World Class Maintenance (WCM): Measurable indicators creating Opportunities for the Norwegian Oil and Gas industry.

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Abstract – **World Class Maintenance (WCM) concept is considered as an integrated approach to perform asset maintenance comprehensible for all participants in an industrial organization. WCM creates opportunities to make the work processes more efficient and effective in a way that these are universally applicable to increase the safety, economy and overall efficiency of the assets. A well-defined WCM work process can offer a unique business opportunity with minimum costing to the assets' owner whilst increasing significant return on investments. This manuscript attempts to explore the adaptability of WCM concept in the Norwegian Oil and Gas (O&G) industry. It further identifies measurable WCM indicators and highlights the current trends of WCM as observed in the Norwegian O&G industry. The identified indicators in this context can be used for mapping current performance of any operating assets by comparing it with the WCM standards.**

Keywords – **World class maintenance, Key performance indicators, Asset maintenance best practice.**

I. INTRODUCTION

History reveals negligence of performing adequate and incompetent maintenance has caused devastating disasters such as; Sea Gem, Alexander Kielland, Ocean Ranger, Piper Alpha, Petrobras P-36, West Atlas and Deep-water Horizon etc. [1]. These disasters have brought some of the operating companies almost into bankruptcy whilst leaving enormous Health, Safety and Environment (HSE) challenges [2]. It is vital to avoid such devastating outcomes especially in the offshore O&G industrial environment where these pose a larger risk to both personnel and the asset. The aftermath incident reports revealed that many of these incidents were due to not only negligence of maintenance and/or inspection activities but also lack of pre- and post-planning, human errors and organizational deficiencies etc. [3]. Hence, it is vital to establish a more global best practice towards existing maintenance regimes to improve such deficiencies.

A number of regulatory requirements (e.g. Norsok standards) together with recommended best practices have been introduced by the Norwegian Petroleum Safety Authority (PSA) to ensure that the petroleum activities maintain higher standards of HSE, reliability and cost-effectiveness. However, an audit conducted in 2006 and 2007 on maintenance management systems of four operator companies and one drilling contractor revealed that most of the Companies did not meet the regulatory requirements [4]. For instance, "the competence requirement lacked or deficient, despite such competence being critical to safety"; "not a good enough overview of how extensive and resource-intensive the need for maintenance is, and what risks the personnel carrying out maintenance work are exposed to" etc. [4]. The aforementioned challenges forced O&G assets owners revitalizing the existing maintenance management work processes, practices and systems.

WCM has been coined as the backbone for meeting effective and efficient maintenance engineering and management process. Having implemented WCM approach, an industrial organization can assure right tasks at the right time utilizing optimum resources on the right location (or equipment) by the competent personnel. Consequently, an asset intensive industrial organization can reach for higher HSE performance and return from the operating assets.

Industry specific tailor made approaches have been adopted in an isolated fashion by different asset intensive organizations to maintain their systems at a world-class level. Here, "World-Class" means to be able to compete anywhere in the world and to be able to meet and beat any competitor by product- price, quality and on-time delivery [5]. Ref [6] revealed that world-class means the art and science of managing maintenance resources performed by best in class industries from around the world.

Many authors have referred to WCM as a transition from a Preventive to Predictive maintenance. Some others focused about achieving excellence through Key Performance Indicators (KPI) [6]. WCM is the collection of best maintenance practices that are followed and adopted by various organizations to transform themselves to be a world-class manufacturer [7]. Therefore, the function of maintenance with the optics of world-class is interpreted like a strategic capacity that a company has and allows it to compete through a good integral management of equipment throughout the service life [7].

WCM requires integration of maintenance management with organizational functions. The purpose of setting up the WCM indicators is not only to identify the measureable indicators, but also to provide an accept criteria for performance measurement. This paper highlights WCM indicators and recommends accept criteria for the Norwegian O&G industry. The accept criteria presented in this paper is based on industry best practices.

II. BACKGROUND

Maintenance performance is an outcome of complex activities which can be evaluated by appropriate indicators comparing actual and expected result [8]. Measurements allow us to determine if the equipment is performing to its intended expectations or not. Such measurements are done in the form of KPIs. The KPIs should be carefully selected as these highlight current and future focus areas for the organization.

