Decision Support System for Medical Equipment Failure Analysis

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***Abstract*—Medical equipment management raises a range of complex problems including those associated with maintenance process. In developing countries, hospitals rarely implement a coherent management plan in medical equipment management. One of the most significant challenges is to distinguish medical equipment that requires repair from those require replacement. Thus, a Decision Support System (DSS) is required to manage this pitfall properly. In this paper, a multi-criteria decision making model, Analytic Hierarchy Process (AHP) is presented to select an optimum maintenance strategy. With reference to literature review and experts' opinions; a set of criteria is employed to calculate a criticality score for each piece of equipment. Therefore, a list of equipment is ranked based on their scores and an optimum threshold is selected to differentiate between maintenance and replacement requirements. Fifty different types of medical equipment located in multiple public hospitals have been used in the validation of the proposed model. Results show that the proposed model can efficiently differentiate the equipment that requires repair and the others that needs to be scrapped.**

Keywords*— *Medical Equipment, Decision Support System, Clinical engineers, Analytic Hierarchy Process

I. INTRODUCTION

Healthcare technology management (HTM) is one of the most important segments in the healthcare system according to The Joint Commission (TJC) environment of care standards because of its main role in the healthcare transformation. The goal of (HTM) is to optimize the acquisition and utilization of technology to achieve maximum beneficial impact on health outcomes [1]. Along the life cycle of medical equipment, hospitals need to make decisions related to different medical equipment management stages such as acquisition, maintenance, and replacement.

In developing countries, almost decisions are made subjectively without considering a coherent management plan that relied on well-known standards. In addition, there is a lack of analytical, realistic and comprehensive assessment of medical equipment failures due to poor analysis of down times, failure rates, life span, utilization level, and relative costs. For instance, we can imagine the consequences of improper judgment on medical equipment malfunction that leads to usage of unreliable equipment instead of scrapping it.

In the 1970s, Analytical Hierarchy Process (AHP) and Multi Criteria Decision Making (MCDM) has been integrated and presented as a methodology by Saaty [2]. It is a theory of measurement through pairwise comparisons which relies on expert's judgment to obtain priority scales that lead to selecting and prioritizing the best alternative [3]. In applications, AHP has been employed for widespread models in decision making problems. This method has the ability to structure organized way of evaluating alternatives as a solution of decision problems to produce reasonable, justified, and unbiased decisions. In healthcare, AHP methodology is employed for multiple applications. One application is to consider it for decision making in diseases diagnosis such as the approach followed in prostate cancer screening as it presented in [4]. Moreover, AHP can be used in medical equipment management. For instance, it was adopted by [5] to select a set of neonatal ventilators in a planned expansion of neonatal intensive care unit (NICU). Another example was introduced by Taghipour and Jardine, in which AHP was used for prioritization of medical equipment that requires maintenance based on a set of criteria [6]. Also, it has applied for hemodialysis machines scrapping/ retirement decision making as introduced by the work [7].

In this paper a novel system is proposed to calculate medical equipment criticality score using AHP. The system enables clinical engineers (CEs) to make a correct decision of medical equipment failures; either repair or scrapping. A multi-criteria decision making framework is presented to give appropriate priority. In this framework, once the criticality scoring index is generated, all medical equipment are ranked for classification according to their scores.

The rest of the paper is organized as follows. The proposed methodology is described and explained in section II. Results and discussion of this study is presented in section III. Section IV concludes the paper.

II. METHODOLOGY

In this study, AHP and MCDM are employed to solve the problem of giving a justified priority for failed medical equipment based on its real status. In fact, AHP is a three-step process. It decomposes a complex problem into a hierarchy.

