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Modeling risk based maintenance using fuzzy analytic network process

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ABSTRACT

The study deals with the problem of maintenance policy selection for an industrial unit. Maintenance policy selection is a multiple criteria decision making problem. Criteria considered here are 'risk of equipment failure' and the 'cost of maintenance'. The maintenance policies considered are Corrective Maintenance (CM), Time Based Maintenance (TBM), Condition Based Maintenance (CBM) and Shutdown Maintenance (SM). For modeling, fuzzy analytic network process (FANP) has been employed. Chang's extended analysis has been applied to deal with the fuzzy variables and the preferred maintenance policy alternative is found out using FANP analysis. The methodology was applied to a unit of a chemical plant and the suitable maintenance policy was found out for each of the 13 equipment of the unit. The results were compared to the earlier study using Analytic Hierarchal Process and Goal Programming (Arunraj and Maiti, 2010) vis-a-vis the existing practices. The results show that CBM is preferred when the risk possessed by an equipment is very high while CM is preferred in those cases where risk is low and cost is the main consideration. But in cases where both cost and risk are somewhat equally important, TBM is the preferred option.

1. Introduction

In recent years, risk of accidents and injuries at the workplace has become a very important criterion for production planning and control, albeit its importance was understood even at the early days of production. Many factors contribute to the occurrence of an accident and careful decisions are to make to avoid an accident. The maintenance policies practiced is one of the very important decisions.

An effective maintenance policy can help reduce the risk of accidents to a great extend. So it is very important to consider risk of accident as one of the criterion for selecting the maintenance policy to be employed. The selection of the type of maintenance depends on the equipment as well as the available maintenance facilities and capabilities. Several kind of maintenance strategies have been devised both at the system level and at the component level. In case of complex systems, groups of components with similar operating conditions may be found and treated uniformly during maintenance (e.g., group preventive maintenance policies). Furthermore, at a component level, assumptions are made regarding the effectiveness of maintenance in restoring the component to a good condition (Tan, 1995; Vassiliadis & Pistikopoulos, 2000). As-Good-As-New (AGAN) policies assume, for example, to restore the component to the original condition as was at the beginning of the operation, while As-Good-As-Old (AGAO) policies bring it back to where it was immediately before the failure occurs or the maintenance task started. The analysis and justification of maintenance strategy selection is a critical and complex task due to great number of factors to be considered, many of which are intangible. The method of selecting maintenance policies normally depends on cost of maintenance policies along with other criteria such as added product quality, spare parts availability, and maintenance time (Bevilacqua & Braglia, 2000). The maintenance strategies adopted in industries can be broadly classified as Corrective Maintenance (henceforth, CM), preventive maintenance (henceforth, PM), Shutdown Maintenance (henceforth, SM) and opportunistic maintenance (henceforth, OM). PM can be further classified as Time Based Maintenance (henceforth, TBM) and Condition Based Maintenance (henceforth, CBM).

CM starts once equipment fails. It is, therefore, also known as breakdown maintenance. It is costly for critical equipment and therefore usually is employed for non-critical and sometimes for independent equipment. PM does not wait for an equipment to fail. It usually is based either on failure history of the equipment or the condition of the equipment. In case of the former, maintenance actions start at periodic intervals and the period is estimated based on the failure distribution of the equipment. It is therefore known as TBM. In case of the later, the condition of the equipment is monitored and the maintenance actions start when the condition of the equipment calls for it. It is therefore known as CBM.

TBM is effective in many capital intensive processes but in some cases the rate of deterioration depends on various other factors like operational and environmental conditions in addition to the amount of time elapsed. As a result the extent of operational period may not be adequate to diagnose the product condition for

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maintenance (Moubray, 1991). Therefore, TBM sometimes imposes unnecessary treatments, which often disrupt normal operations and induce malfunctions due to missed operations. CBM comes to its rescue. CBM was proposed based on the development of machine diagnostic techniques in the 1970s (Khan and Haddara, 2003; Luce, 1999), where preventive actions are taken when symptoms of failures are recognized through monitoring or diagnosis. Therefore, CBM enables taking proper actions at the right timing to prevent failures, if the diagnostic is done properly. However, CBM is not always the best method of maintenance, especially from the perspective of cost effectiveness (Al-Najjar & Alsyouf, 2003; Tsang, 1995; Yang, 2003). When failures of machines or components are not critical, one can allow Corrective Maintenance (CM), in which actions may be taken after failures are detected. When the lives of machines or components can be estimated precisely, TBM is the most effective means of maintenance. Therefore, from the latter half of the 1980s, the importance of selecting proper maintenance strategies has been acknowledged in various areas.

