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Medical Equipment Replacement Prioritisation: A Comparison Between Linear and Fuzzy System Models

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Abstract

In hospital management, health technology assessment techniques are being increasingly developed. This paper presents a comparison of the results obtained using two models for replacement priority value calculation applied to the Galliera hospital in Genoa (Italy). One the models was developed at the Galliera Hospital along the lines of the model by Fennigkoh and addresses four primary replacement issues: equipment service and support, equipment function, cost benefits and clinical efficacy, by a "yes-no" scheme. This model is compared with a model based on fuzzy logic. The comparison between the two models shows a conservative behaviour by the Galliera model, according to which 77.4% of the analysed instrumentation is maintained, whereas the classification by the fuzzy model allows for a better discrimination among the devices.

Keywords:

Fuzzy Logic, Health technology assessment model

Introduction

In the last few years, very fast health technology changes have taken place, but they have not been paralleled by progress in management. Medical equipment requires very time-consuming and costly maintenance, which makes it crucial to introduce innovative technology management strategies focused on appropriateness, efficiency and cost effectiveness. Many health technology assessment (HTA) procedure have been proposed, often identifying mathematical models which require mostly subjective parameters. Many hospitals are carrying out research on models that objectively express obsolescence.

A linear multiparametric model for medical equipment replacement has been proposed by Fennigkoh [3]. This model can be adapted to each specific hospital by changes in the parameters and has often been used. A model based on this approach has been developed for the Busto Arsizio hospital (Northern Italy) [2] and has subsequently been adapted to meet the needs of the Galliera hospital in Genoa (Italy). Subsequently, a model based on fuzzy logic has been developed. A comparison of the two models is presented.

Methods

The model based on the Fennigkoh approach follows the one which has been adopted by Caimmi et al. [2] for the Busto Arsizio hospital, but it is simpler. In the first place some difficulties deriving from the retrieval of data such as maintenance cost for individual devices have been avoided. Secondly, the model by Fennigkoh requires choices as to which parameters should be regarded as relevant for decisions about substitutions. In this respect, some of these choices may not be generally valid and may not be the most appropriate in different contexts. Moreover, obtaining subjective opinion of medical users about the equipment in use and/or to be purchased is difficult. Therefore, the procedure for calculating the replacement priority value (RPV) has been divided into two phases. In the first phase (RPV1) only objective parameters are considered – and only if they exceed a threshold. Subjective data are considered in the second phase (RPV2). This allows to reduce the overall workload and the dependence on subjective factors. RPV2 is calculated only if RPV1 is above a predetermined threshold.

The following parameters have been taken into account.

● Age (x_1) – It is calculated by the following

$$x_1 = \begin{cases} 0, & if \ \dfrac{\text{current year} - \text{year of purchase}}{\text{functional age}} < 0 \\ 1, & otherwise \end{cases} \qquad (1)$$

identifying if a device is over its functional age. The functional age is indicated by the manufacturer of the equipment and may also vary among devices belonging to the same group.
● Downtime (x_2) – A threshold value of 6 days was set up as indicated by the hospital. x_2 takes the value of 0 if it is below the threshold and 1 if it is above the threshold.
● Equipment function (x_3) – Same as in BA model (1 to 4).
● Manufacturer support, maintenance service, and availability of parts (x_4) – As in Fennigkoh's model, $x_4 = 0$ if parts, consumables, maintenance service, or manufacturer support are available or adequate (availability is guaranteed by law for 10 years after purchase); otherwise $x_4 = 1$.
RVP1 has been calculated as linear combination of these parameters according to the following

$$RPV_1 = 9(x_1 + x_2) + 7.5x_3 + 25x_4 \qquad (2)$$

Ranking of the result is the same as in BA Model. Specifically: RPV1 < 40 → good conditions, no need to proceed, 40 ≤ RPV1 ≤ 60 → critical device, enter the second step, RPV1 > 60 → very critical device, replacement suggested as soon as possible. If RPV1 is between 40 and 60, it enters the second assessment phase, as in the BA model.