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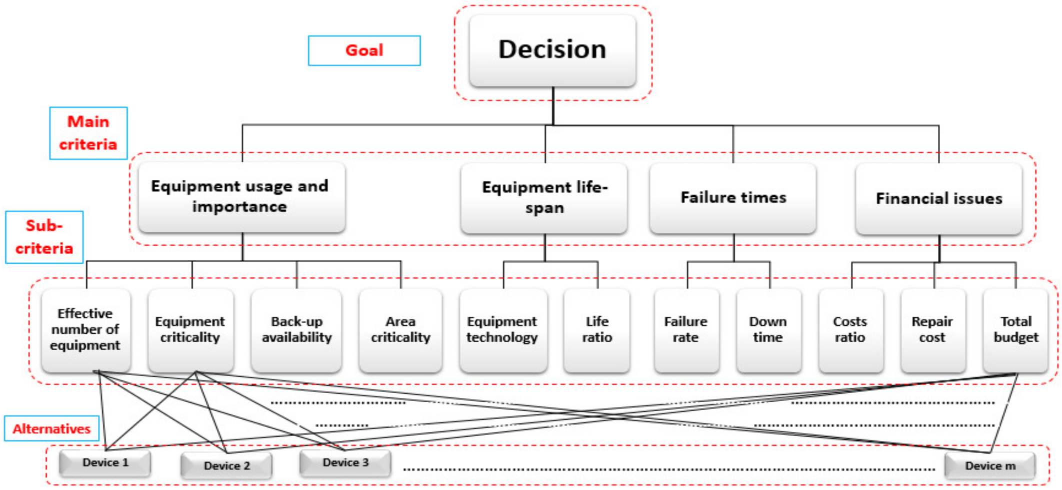

The overall decision objective (goal) lies at the top and the criteria, sub-criteria and decision alternatives are on each descending level of the hierarchy. Decision makers then compare each criterion to all other criteria at the same level of the hierarchy using a pairwise comparison matrix to find its weight or relative importance [4]. The optimal solution (decision) is the alternative with the greatest cumulative weight.

Two types of comparisons can be employed in the AHP; absolute *and relative* measurements [8]. Absolute measurement is applied to rank the alternatives based on the criteria independent of other alternatives regardless adding or deleting alternatives. In relative measurement, Criteria are compared in pairs according to a common attribute. The proposed model uses both relative and absolute measurements.

A. Model Description

The first step in applying AHP is to construct the hierarchy structure of the goal, namely, proper decision of medical equipment failures. Figure 1 shows a decision hierarchy for classification of medical equipment. The assessment criteria lie at the second level of the hierarchy structure. Relative measurement method is used for pairwise comparison of the assessment criteria and for determining their relative importance or weights with respect to the goal. In other words, the weight of each criterion is determined by comparing its relative contribution to the goal with other assessment criteria. Therefore, if a new criterion is added or an existing one is deleted from the hierarchy, all criteria should be reassessed to find their new weights.

The alternatives which here are medical equipment compose the third level of the hierarchy. The objective is to assign a criticality score for each piece of equipment participating in this framework. However, the large number of alternatives (equipment) makes their pairwise comparison with respect to all criteria almost impossible. Moreover, medical devices are dynamic, because they are added to and removed from the inventory over time, so we suggest an absolute measurement technique for ranking alternatives. Therefore, each piece of equipment is assessed with respect to each criterion and is given the most descriptive grade without comparing it with others.

Indeed, to be able to assess medical equipment with respect to a criterion, the criterion's grades and their associated intensities should be defined in advance. In this paper, the grades and their descriptions are either obtained from the available standards and previous literature, or proposed by the experts and approved by the CEs through online survey.