Reliability Centered Maintenance (RCM), Risk-Based Inspection (RBI) and Risk-Based Maintenance (henceforth, RBM) are the most well known methodologies for this purpose. Among these methodologies, RCM is designed to minimize the maintenance cost by balancing the higher cost of Corrective Maintenance against the costs of other maintenance strategies (Carretero et al., 2003). Moubray (1991) defined RCM as a methodology to determine what must be done to ensure that the asset continues fulfilling its intended functions. In case of RBM, the method is used for determining the priority of maintenance using risk which integrates both safety and failure. The main aim of this method is to reduce the overall risk that may result as the consequence of unexpected failures of operating facilities (Khan & Haddara, 2004). The high-risk components of a system, rather than the low risk components, should be inspected and maintained usually with greater frequency and thoroughness (Arunraj and Maiti, 2007; Brown & May, 2003; Moore & Starr, 2006).

RBM first involves risk assessment of an industrial unit and then depending on the amount of risk the maintenance planning is done. The risk assessment process involves: (i) hazard identification, (ii) likelihood and consequence estimation which are multiplied to compute risk, and (iii) risk evaluation. In risk evaluation the computed risk is compared to a standard risk value which is acceptable. If the computed risk exceeds the acceptance criteria, proper steps have to take to reduce the risk. Since with proper maintenance, the risk of failure can be lessen to a significant extent, risk can be a very important criterion for maintenance planning. In RBM, the main objective is to reduce the overall risk that may result as the consequence of unexpected failures of operating facilities. The inspection and maintenance activities are prioritized on the basis of quantized risk caused due to failure of the components, so that the total risk can be minimized using RBM.

This paper is organized as follows: (i) first, a brief literature review is presented on maintenance selection, ANP and uncertainty in decision making, (ii) second, a methodology is proposed for maintenance policy selection using FANP, and (iii) finally, the application results are presented with comparison to earlier study in this line. The following sections describe them in detail.

2. Literature review

2.1. Maintenance selection as a complex multi criteria decision problem

In recent years, multi criteria decision making approach has been gained momentum in the field of maintenance strategy selection (Bertolini & Bevilacqua, 2006; Bevilacqua & Braglia, 2000; de Almedia & Bohoris, 1995; Triantaphyllou, Kovalerchuk, Mann, & Knapp, 1997). Triantaphyllou et al. (1997) suggested the use of AHP for maintenance strategy selection considering cost, reparability, reliability, and availability. Bevilacqua and Braglia (2000) also used AHP for selecting the maintenance strategy for an Italian oil refinery based on four important criteria namely cost, damages, applicability, and added value. Bertolini and Bevilacqua (2006) presented a combined analytic hierarchy process and lexicographic goal programming approach to select the best maintenance policies for the maintenance of critical centrifugal pumps in an oil refinery, taking into account budget and maintenance time as constraints. The criteria considered by Bertolini and Bevilacqua (2006) are failure occurrence, its severity and delectability. Recently considering the importance of risk of equipment failure, Arunraj and Maiti (2010) devised a methodology for maintenance policy selection in chemical industry taking risk and cost as the criteria. They utilized AHP and Goal Programming method to arrive at the result. The AHP results show that considering risk as a criterion, Condition Based Maintenance (CBM) is a preferred policy over Time-Based Maintenance (TBM) as CBM has better risk reduction capability than TBM. Similarly, considering cost as a criterion, Corrective Maintenance (CM) is preferred. However, considering both risk and cost as multiple criteria, the AHP–GP results show that CBM is preferred.

2.2. Analytic Network Process

In Analytic Hierarchy Process (Saaty, 1994), the problem of maintenance policy selection is modeled in a form of the hierarchy. So, the components of AHP namely, goal, criteria and alternatives are connected top to bottom. The AHP model is based on the premise that the problem of the decision-making can be modeled in a linear top-to-bottom form as a hierarchy. The upper level node in the hierarchy does not depend on the lower levels and the elements present in a node (at the same level in a hierarchy) are also independent of each other.

This one sided network fails to capture the complex interactions and feedbacks which might be present in the system. To get rid of this limitation, the present problem is modeled using Saaty's Analytic Network Programming (ANP) (Saaty, 1996). This is a generalization of previously used AHP where the goal, criteria and alternatives are in the form of clusters and all possible interaction between the clusters and elements within a cluster are considered (Fig. 1). The ANP is a coupling of two parts (Saaty, 1996): The first consists of a control hierarchy or network of criteria and subcriteria that control the interactions. The second is a network of influences among the elements and clusters.

Analytic network process has been used in solving many complicated decision-making problems because it is a comprehensive multi-purpose decision making method. There are many studies and applications on ANP. Wua and Lee (2007) developed a method based on the ANP to help companies that need to select knowledge management strategies. Patrovi (2001) quantified strategic service vision using analytic model and Partovi (2006) studied strategic service vision the facility location problem which incorporates both external and internal criteria in the decision-making process. Chung, Lee, & Pearn (2005a) dealt with an application for the selection of product mix for efficient manufacturing in a semiconductor fabricator. In addition to these studies, other studies where ANP was used are: Yurdakul (2003) evaluated long-term performances of production systems; Meade and Presley (2002) evaluated alternative research-development projects; and Mikhailov and Singh (2003) studied the development process of a decision support system.

2.3. Uncertainty in decision making

In both AHP and ANP, there is a need of the integration of the mathematical model to human experiences. In order to prioritize