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Criticality-based maintenance of a coal-fired power plant

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ABSTRACT

The need for an evolution from the consolidated RCM (Reliability Centered Maintenance) models is something that quite a few experts have been pointing out for quite some time now. Various authors are frequently considering the addition of different techniques in a RCM analysis to increase its efficiency and quality. The objective of this work is to present a method that identifies the most critical components of a system, in order to contribute to the prioritization of maintenance actions. The method uses reliability and risk analysis techniques, such as Hazard and Operability Study (HAZOP), Fault Tree Analysis (FTA) and Failure Modes and Effects Criticality Analysis (FMECA). It also uses a multi-criteria decision method, the Analytic Network Process (ANP), for ranking the most critical components. The method is applied in the Flue Gas Desulfurization System of a Coal-Fired Power Plant. The results obtained with the implementation of the method indicate the most critical components for which maintenance planners shall focus attention, aiming at increasing the availability and decreasing the risk in relation to the plant operation.

1. Introduction

Although corrective maintenance has always been a common activity in all walks of life, modern industrial society has realized for quite some time now, that in many instances it is seldom the most cost-effective way of keeping machinery and equipment available for production or any other intended purpose. Therefore, since the inception of the industrial revolution some kind of scheduled Preventive Maintenance (PM), based simply on experience, was implemented by the early builders and operators of industrial equipment [1].

As technology evolved, however, and with the development of reliability engineering particularly by the electronics industry, it soon became clear that it would be possible to use more accurate methods in PM instead of relying on experience and judgment alone. It was the airline industry task force, formed in 1960 to investigate the capabilities of preventive maintenance, which led to the development of a series of guidelines to be used by airlines and aircraft manufacturers when establishing maintenance schedules for their aircraft. In 1974, the US Department of Defense commissioned United Airlines to write a report on the processes used in the civil aviation industry for the development of maintenance programs for aircraft [2]. Besides the use of PM, the task force proposed the use of predictive maintenance (PRM) based on the development of machine monitoring and diagnostic techniques where preventive actions are taken when failure symptoms are detected and recognized. This report [3], entitled Reliability-Centered Maintenance (RCM), has become a basic reference for all subsequent RCM approaches to this day.

From its aviation-related onset, RCM experienced a widespread acceptance wherever maintenance is considered a required activity [4–7]. According to NASA [8], RCM and its variations are employed to address reliability issues in order to improve overall equipment effectiveness and lower its life cycle cost.

According to those references, RCM can be defined as a methodology to determine what must be done to ensure that the equipment continues executing its intended functions, with a predefined performance in a specific operational context with a minimized maintenance cost.

As an evolution of the RCM philosophy and considering that maintenance activities may contribute to control business risks, the Risk-Based Maintenance (RBM) philosophy was proposed to

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determine the priority of maintenance using risk concepts that integrates both equipment failures and asset safety analysis [9,10]. The objective of RBM is to reduce the overall asset operational risk that may result as consequences of unexpected failures of asset pieces of equipment. The high-risk components shall receive priority attention from maintenance planners aiming at reducing their failure probability [11–18].

The decision-making problem regarding the selection of critical components of an asset as for maintenance planning based on RBM concepts can be considered a complex task. The risk profile associated with a component failure mode may be composed of many consequences categories such as threaten to human life, environmental impact, asset damage and loss of production costs. Defining in a monetary base all the consequences may be an extremely difficult and imprecise task. To solve this problem multi criteria decision-making approach may be used once they can handle pair wise comparison of different consequence categories associated with risk description linked to a component failure mode.

The objective of this work is to present a method that identifies the most critical components of a system, in order to contribute to the prioritization of maintenance actions. The method uses reliability and risk analysis techniques, such as Hazard and Operability Study (HAZOP), Fault Tree Analysis (FTA) and Failure Modes and Effects Criticality Analysis (FMECA) to perform asset risk assessment taking as hazards the components failure modes. The consequences for asset performance and safety are evaluated based on criteria that consider threats to human life, environmental impact and operational availability. It also uses a multi-criteria decision method, the Analytic Network Process (ANP), for ranking the most critical components based on their failure consequences evaluation. The method is applied in the Flue Gas Desulfurization System of a Coal-Fired Power Plant.

