operation, more or less becoming a joint operational foundation for the offshore sector.

Challenges with CBM

CBM requires improved equipment to be developed and installed, and so the initial cost of CBM is high and must be carefully evaluated and compared to the expected improvements (i.e. increased production and reduced overall and long-term maintenance costs). Much of the reason for this high initial cost, so far, has been that CBM offshore has been associated with heavy rotating machinery which is already a high cost area, and subsequently the equipment needed for CBM on this equipment has been expensive.

On the technical side, challenges will arise within monitoring, collection and processing of the data needed to build a condition based operational status. Though heavy rotating equipment has obvious data sources in vibration, oil analysis and input/output comparison, further use of CBM with other types of equipment will require new equipment and procedures to make CBM possible.

Changes in how maintenance is done within the company will occur, and such changes will no doubt result in challenges of their own. Organizational and managerial changes are in general difficult and demanding, and so the change will lie not only in how maintenance is performed but also in the entire maintenance system in the organization. These issues will require a high level of commitment and trust to make them work.

Some advantages and disadvantages related to CBM have been listed below;

Advantages

- Fewer number of maintenance operations, with accompanying decreased human involvement cost and subsequent risk exposure
- Improved system reliability due to higher predictability
- Decreased total maintenance cost over time

Disadvantages

- Costs are less predictable and less stable, due to the timing of maintenance actions being less rigid
- High initial costs associated with purchase, installation and implementation
- CBM in itself will require an increased number of parts, adding to the amount of equipment requiring maintenance and is needed for secure production.

This thesis has been addressing the criteria for deeming a component fit for CBM. Also the areas of authority requirements, changes in maintenance and criticality analysis, and certain preparations for the transition have been addressed. With respect to both preparation and the impact on the existing maintenance scheme vendor and operator involvements have been mapped, and key elements such as warranties, possibilities of a "strategy adaptation" scenario and employer considerations has been mentioned. The purely technical challenges for an ICT / CMMS system are discussed under chapter 5, with an example of such a solution in the Shell Smartconnect system. The maintenance strategy development process has been redesigned, and is suggested to better suit a maintenance regime where CBM and PM both can be the output of a selection process and coexist.

Way forward

The way forward within development, implementation and operation of CBM holds many challenges. Some of them have been addressed in this thesis, and will require further work in the future.

- Contractual Obligations

The co-work and relations between vendors and operators is an interesting field because of the potential advantages with respect to maintaining and developing warranties on the equipment, and achieving increased operational performance.

- ICT Solutions

As CBM and IO both depend on ICT systems, the further research and development in this area will set the bar for the future potential of maintenance and production offshore. A specific example can mentioned in the not yet developed modules and "missing" standards in the OSA-CBM model and also the subsequent issues within transmitting, storing and processing maintenance data efficiently and safe. As data transmitting increases, means to keep the data from getting into the wrong hands will play an important role.

- Manning

The potential of CBM includes the overall reduction of maintenance being carried out offshore and subsequently the personnel need offshore. As the reduction and / or relocation of manpower is addressed it will prove a challenging task to balance the competence needed from a managerial, human and technical point of view.

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