



Decision Support

A multi-criteria model for auditing a Predictive Maintenance Programme

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ABSTRACT

Auditing tools can play a key role in the continuous improvement of maintenance policies, in particular to enhance predictive maintenance (PM). This paper proposes a multi-criteria model for auditing a Predictive Maintenance Programme (PMP) developed and implemented in the General Hospital of Ciudad Real (GHCR) in Spain. The model has a two-level structure, with top level auditing areas specified by second level auditing criteria on which the performance of the PMP should be appraised. This structure resulted from the analysis and discussion of an internal questionnaire to the management, technical and consulting staff of GHCR. This also guided the association of a performance scale with each criterion, describing several reference levels of accomplishment. Using the MACBETH (Measuring Attractiveness by a Categorical Based Evaluation Technique) approach, a hierarchical additive value model was constructed, with criteria weights and value scales derived from staff judgments of comparison of different reference levels and profiles of performance. This model enables managers to measure the performance of the PMP and its added value for the hospital, not only against each audit criterion individually, but also on each area and in overall terms. Integrated in a management “tableau de bord”, the model outputs permit the identification of PMP deficiencies requiring urgent intervention and corrective measures for its continuous improvement.

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1. Introduction

Preventive maintenance consists of the systematic inspection, detection, correction, and prevention of incipient failures, before they become actual or major failures; and, predictive maintenance (PM) is a special type of preventive maintenance in which maintenance is performed continuously or at intervals according to the requirements to diagnose and monitor a condition or system (Luthra, 2010). PM can generate high gains in terms of increased availability, safety, quality, productivity of equipment and facilities and decreased maintenance and insurance costs (Christer et al., 1997; Villar et al., 2000; Lupinucci et al., 2000; Weyerhaeuser, 2000; Swanson, 2001; Wang, 2002; Mobley, 2002; Carnero, 2005). The use of PM is particularly crucial where security is critical (e.g. in nuclear power plants) and where machines must operate with an availability, safety and quality close to 100% (e.g. in hospitals). Accordingly, the definition and implementation of a Predictive Maintenance Program (PMP) has been recognized as a strategic management decision (Tsang, 2002). PMPs use the most

cost-effective tools (for example, vibration monitoring, lubricant analysis or thermography) to obtain information on the actual operating condition of critical facilities, and based on this, all maintenance activities are scheduled on an as-needed basis (Mobley, 2002). PMPs have been increasingly adopted (Carnero, 2005); according to Mobley (2002), the average plant invests 15.8% of its annual maintenance budget in PMPs. Nevertheless, evidence points out that a high percentage of PMPs have limited use or are eliminated after brief periods of time because they fail to provide promised and measurable benefits (Mobley, 1997). This is certainly related to practical difficulties in evaluating maintenance performance in general (Waevenberg and Pintelon, 2002), in comprehensively defining a PMP which involves multiple users, equipment and facilities and in making the organizational changes for a full utilization of predictive tools (Mobley, 2002). However, above all, it is because there is a lack of proper tools to monitor and control factors that lead to the appearance and development of deficiencies during the life cycle of a PMP (Carnero, 2004). The multi-criteria model for auditing a PMP proposed in this paper is a contribution to fill this gap. Previous applications of multi-criteria decision analysis (MCDA) in other auditing contexts can be found in Akoka and Comyn-Wattiau (1996), Comyn-Wattiau and Akoka (1996), Bayraktar (1998) and Pasiouras et al. (2007), but we did not find in the literature applications of MCDA to a PMP audit.

The proposed multi-criteria audit model was developed and implemented in the General Hospital of Ciudad Real (GHCR) in

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Spain, within the scope of a R&D project with the University of Castilla-La Mancha. The project involved management, technical and consulting staff of GHCR and was motivated by the recognition of the importance of PM to pursue the hospital mission. In fact, the GHCR was the first hospital in Spain to set up a PMP. The project included the study of the potentialities of applying the MACBETH (Measuring Attractiveness by a Categorical Based Evaluation Technique) approach to PM (Carnero, 2009), which led to an initial prototype of the model (Carnero, 2006). MACBETH (Bana e Costa and Vansnick, 1994; Bana e Costa and Vansnick, 1999; Bana e Costa et al., 2011) enables a quantitative PMP audit model to be built based on staff qualitative judgements about differences in attractiveness (or added value to the hospital) between reference levels of performance of the PMP in multiple audit dimensions. A brief technical overview of MACBETH is included in Section 3.1.1. Before that, Section 2 presents background information on the scope and purpose of the project. The model was developed as described in Section 3 and implemented in the GHCR in 2008. Results from the first year of application of the model to audit the hospital PMP are presented in Section 4. Finally, Section 5 discusses issues and lessons learned from the process of developing and implementing the model.

