Collaborative Learning in Condition Based Maintenance

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***Abstract*—In recent years, the importance of reliable and consistent production equipments has increased. As a result, companies are shifting their maintenance policy from preventive maintenance towards Condition Based Maintenance (CBM). Despite the growing trend in this area and success stories of CBM implementation in the literature, in reality, many programmes do not meet the predefined targets. In this paper, we investigate how collaborative learning within asset life cycle and between operation and maintenance disciplines effects CBM programmes success. The theoretical arguments are supported through a case study within an industrial plant.**

***Index Terms*—Condition based maintenance, physical asset management, predictive maintenance**

I. Introduction

Maintaining the integrity of plant assets is one of the most important elements in modern day asset management. The emphasis is on the machine availability improvement, which results in economic gain [1]. Ineffective maintenance management worldwide causes a loss of more than $60 billion each year [2]. The dominant reason for this ineffective management is the lack of factual data to quantify the actual need for repair or maintenance of plant machinery, equipment, and systems (ibid). Therefore, it is very important to select an appropriate maintenance policy to support decisions for inspection or repair. Condition Based Maintenance (CBM) is one of the maintenance policies that support the above notion through providing real-time status information of the equipments which assist maintenance engineers to achieve higher availability of the system.

Despite the growing trend in this area and success stories of CBM implementation in the literature, in reality, many programmes do not meet the predefined goals. In this paper, we investigate how collaborative learning within asset life cycle and between operation and maintenance disciplines effects CBM programmes' success. The remainder of this paper is organized as follows. Section II gives further insight about CBM. In section III, the concept of collaborative learning and its application in CBM programmes is discussed. In section IV, methodology is explained and the case is introduced. Following that, the results are analyzed in section V; and finally in section VI, the conclusion is presented.

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II. Condition Based Maintenance

A. *Maintenance policies - Paradigm shift*

In the literature, maintenance is categorized into corrective maintenance policy and preventive maintenance policy [3],[4]. Corrective maintenance (also called breakdown maintenance or run-to-failure) is repairing equipment (or components) after failure has occurred. Preventive maintenance (also called planned maintenance or time-based maintenance) involves preventive actions such as inspection, repair, or replacement of the equipment. It is performed in fixed schedules and regardless of the status of a physical asset. This policy has advantages in comparison with run-to-failure such as minimizing unscheduled downtime, labor costs, and maintenance costs [5]. However it is not an ideal solution and has some drawbacks too. Preventive maintenance does not eliminate catastrophic failures and includes performing unneeded maintenance activities, which exposes equipments to possible damage [3].

The rapid development of new technologies has made products more complex and reliable, causing higher preventive maintenance cost [6]. At the same time, firms prefer such maintenance services to increase equipment availability rather than to develop entirely new plant. These reasons are moving the plants from the traditional corrective and scheduled maintenance towards condition based maintenance policy [7] (see Fig. 1).

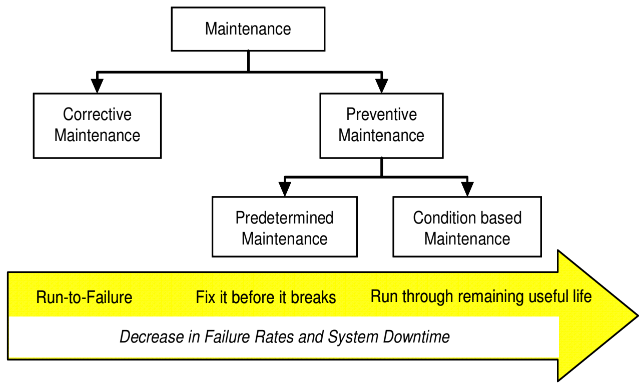

Fig. 1: Paradigm shift in industrial maintenance

B. *Condition Based Maintenance – Opportunity or Trap?*

According to [6], "Condition based maintenance is a maintenance program that recommends maintenance actions based on the information collected through condition monitoring techniques". The CBM techniques (e.g. vibration analysis, fluid analysis, infrared thermography, voltage and current monitoring and etc) are designed to actively monitor

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equipment conditions. In recent years, there has been a surge of academic interest in the area of CBM and condition monitoring, which can show partially a trend of this maintenance policy within practice. However, despite the growing trend in this area and success stories of CBM implementation in the literature, in reality, many of the CBM programmes fail or are not financially justified [2],[8]. In the literature survey of CBM [9], it is found that the majority of publications are theoretical in nature, or consists of micro-level applications of parts of CBM programme implementation and mostly have focused on success stories rather than reasons for failure. Though, in the next chapter firstly the notion of collaborative learning is introduced and later we discuss its role as one of the major factors in CBM programmes success.

