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Decision Support System for maintenance policy optimization in medicinal gases subsystems

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Abstract: This article shows an innovative decision support system built by integrating Markov chains with the multicriteria *Measuring Attractiveness by a Categorical Based Evaluation Technique* (MACBETH) for managing medical assets in a Health Care Organization. This model makes a choice of optimal maintenance policies on different typologies of subsystems for the distribution of medicinal gases and vacuum. The model uses a decision group made up of various departmental heads of a Health Care Organization. It should be noted that it has also been applied to a public general hospital.

Keywords*:* Maintenance, Decision Support System, MACBETH, Markov Chains, medicinal gases subsystems.

1. INTRODUCTION

Health Care Organizations have technologically very complex equipment and facilities, which is constantly being renewed (Wild and Langer, 2008), together with conventional machines and facilities; also, the direct interaction between the care equipment and the patient means that the Technical Services of Health Care Organization must have much higher goals of availability, safety and quality than other organizations. This is because many medical devices operate directly with the patient and so can directly influence people's lives (Gómez, 2013). It is therefore necessary to develop decision models to guarantee the best management of assets and facilities.

And so the maintenance policy applied conditions the availability and efficiency of the clinical equipment, the safety of the patient and of the health professionals who use the machinery, and the operational quality of the devices and facilities. The choice of the optimal maintenance policy is thus essential to the provision of quality healthcare to patients (Cruz et al., 2014); furthermore, economic resources are wasted by inefficient maintenance programmes (Bashiri et al., 2011).

The choice of maintenance policies is a complex decision as it combines strategic matters with technical questions. And so it is a decision which requires the use of objective mathematical models which can take into account a variety of qualitative and quantitative criteria. The use of Multi-Criteria Decision Making techniques (MCDM) is therefore justified.

Multicriteria techniques have been successfully applied to choice of maintenance policies (Zaim et al., 2012) in many types of company. Notable examples include Labib et al. (1998), Ramadhan et al. (1999), Bevilacqua and Braglia (2000), Emblemsvag and Tonning (2003), Carnero (2006), Bertolini and Bevilacqua (2006) and Goossens and Basten (2015), who use the multicriteria technique Analytic Hierarchy Process (AHP). Wang et al. (2007) and Ghosh and Roy (2009) apply fuzzy AHP. Ilangkumaran and Kumanan (2009) combine fuzzy AHP and TOPSIS; Ishizaka and Nemery (2014) use ELECTRE-SORT and Cavalcante and Lopes (2015) use a multi-attribute value function.

However, there is a serious shortage in the literature of work on choice of maintenance policies in Health Care Organizations. There is only one example, from Taghipour et al. (2011), which uses AHP to obtain a prioritization of medical devices; from the total criticality score values guidelines are established to select appropriate maintenance strategies.

This study presents an innovative decision support system which integrates Markov chains for repairable systems with the Measuring Attractiveness by a Categorical Based Evaluation Technique (MACBETH) to develop optimal decision making in the distribution subsystems of medicinal gases and vacuum, for different typologies and criticities. It should be noted that the model gives the best combination of maintenance policies to apply, while most of the literature looks at selection of maintenance policies as the application of a single alternative to the machines, without considering that in real life companies apply combinations of the different maintenance policies to achieve the goals of availability, quality, cost and safety established by the organization.

This research may serve as an example to other hospitals which could produce their own decision makers and make

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assessments as a function of their specific conditions, about the most suitable combination of maintenance policies to be applied, based on objective mathematical tools, rather than basing decision making solely on experience. It should also be noted that this method has been successfully applied to a public general hospital.

Section 2 sets out an introduction to Markov chains for repairable systems applied to the subsystems analysed. Section 3 describes the criteria, weighting process and alternatives of the multicriteria model. Section 4 sets out the results obtained. Section 5 gives the conclusions.

2. MARKOV CHAINS FOR MEDICINAL GASES AND VACCUUM SUBSYSTEMS

The medicinal gases and vacuum subsystems distribute and regulate the pressure in use of medicinal gases and vacuum throughout the Hospital, from the regulation and area alert panel to the point of use.

These subsystems consist of an alarm panel, an internal pipe network and rapid connectors suited to each type of gas and vacuum. The alarm panel gives out a light and sound signal at each nursing station and common area in which a staff member is physically present, if the pressure or vacuum is above or below the set limits. This may be caused by a leak in one or more pipes, a bad connection in the machines or a leak in the pipe network.