Organizations are always focused on controlling maintenance cost as this can be up to 40% of the total operational budget. These costs need to be optimized in a way that minimal cost is used to keep the equipment performing its intended functions when and where needed. But such cost reductions are not possible to be optimized over the night. At first, the existing process should be improved by benchmarking (internal and external), with best practices. Such best practices provide a sound basis for the O&G industry to run their assets with effective costs and highest possible safety standards. Best practices are usually defined as the maintenance practices that enable a company to achieve competitive advantages over its competitors [9]. Benchmarking is a process of continuously comparing and measuring an organization with business leaders anywhere in the world to gain information that will help the organization take action to improve its performance. Benchmarking provides an effective means to identify and quantify reliability and maintenance improvement opportunities [10].

The management should support this journey of excellence in implementing best practices. Next step is to determine the strategies, programs, and/or activities required to make the improvements as a result of a change management process. It is not practically feasible to recommend a generalized set of KPIs and indices suited for an organization as the KPIs varies from business to business. There is no single and perfect KPI that can measure the performance of one particular industry. As a result, there are different sets of KPIs and organizations need to select the most suitable KPIs for performance measurement and monitoring. Both maintenance and operation should agree upon which indices they want to measure and what they can control. In the field of maintenance management, it is possible to measure the failure rate or number of breakdowns, downtime, availability, utilization, Mean Time Between Failures (MTBF), Mean Time To Failure (MTTF), Overall Equipment efficiency (OEE), set-up-time, Mean Time To Repair (MTTR), maintenance costs, spare costs and so on.

III. MEASURABLE WCM INDICATORS

WCM indicators measure the maintenance performance compared with the "world-class" levels. Measuring performance allows to identify the area of improvements and likewise to determine which strategies, programs or activities are required to make the improvements [6]. Measurable indicator means that the indicators are capable of measuring current status of an organization. Therefore, the indicators identified in this paper are attributed with numerical values. The values are based on industry experiences and provides an accept criteria to compare the performance with WCM standards. These indicators are as follows:

A. Preventive Maintenance to Corrective Maintenance ratio

This indicator is called '6 to 1 Rule'. It is a ratio of Preventive maintenance and Corrective maintenance tasks. The rule says that there should be a corrective maintenance work after at least 6 preventive maintenance works. The '6 to 1 Rule' is proven by John Day, JR. Manager of Engineering and Maintenance at Alumax of South Carolina. In 1989, Alumax of South Carolina was certified as the first organization in compliance with the World-class standards [11].

The theory assumes that the Preventive maintenance and inspections should reveal some type of corrective work. If the ratio is greater than 6:1, the preventive maintenance is being performed too often resulting very small time allowed for emergency work and no time left for solid corrective work to prevent emergencies or perform other unplanned work. If the ratio is less, the PM is not often enough. At the same time, if the PM activities are not finding any problems, the PM program may not be effective enough [11]. The important fact here is to set up the right balance between the frequency of PM activities. Frequency of performing a PM should be based on asset failure rate or Mean Time Between Failure (MTBF) rate. In the useful life phase from a bathtub curve distribution (where the failure rate is almost constant), MTTR can be used as a representative for PM interval. To establish the right PM program, it is required to identify an initial interval based on available information such as manufacturer's recommendations, Safety Integrity Limit (SIL) requirements and Safety Requirement Specifications (SRS) etc.

Experts from Norwegian O&G industry have recommended this ratio to be around 5:1. Since the offshore installations are complex in operation, safety issues are to be of the highest priorities. It is quite common that the emergency situation might occur anytime. Therefore, more time is required for emergency corrective works. As a conclusion, after 5 preventive work orders, there may be 1 corrective work order.