III. Collaborative Learning

The notion of 'Collaborative Learning' is usually used in educational systems which is based on the idea that learning is a naturally social act and it occurs during communication among participants[10]. In [11] collaborative learning has been defined as " a situation in which *two or more* people learn or attempt to *learn* something *together*". This definition has some key words which explaining them will enable us to address the paper objective. 'Two or more' can be a pair, a small group (5-10 people) or a large group (20-30 people). The 'learning' may happen through following a course, performing problem solving activities or learning from lifelong work practice. 'Together' can be face-to-face or computer-mediated.

Information (and knowledge) management is one of the success factors in maintenance management and plays an essential role in decision-making [12]. Among different maintenance policies, CBM has substantial interaction with other departments (e.g. engineering, operation) and due to its nature, it requires different types of data, information, and knowledge. Therefore, it seems that the notion of collaborative learning is quite applicable for CBM programmes and above defined elements can be easily found in an organization. The participants of this learning are scattered through the asset life cycle. Though, the learning process can happen in acquisition phase (i.e. stages before production), utilization phase (i.e. stages after final commissioning) or both [13].

A. CBM in acquisition phase

Intrinsic complexity of competitive global economy has drawn the attention towards Asset Lifecycle Management (ALCM)) [14]. The necessity to maintain or even increase operational effectiveness with simultaneous costs reduction is the largest challenge of this 'next wave' [15]. In this concept, maintenance is one of the key elements that directly affect the plant's reliability and availability. Although many articles have been written on the relationship between lifecycle management and maintenance, only a few authors have investigated CBM or condition monitoring techniques in acquisition phase. For instance, in [16], it is tried to determine diagnostic/prognostic technology requirements during the design phase and in the other paper [17], the importance of *event* data (i.e. installation, inspection etc) for CBM has been emphasized. In practice, CBM policy has been neglected in earlier phases as well and the focus has been on the traditional maintenance policies. Design for Reliability (DfR) and Design for Maintainability (DFM) are being utilized in which the former is mainly dealing with technical empowerment of the system for the failure prevention and the latter consider the ease of repair or replacement.

On the one hand, condition based maintenance requires advanced theoretical knowledge of equipment, comparing with the traditional maintenance policies (i.e. preventive and corrective) and on the other hand, design engineers have higher theoretical background in comparison with the field engineers. Therefore, design engineers would serve as better candidates to define CBM guidelines, threshold levels and other CBM requirements. Furthermore, functional capabilities of information systems have the most profound impetus for a holistic approach to physical asset management [18] through: 1) Easing data, information and knowledge transfer along the value chain and between the life cycle stages; 2) Facilitating the pertinent analyses for the decision-makings; 3) Removing legacy distinctions between core competencies required for effective physical asset management.

Thereby, The designers can involve in collaborative learning process through considering CBM concept in the process control philosophy, generating structured document useful for both operation and maintenance and enriching a knowledge platform that support CBM decision-making processes which would have positive effects on success of CBM programmes in the utilization phase.

B. CBM in utilization phase

Today's complex technical systems do not allow to a single discipline to judge about the technical condition of a system [19]. In the utilization phase, process control and CBM, which are performing under the responsibility of operation and maintenance respectively, each has partial knowledge of the system. CBM programme success depends on the level of interactions between these two groups and the knowledge transferred through a collaborative learning system. However, this collaboration will not take place easily.

Process control systems are designed to adjust the manipulated variable to maintain the controlled variable at its set point in spite of disturbances [20], and are not intended to support maintenance functions. Although some statistical techniques like Principal Component Analysis (PCA) have been introduced in literature [21], however their capabilities in fault isolation are limited [22] and mainly are designed for analyzing process parameters rather than equipment failures. Meanwhile, in practice, hierarchical control system and inappropriate infrastructure still exist and there is a grey area between maintenance management and process control.

Moreover, every company has some barriers in its organizational structure that prevents effective coordination and cooperation among and within its functions [23]; this phenomenon may bring lots of challenges especially between operation and maintenance discipline during CBM execution.

Thus, collaborative learning in CBM has a crucial role in CBM programmes' success and it happens if only the technical infrastructures are well prepared (or designed) and organizational barriers removed beforehand.