Fuzzy logic-based systems have been developed in hospital management only recently even though for analogue qualitative reasoning approaches has already been applied many years ago in bioengineering [1; 4; 5; 7; 8], where the problem of uncertain values of variables has similar effects. The limited availability of financial resources and of qualified personnel are among the causes of improper and incorrect management of biomedical instrumentation. This has inspired some work [9] and the set up a fuzzy model for the classification of biomedical instrumentation according to the risk level [10]. Moreover, an inferential fuzzy model has been proposed [6].

Biomedical equipment can be classified by type of device (life support, therapeutics, diagnostics and others). Moreover, all instruments in the same class of equipment may not have the same functional age. In this respect, different fuzzy models have been produced which differ as relates to two features: rules (which allow a stricter assessment for life support or therapeutic equipment than for diagnostic or other devices) and age-related membership function. The variables that have been chosen are the same as for the GA model.

The model that has been developed is a fuzzy *mamdani* model in which preamble and conclusions are linguistic concepts (model with set of inferential rules). The model has the four variables (corresponding to the variables used in RPV1) and provides an output that suggests whether a device should be replaced. Specifically, the variable can give four suggestions: maintain, maintain over the functional age, re-evaluate (second phase), replace. The Fuzzy model presented here aims to replace the first phase of the GA model. The model has been implemented using the MATLAB Fuzzy Logic Toolbox.

For each input and output variable, the corresponding membership functions have been created. The membership functions define how each input (or output) value is mapped between 0 and 1. For each input, the degree of membership in fuzzy sets has been calculated by the application of IF-THEN type rules which have been set up on the basis of the suggestions by the Galliera Hospital. The fuzzified inputs have been applied to the antecedents: since the rules used have more than one antecedent, the AND intersection operator has been used to obtain the result of the antecedents. This operator provides the minimum degree of belonging among those present. The result of the antecedents has been applied to the function of membership of the consequent one according to the Clipping method, which simply cuts the consequent at the level of membership of the antecedent. The aggregation has allowed the unification of the consequent of all rules. The fuzzy set for the output variable has been obtained from this process. The last step is defuzzification, transforming the aggregates fuzzy set into RPV1.

Results and discussion

This work focuses on the analysis of six categories of instrumentation: electro-controlled bed for intensive care (BED), patient monitors (MON), biological refrigerators (BIR), surgical lights (SUL), ultrasound machines (USM), armchairs for therapy and blood samples (ARC). Both the GA model and the fuzzy model have been tested on the same equipment classes. Although most of the instrumentation has been analysed, for each class there is a number of biomedical equipment "not found" or for which it has not been possible to find the data necessary to calculate the RPV. The reasons for this are a number of factors, including problems in the outsourced service of management and monitoring of the technological park, difficulties in obtaining direct feedback from suppliers and/or technicians and equipment ageing.

The two models have been defined on the basis of different logics, but they do not differ greatly as relates to identification of the instrument RPV classes. The GA model has a tendency towards a more conservative behaviour, about 78.2% of the analysed instrumentation is maintained, 22% pass to the second phase of evaluation and suggests replacement only for 0.6%. The Fuzzy model suggests maintenance of the devices analysed for 70.8%. It also further specifies that 58.3% of the instruments are certainly to be maintained and that 12.6% of the instruments at this time are not a source of concern, but that their age or functional state could cause a significant increase in RPV in the future. This model also identifies the need for re-evaluation for 25.1% of the instrumentation analysed and 4% of the total recommends replacement without further evaluation.

The two largest differences between the models are found for ultrasound machines (USMs) and patient monitors (MON). Specifically, it is suggested to maintain 83.3% of the total USMs analysed according to the GA model and 58.3% according to the Fuzzy model, while for MON, the GA model identifies 36.7% of instruments to be maintained, 57.6% to be revalued and no instruments to be replaced immediately. The Fuzzy model identifies 15.1% of MON to be replaced.

At this initial stage, both models have been validated on a limited number of equipment classes. This is the basis of a much broader analysis. The Galliera Hospital showed interest in the Fuzzy model, whose results have been regarded as more satisfactory than those obtained by the GA model. Exploiting the uncertainty elements, as allowed by the fuzzy model, could be an advantage for the evaluation of the future availability of spare parts for each specific instrument.

In this respect, the Galliera Hospital intends to extend the application of the fuzzy model to the its entire technology park.

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