2. Literature review

The need for an evolution from the consolidated RCM models is something that quite a few experts have been pointing out for quite some time now. As far back as the closing years of the last century Crocker and Kumar [19] already proposed a new approach to RCM using the concepts of soft life and hard life to optimize the total maintenance cost and to find the optimal maintenance policies in the case of military aero-engines using Monte Carlo simulation. In spite of their intention, however, the authors did not provide a conclusive approach about the real advantages of the method application.

Even though risk-based maintenance is in itself an evolution from reliability-centered maintenance proper the application thereof has never ceased to be refined, tuned up as it were. Krishnasamy et al. [20] for instance stated that adapting a risk-based maintenance (RBM) strategy is essential in developing cost-effective maintenance policies, and therefore proposed a RBM methodology comprised of four modules in order to identify critical equipment based on the level of risk and a pre-selected acceptable level of risk. The authors claimed that, in addition to increasing equipment reliability, their approach proved to be capable of reducing the cost of maintenance including the cost of failure when applied to a power-generating unit.

More recently, some authors began to consider that other ingredients should and could be profitably added to the RCM analysis process so as to increase its efficiency and quality. Cheng et al. [21] proposed to borrow case-based reasoning (CBR) from artificial intelligence (AI) and to build a framework for intelligent RCM analysis (IRCMA) considering that the historical records of RCM analysis on similar items can be referenced and used for the current RCM analysis of a new item. In their conclusion the authors stressed that RCM analysis is a much repeated task, and dependent on RCM analysis experience, and indicated that the IRCMA was substituting the traditional computer aided RCM system (CARCMS) within China's military industry, and is becoming the new generation of RCM analysis tool for weapon systems under development.

Being respectively parent and derived concepts, it seems only natural to propose that reliability-centered maintenance and risk-centered maintenance could be the object of a unified approach. Accordingly, Selvik and Aven [22] suggested an extension of the RCM to reliability and risk centered maintenance (RRCM) by also considering risk as the reference for the analysis in addition to reliability. The authors used a case from the offshore oil and gas industry to illustrate and discuss their suggested approach, and concluded that with application of RRCM an improved basis can be established for informing decision makers compared with the RCM method, as the importance of risk and uncertainties is more adequately taken into account.

Both Igba et al. [23] and Sainz and Sebastián [24] are representatives of those authors whose effort is to take the RCM method to wind-powered installations or any similar power generation project independently of its technical complexity or difficulty of access to the industrial plant facilities. In the former paper, the authors stated that they aimed to aim “to take the RCM technique further from just the functional failure analysis and optimization of maintenance strategies by looking more holistically through the application of systems thinking tools & techniques. In their concluding remarks, however, they conceded that limitations with the proposed model focus around the usability. Still within the wind-power domain, Florian and Sørensen [25] later carried out a comparison between two strategies for a life-cycle model built to simulate operation and maintenance activities on the degrading blades of an offshore wind turbine: a conventional condition based strategy and a non-conventional reliability based approach. Maintenance optimization was made for both strategies in terms of lifetime expected cost thereof, and the authors concluded that a reliability-based approach has a higher potential of reducing expenses, mainly because inspections are not carried out unless motivated by a high failure probability in the near future.

In a broader context, i.e., electric power distribution systems, Yssaad et al. [26] on the other hand have approached the subject of the importance and applicability of RCM using a single more conventional methodology based on the FMECA method and its associated Risk Priority Number (RPN). Accordingly, presenting data supplied by an actual electric feeder system (EFS), the authors stressed the importance of assigning maintenance focus levels based on criticality and ranking elements in ascending order above an established inferior “threshold of criticality” value.

Kundu, Chopra and Lad [27] propose an evolutionary risk based maintenance (RBM) methodology to optimize forecast of a gas turbine failures, where risk should be continuously updated with the age of the unit to increase the effectiveness of RBM policy.

The authors claim that, in addition to increasing availability and reducing the overall maintenance cost, their approach leads to the conclusion that Bayesian update can be used to increase the availability and optimize the high value critical assets.

Kiran et al. [28] emphasized the importance of adequate maintenance planning. It is interesting to note that those authors adopt the modern standpoint of placing on the same level equipment efficiency and environmental protection. This latter concern is paramount not only in their cement plant example but also in the majority of present electricity generation plants, particularly in those burning coal.