IV. Methodology

In order to analyze the role of collaborative learning in condition based maintenance policy, we performed a case study in an industrial plant. Three main criteria have been considered in selecting this plant. Firstly, Due to nature of this project we were able to interview design engineers in early stages of asset life cycle. Secondly, the case company was in process industry, in which CBM is mostly being practiced. Thirdly, the selected company had multiple CBM cases, which can provide literal replication for the results. The plant, hereafter called ABC, is one of the prominent companies in the process industry in the Netherlands. ABC consists of different units, which are distributed in the 50 km^2; each unit has been developed, built, and maintained through an EPCM (Engineering, Procurement, Construction, and Maintenance) contract. The case study was performed during the period that the majority of the units were in operation and few of them were in engineering or construction phase. Therefore, we had a chance to perform semi-structured interviews with the staff of the different organizational disciplines (i.e. design, maintenance, operation, reliability engineering, etc) and review relevant documents in the company's intranet, their SAP system and etc.

V. Results

During the case study, it has been revealed, like already shown in some publications [2], [3], that the majority (8 out of 10) of CBM cases has failed or has only partially been successful.

Analyzing the interviews and documents has clarified that the following lack of collaborative learning during asset life cycles and among different disciplines were one of the main reasons for the failures (see table 1).

Equipment/Unit	Diagnisos	Prognosis	Using results in shutdown planning
Cold Heat Exchanger	Not sure	Extrapolation	-
Hot Heat Exchanger	Not sure	Extrapolation	-
Glycol pump	Not sure	-	-
Waco pump	Not sure	-	-
Demin Water	OK	-	-
Guard Filter	-	-	-
Seal Gas Filter	-	-	-
Instrument Air Unit	Not sure	-	-

Table 1: CBM cases result at ABC

A. Acquisition phase

In the engineering phase, different engineering disciplines were involved. Chemical and control engineers were mainly responsible for process design and preparing process control documents while mechanical engineers were preparing work instructions, maintenance manuals and contacting with manufacturers. These two groups had some interactions mainly about process design and control philosophy. Maintenance subject and more specifically CBM has been discussed only within mechanical engineering discipline. During this phase, all the information required for performing Reliability Centered Maintenance (RCM) analysis were available and design engineers had enough knowledge to define equipments maintenance policy however, this decisions have been postponed to the utilization phase. As a result, since design engineers did not know for which equipment CBM will be practiced, no guidelines or any other relevant information such as threshold levels (e.g. vibration level) were included in the equipments data sheets or even requested from manufacturers. And all the maintenance documents were prepared (or requested from suppliers) for traditional maintenance policies.

Moreover, as it can be seen in table 2, numbers of operation (i.e. process control) documents have a high potential to be used as CBM reference but due to their unstructured formats it is almost impossible to be used during plant operation phase.

Operation	Operation & Maintenance	Maintenance
Operation philosophy Process design envelope Instrumentation	FMEA Process control narrative Cause and effect diagrams Equipments data sheet Hazop	Maintenance manuals Work instructions Shutdown manuals Process narrative

Table 2: Typical operation and maintenance documents prepared in acquisition phase

B. Utilization phase

Maintenance and operation had their own agenda regarding definition, features, implementation, and desired prediction of CBM that in some cases resulted confrontation instead of collaboration. The main reason for above problem was coming back to their view of physical assets. Plant's availability, reliability, and capacity were the main concern of the operation discipline. Also they were interested in process parameters such as temperatures, pressures, volumes, concentrates of chemicals, flows of materials, which drove their viewpoint to the top-down perception, while the maintenance group were responsible for the failure of single component and tried to have prognosis for equipments failure and they were interested in lubrication oil, noise, dust, vibrations analysis (Bottom-up view)(see Fig. 2).