B. Annual Maintenance Cost as a Percent of Replacement Asset Value (RAV)

This indicator has been standardized by the Society of Maintenance & Reliability Professionals (SMRP) based on their experience and consensus of its Best Practices

Committee. This standard will allow to compare the maintenance expenditures with other plants of varying size and value, as well as to benchmark. This indicator can be expressed by the following formula:

$$\text{Annual Maintenance Cost per RAV (\%)} = \left(\frac{\textit{Annual Maintenance Cost}}{\textit{Replacement Asset Value}}\right) \times 100 \quad (1)$$

In Equation 1, Maintenance cost = Equipment repair cost + loss of production due to downtime.
Where,
Equipment repair cost = (Number of men X hours used in maintenance work) + material cost

In most of the cases loss of production is not added for calculating maintenance cost, which may vary from 2 to 15 times of the repair cost.

Replacement Asset Value is the value that is needed to replace the production capability of the present assets in the plant. It includes production or process equipment as well as utilities, support and related assets.[6].

To achieve WCM standards, annual maintenance cost should be in between 1.5% to 2.5% of the RAV. Recent research shows that the maintenance cost is 1.8% of the replacement asset value for the Norwegian industry [11]. In Norwegian O&G industry, it may be sometimes quite challenging to precisely evaluate the maintenance cost due to many variables. For simplicity, it is recommended that the maintenance cost to be regarded as work "man-hours", i.e. more the man-hours, higher the maintenance costs.

C. Maintenance Schedule Compliance

Schedule compliance is defined as the percentage of work orders completed during the scheduled period before the required date. It is calculated either as a ratio of maintenance labor hour consumed for jobs or tasks completed (approved) divided by the total available labor hours during that period [10]. Another way to calculate schedule compliance is as a ratio of the number of jobs/tasks completed (approved) divided by the total jobs/tasks on a schedule.

Schedule compliance indicator ranges from 35% to 95% from organization to organization. As it is quite impractical to achieve 100 % schedule compliance due to the fact that reactive work might appear during weekly schedule. In order to comply with world-class standards an organization with more than 90% schedule compliance can be regarded as achieving its excellence. High schedule compliance means higher uptime and higher asset utilization rate. Based on industry experience, it is recommended for the Norwegian O&G industry that there should be zero overdue (no overdue). Some experts have suggested a flexible range of schedule compliance from 90% to 95% for the Norwegian O&G industry to achieve world-class status.

D. Equipment Availability

Maintenance plays an important role to keep the equipment in an operable condition. Availability is defined as the time a machine is available for work less all the downtimes (both planned and unplanned downtime) divided by the total available time. Asset availability is calculated by the following formula. [6].

$$\text{Availability} = \left(\frac{\textit{Available Time} - \textit{All Downtime}}{\textit{Available Time}}\right) \times 100 \quad (2)$$

One rule of thumb is that improvement in availability by 1% will reduce the maintenance cost by 10%. The main difference of World-class standards with prevailing maintenance concept is that WCM has the right number of equipment available at the right time to achieve its function.

Equipment availability is considered as a maintenance indicator because the performance of an equipment is influenced by the maintenance. This indicator ranges from 65% to 99%. World-class organizations exceed 97% of equipment Availability. [9]. For Norwegian O&G industry, equipment availability is also recommended to be more than 97% to achieve world-class status based on industry expert's experiences.

E. Percent of Preventive Maintenance or Predictive Maintenance hours to total hours

Preventive maintenance is the strategy based on inspection, component replacement and overhauling at a fixed interval regardless of its condition at that time. On the other hand, in Predictive Maintenance, equipment condition is measured after observing signs of degradation or impending failure based on either continuous monitoring or statistical data of the equipment and initiatives are taken accordingly [13].

Preventive Maintenance (PM) or Predictive Maintenance (PdM) can save as much as 1.2% of the total plant output. PM allows the organizations to plan better and thus reducing the maintenance cost. Based on a survey on USA's manufacturing industry, it is found that only 22% of the organizations are practicing Preventive maintenance [13]. To be more effective in implementing PM, there should be coordination between operation and maintenance. Almost ¾ of all organizations experience problems in coordinating preventive maintenance with the operation group. But the results of implementing PM/ PdM cannot be consumed at once. It can take three to five years to feel the improvements by best practices. The percentage of hours spent on preventive and predictive maintenance activities ranges from 20% to 50% compared to the total hours spent. The world-class requirement is 50% of total hours should be spent for PM/PdM activities. In Norwegian O&G industry, it has been found that the percent of preventive or predictive maintenance is 30.9% of the total maintenance hours. Recommendation for world-class status is more than 40% of the total time [12].