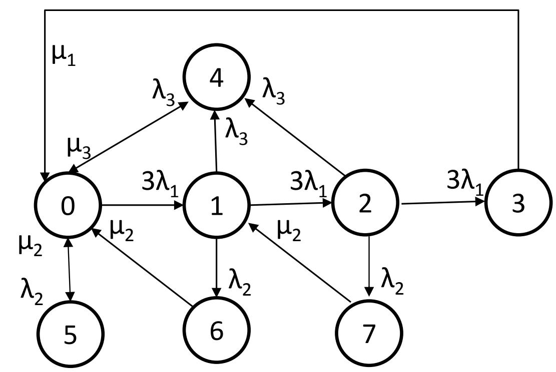
Subsystems containing two, three or four gas networks (oxygen, vacuum, medicinal air or protoxide) are known as types A, B and C respectively. In the case of subsystem failure, it has other auxiliary systems which perform the same function, but manually and for a limited time.

Wear is modelled discretely in three steps or levels. The mean time in each state is $1/3\lambda_1$, where $1/\lambda_1$ the mean failure time for the system. For each state of the subsystem preventive maintenance is carried out to return it to the conditions of the previous state, with periodicity $1/\lambda_2$ and mean repair time $1/\mu_2$. When the final state of wear is reached, the subsystem fails, leading to a repair which returns it to the initial state, with a repair rate of μ_1. It is considered that in each state a random failure may occur with failure and repair rates λ_3 and μ_3 respectively, which return it to its original state.

Four maintenance alternatives are considered: corrective maintenance, corrective with quarterly preventive check-up, corrective with biannual preventive check-up, and corrective with annual preventive check-up, where D_0, D_1, D_2 and D_3 are the respective availabilities. The Markov graph associated with this subsystem is shown in Fig. 1.

Equation (1) is the transition matrix corresponding to the Markov graph.

$$D_1 = \begin{pmatrix} -3\lambda_1-\lambda_2-\lambda_3 & 0 & 0 & \mu_1 & \mu_3 & \mu_2 & \mu_2 & 0 \\ 3\lambda_1 & -3\lambda_1-\lambda_2-\lambda_3 & 0 & 0 & 0 & 0 & 0 & \mu_2 \\ 0 & 3\lambda_1 & -3\lambda_1-\lambda_2-\lambda_3 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 3\lambda_1 & -\mu_1 & 0 & 0 & 0 & 0 \\ \lambda_3 & \lambda_3 & \lambda_3 & 0 & -\mu_3 & 0 & 0 & 0 \\ \lambda_2 & 0 & 0 & 0 & 0 & -\mu_2 & 0 & 0 \\ 0 & \lambda_2 & 0 & 0 & 0 & 0 & -\mu_2 & 0 \\ 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \end{pmatrix} \quad (1)$$



State 0: normal operation.
State 1: controlled wear corresponding to first period.
State 2: controlled wear corresponding to second period.
State 3: failure through wear. Failure of the subsystem.
State 4: uncontrolled stoppage. Failure of the subsystem.
State 5: first preventive inspection and check-up.
State 6: second preventive inspection and check-up.
State 7: third preventive inspection and check-up.

Fig. 1. Markov graph for subsystems medicinal gas and vacuum installation.

Solving the system of equations gives the vector values C_m. Bearing in mind that the subsystem is operational in states 0, 1 and 2, the mean availabilities for the several maintenance alternatives are:

$$D_{0m} = \frac{\mu_3}{\mu_3 + \lambda_3} \quad (2)$$

$$D_{1m} = C_{10} + C_{11} + C_{12} + C_{15} + C_{16} + C_{17} \quad (3)$$

$$D_{2m} = C_{20} + C_{21} + C_{22} + C_{25} + C_{26} + C_{27} \quad (4)$$

$$D_{3m} = C_{30} + C_{31} + C_{32} + C_{35} + C_{36} + C_{37} \quad (5)$$

C_{nm} are the coefficients obtained by solving (6) (Hillier and Lieberman, 2002) for each value used in each alternative of λ_1, μ_1, λ_2, μ_2, λ_3 and μ_3.

$$\begin{pmatrix} P_0' \\ P_1' \\ \cdot \\ \cdot \\ P_{m-1}' \\ P_m' \end{pmatrix} = \begin{pmatrix} -\sum_{j=1}^{m} \lambda_{oj} & \mu_{1,0} & \cdot & \cdot & \mu_{m-1,0} & \mu_{m,0} \\ \lambda_{0,1} & -(\sum_{j=2}^{m} \lambda_{1j} + \mu_{1,0}) & \mu_{2,1} & \cdot & \cdot & \mu_{m,1} \\ \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\ \lambda_{0,m-1} & \lambda_{1,m-1} & \cdot & \cdot & -(\lambda_{n-1,m} + \sum_{j=0}^{m-2} \mu_{n-1,j}) & \mu_{m,m-1} \\ \lambda_{0,m} & \lambda_{1,m} & \cdot & \cdot & \lambda_{m-1,m} & -\sum_{j=0}^{m-1} \mu_{n,j} \end{pmatrix} \begin{pmatrix} P_0 \\ P_1 \\ \cdot \\ \cdot \\ P_{m-1} \\ P_m \end{pmatrix} \quad (6)$$