2. Scope and purpose

The GHCR is a large and new hospital with 560 beds (opened in 2005) located in the Castilla-La Mancha region. It covers a catchment area of 42 municipalities, receiving patients from several hospitals operating in its catchment area, and has an extensive supply of medical equipment, ranging from medical imaging equipment for diagnosing (e.g. MRI) to medical monitoring equipment (e.g. ECG). At the beginning of 2010, the GHCR integrated 1249 permanent health personnel, 709 permanent auxiliary personnel and 434 temporary staff.

Managing all these personnel and equipment simultaneously is a daunting task, and is the responsibility of the Sub-Director of Technical Services who works under the direct dependence of the hospital's Executive Manager. The maintenance area integrates 57 employees and three outsourced full-time technicians in charge of maintaining medical devices. The Sub-Director of Technical Services was assisted by one of the authors of this paper in the design and implementation of the PMP, and currently in its management. The PMP uses thermography as the technique for PM, meaning that through the detection of thermal abnormalities in equipment, an easy location and diagnosis of problems in an early stage is obtained (analysis of temperature is operated with cameras). Measurements are carried out in two hospital areas – electromedicine, and electrical facilities and lighting – and covers machines as well as other equipment.

Some aspects regarding the nature of hospital activity should be taken into account when building a tool to assist PM in the hospital context, in particular a PMP auditing model, and when interpreting the results of its use. Namely, hospitals are complex social systems because of structural, technological and human resources factors and commonly aim to pursue efficiency, access and quality of care objectives, while taking into account cost considerations (McKee and Healy, 2002). Maintenance is regarded as a key function in hospitals (Shortell and Kaluzny, 2005) and faces a wide range of pressures, as outlined below:

- A high rate of technological change requires constant updates and interactions between equipment.
- Hospital equipment is highly complex, involving mechanic, electronic, hydraulic, pneumatic mechanisms and software components (Carmo et al., 2007).

- There is a need to use highly qualified personnel with continuous training in hospital maintenance, with the operation of hospital equipment being done by a large number of individuals that directly or indirectly participate in maintenance.
- The maintenance strategy should be in line not only with the hospital strategy but also with the points of view of multiple departments (Arts et al., 1998), thus requiring some sort of participation. One should note that, very frequently, hospital stakeholders are resistant to changes (McKee and Healy, 2002).
- Maintenance requires fulfilling many requirements for adopting procedures for exchanging information between multiple hospital departments, centres and other units, as well as complying with structural (and evolving) factors such as national and transnational legislation and environmental and safety concerns.
- Maintenance is to be completed while delivering care 24 hours a day, meaning that high availability and reliability of facilities and equipment needs to be ensured; high standards of safety related with the supply of vital inputs such as electricity, gas, liquids, etc., and the normal operation of facilities and equipments under standard maintenance plans are required to ensure the integrity of persons and facilities (catastrophe plans and integral safety plans are always required).

In a review of the literature, we found virtually no studies proposing methodologies to assist in defining and implementing PMP policies in the hospital context. Some studies have focused on the development of methodologies to manage healthcare technologies (David and Jahnke, 2004) and for planning new equipment and optimizing stocks (Jahnke and David, 2005), but are not adequate to assist PMP auditing. Therefore, a novel PMP auditing model had to be constructed at GHCR. It was agreed that the model should: (1) incorporate all relevant PM dimensions and translate them into audit criteria structured by area of intervention (e.g. acting on the availability of resources, acting on the planning of predictive activities, etc.) and enable to appraise the performance of the PMP; and (2) measure its added value for the hospital, not only against each audit criterion individually, but also aggregated by area and in overall terms. The model outputs and its analysis at different moments in time should constitute a management tool used by PM hospital managers in identifying and communicating PMP deficiencies requiring urgent intervention and corrective measures in view of its continuous improvement. We envisage this management tool as a sort of “tableau de bord” (TDB): “The TDB was introduced in France in the 1930s and was described as being similar to a “dashboard” (i.e. the literal translation of *Tableau de bord*) used by “pilots” (i.e. managers) to guide organizations to their destinations. Often the TDB would be constructed in the form of ratios or graphs that could be used by decision makers to inform them of their current position and be able then to guide their firms” (Bessire and Baker, 2005, p. 650).

Finally the development of the model should also respect a set of conditions required for a successful implementation of a PMP (Moblely, 2002), namely: a proper structuring and detailed and comprehensive definition (so as to focus on the whole organization), a culture change towards PM (involving all the stakeholders related with maintenance), as well as proper training for technicians and analysts; a measurement of PMP benefits, and the availability of tools to enable proper tracking and evaluation.

3. The multi-criteria model for PMP audit

3.1. Outline of the model building process and outputs

3.1.1. Model building process

Multi-criteria value analysis (von Winterfeldt and Edwards, 1986; Keeney and Raiffa, 1993; Belton and Stewart, 2002) is a wise

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