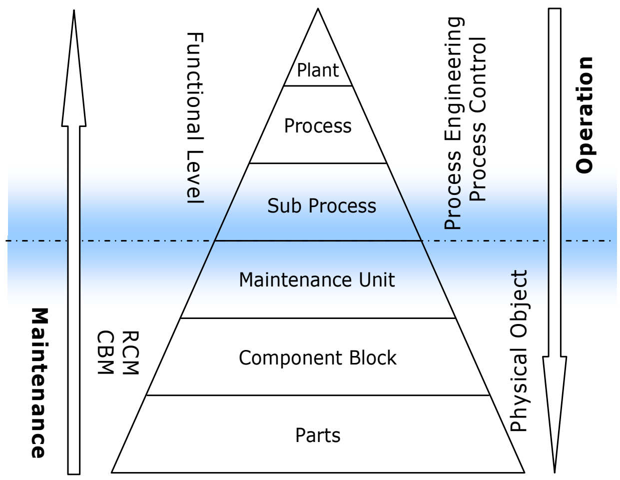

Fig. 2: Operation and maintenance viewpoints

The initial risk associated with operating a process unit (or a piece of equipment) was reduced by applying a range of risk reduction measures, including mechanical devices such as relief valves, bursting discs, etc and instrumented devices like IPFs (Instrumented protective function). All risk reduction measures had to bring the residual risk to a level below the tolerable level. The plant used a hierarchical process control system in which PID (proportional –integral – derivative) controllers removed the deviated feedbacks.

Operator, in control room, usually took action just for highly critical alarms and interacted with maintenance when there was a critical condition or major equipment failure. In such cases, usually, there was a serious failure but it was too late for preventive actions and corrective maintenance had to be performed.

There were quite limited interactions during CBM implementation among different disciplines (and more specifically between maintenance and operation). Maintenance staff used their own real-time databases for equipments conditions and analyzed the failure history in CMMS (Computerized Maintenance Management System) and SAP system. In some occasions, they diagnosed a failure and sent a notice to operation. In the control room, operators were checking the data gathered by DCS (Distributed Control System) and analyzing plant capacity and availability with their own tailor made software, as far as the degradation (or equipment failure) is within the control limits, they did not take any actions.

For the equipments with back up (redundant), the operator even did not know whether the equipment was failed or not. The failed equipment were switched off automatically through control hierarchy and the back up one were became online (see Fig. 3).

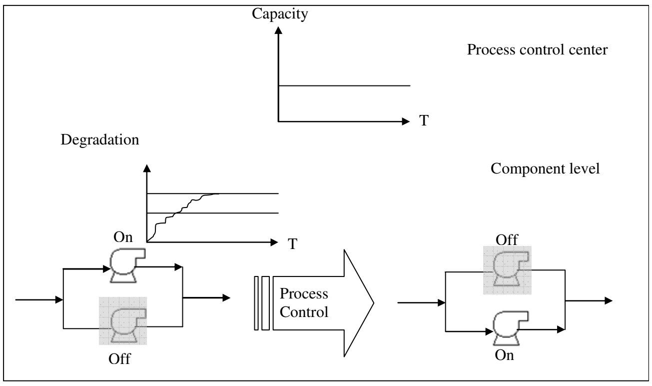

Fig. 3: Process control action when a degradation occurs

VI. Conclusion

Condition based maintenance advantages have been described enormously and many success stories can be found in the literature. However, in practice, most of the times, CBM programmes do not meet the predefined goals. In this paper the notion of collaborative learning has been discussed and it is introduced as one of the main factors in successful implementation of CBM programmes. A case study has been carried out; the results of which confirmed the theoretical framework. During the case study, it is revealed that there is a gap between different engineering disciplines about maintenance and more specifically CBM. No specific documents regarding CBM has been generated in acquisition phase and in process control philosophy CBM has not been considered either. The gap is continued in the utilization phase that prevent collaborative learning among operation and maintenance which consequently resulted in failure of CBM programme (See Fig. 4).

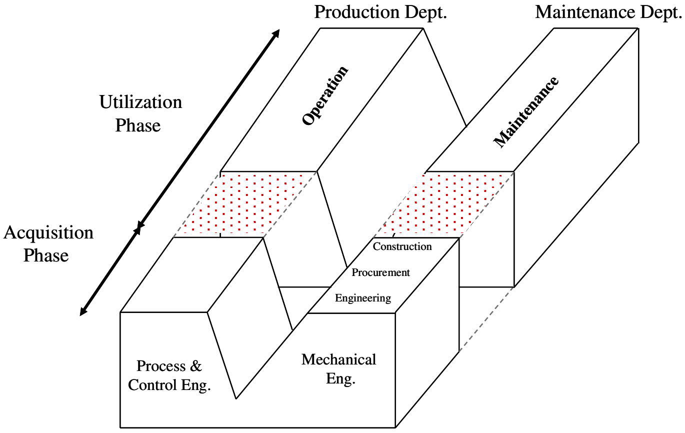

Fig. 4: Gap between operation and maintenance within asset life cycle

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