F. Stores Service Level

Store service level means the percentage of the time a part or material is found in the right location and that the quantity of them in the store matches with the system inventory number. In many companies, inventories may be 20% to 30% higher than necessary because of lack of management attention. Many companies overstock the store room to solve maintenance material problem. With successful maintenance inventory management service, material cost can be reduced up to 19% compared to the company who does not pay attention in this area [9]. The savings from reduction of insurance inventories can actually finance the entire preventive maintenance program. It should be kept in mind that storing parts costs are over 30% of the items per year. The store service level ranges from 80% to 99%. World-class maintenance organization service level should be more than 95%. A service level below 95% will result in unnecessary downtime due to parts outages. A service level above 97% indicates too many spare parts are being carried [13]. There should be a balance between financial considerations for downtime and insurance cost for holding the spare parts. Based on experts' advice, in Norwegian O&G industry, the stores service level should be 80-90% to comply with WCM standard.

G. Reactive Hours as a percentage of Total Hours

The percentage of reactive hours compared to total hours spent in maintenance work varies from organization to organization. Generally, this indicator ranges from 5% to 50% or more. But to be a world-class organization, the reactive hour should be less than 10% even though this is not the limit. It is always possible to have some reactive works which is beneficial for a cost-effective maintenance program. Statistics from manufacturing industry in USA shows that 14.1% of the total maintenance work time is overtime indicating the reactive attitude towards maintenance. For WCM, it should be about 4.7% [13]. This overtime cost is to meet the schedule compliance and the production not made on time. As a rule of thumb, if the corrective maintenance costs rise up to 80% of total cost of the equipment, a detailed Cost Benefit Analysis (CBA) is recommended to evaluate possibilities for modification and/or replacement of the equipment. To control reactive hours, detailed Root Cause Failure Analysis (RCFA) is recommended to identify failure causes and to initiate mitigating actions accordingly. It has been found that in Norwegian O&G industry, percent of reactive work is 23.7% whereas, in order to comply with world-class standards, recommended range should be less than 5% [12].

IV. COMPARISON OF MAINTENANCE PRACTICES

Table 1 shows a comparison of current maintenance practices with world-class standards. The information provided here is mainly based on literature review, experts' opinion and available industrial best practices. The table shows that the indicators have a conservative range of world-class for the Norwegian O&G industry compared to generic world-class range for other industries. This is because of the risks involved in the complex offshore installations.

The table below summarizes all mentioned WCM indicators with recommended accept criteria for Norwegian O&G industry.

TABLE: 1
A SUMMARY OF WCM INDICATORS

WCM Indicators	Typical Range	World-class Range	Norwegian industry practice	Recommended for Norwegian O&G industry
PM to CM ratio	3:1	6:1	3:1	5:1
Annual Maintenance cost as a percent of RAV	3-9%	2.5% to 3.5%	1.3	Less than 1.8%
Maintenance Schedule Compliance	35-95%	More than 90%	58.3%	90-% to 95%
Equipment Availability	65-99%	More than 97%	89.8%	More than 90-% to 95 %
% of PM or PdM hours to Total Hours	20-50%	50%	30.9 %	More than 40%
Store Service level	80-99%	95%	Not found	90-% to 95%
Reactive Hours as a % of Total hours	5-50%	Less than 10%	23.7%	<5%

V. CONCLUSION

The WCM indicators suggested in this paper provide an opportunity to compare the asset performance with world-class standards. Implementation and effective follow-up of these indicators provide opportunities for the Norwegian O&G industry to improve their asset performance. In order to gain full benefits of the suggested WCM indicators, it is necessary to understand the resulting organizational changes. Management, therefore, must facilitate and monitor the WCM process. It requires integrated collaboration of several departments and may impact the company culture and values. WCM standards in this context are provided with an accept

criteria which can enable an organization to evaluate how far or close their existing processes lie in complying with the world-class standards within asset maintenance.

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