The grades are subjective; so each grade should be assigned an intensity value indicating its score or importance with respect to the criterion. Thus, quantifying the grades is a necessary step in establishing the framework. By defining the grades and intensities for all criteria, the model is ready to be used to assess the equipment. The proposed methodology can be summarized in the following steps:

- Identify all proposed independent criteria and sub-criteria for criticality assessment of equipment.
- Determine weight values for all criteria and sub criteria.
- Set up grades and determine intensities for each criterion using relative measurement method.
- Evaluate alternatives (medical equipment) with respect to each criterion, and assign the most descriptive grades using absolute measurement method.
- Calculate the criticality score for each piece of equipment as follows:

$$CSi = \sum_{i=1}^{m} \sum_{j=1}^{n} WjSij \qquad (1)$$

i=1, . . . , m where m is the maximum equipment number, j=1, . . . , n where n is the maximum criteria, wj is the weight of the jth criterion which taken from CEs online survey, and Sij is the score (intensity) of the ith equipment with respect to the jth criterion, taking into account the total summation of the weights is equal to one.

- Ranking all equipment according to their criticality scores after selecting the optimum threshold.

The Proposed Criteria and Sub Criteria

In the proposed model, four main criteria are used to compute the medical equipment criticality score. These criteria are equipment usage and importance, equipment lifespan, failure times and financial issues as shown in Table I. These criteria are divided into sets of sub criteria as discussed below.

1) Equipment usage and importance (C1)

This classification implicitly represents the main purpose and importance for which the equipment is to be used. A set of sub criteria are suggested as follows:

a) Effective number of equipment (C11): It is the mean effective number of reliable medical equipment versus the total number of equipment in one department.

b) Equipment function (C12): This parameter represents the main purpose of equipment usage that categorized as life support, therapeutic, diagnostic, analytical, and miscellaneous [9].

c) Back-up availability (C13): Although not always true, with decreased backup and less similar equipment at hand, the situation of an equipment in care delivery process becomes more critical, especially when it is in high demand within the hospital. It can be indicated by YES or NO as shown in Table I.

d) Area criticality (C14): Department criticality should be regarded. It is important to evaluate the equipment based on the criticality level of the department. It depends on the type of department and patients flow rate within the department.

- *Type (C141)*:): It demonstrates entitity of the department whether being urgent area, or intensity care unit, or diagnostic area, or low intensity area, or non clinical area.
- *Flow rate (C142)*: It presents the rate of patient flow whether being high, or medium, or low.

2) Equipment lifespan (C2)

This criterion describes equipment status during its life cycle. It can be evaluated using the following sub criteria

a) *Equipment technology (C21):* Technology of medical equipment is classified according to obsolescence, manufacturer technical support, spare parts and accessories availability.

b) *Life ratio (C22):* It is a parameter that measures the ratio between the age of equipment and its expected life span.

3) Failure times (C3)

Failures of medical equipment should be recorded regularly. History of equipment failures could reflect the efficiency and the performance of equipment. Some parameters are used to measure this factor as follows.

a) *Failure rate (C31):* Failure rate is the likelihood of a failure occurrence. Due to the importance of this parameter, the National Center for Patient Safety has designed an analysis tool that called Healthcare Failure Modes and Effects Analysis (HFMEA) for this purpose [10].

b) *Down time (C32): Downtime is generally the average recorded time that a piece of an equipment is out of service.*

4) Financial issues (C4)

This parameter is very substantial for any medical facility especially for developing countries. It reflects the financial availability to repair failed equipment or to postpone it to the next financial year. It can be expressed by:

a) *Costs ratio (C41):* It is the ratio between cumulative maintenance costs (include previous repairs, service contract cost and calibration fees if available) and new equipment price.

b) *Repair cost (C42):* This criterion introduces the cost value of repair quotation.

c) *Total budget (C43):* It is the annually allocated budget for the maintenance of medical equipment.

C. Scoring approach

Absolute measurement technique is used for setting up grades and intensities for each criterion. In our application, it is more convenient to use such approach because of the dynamic nature of medical equipment as well as the large number of equipment. Firstly, descriptive weights for each criterion are constructed based on experts opinion (58 CEs), then the grades are pairwise compared according to their corresponding criterion to find grade intensities. In the AHP hierarchy, the qualitative grades and intensities should be determined for all proposed criteria/sub-criteria. Each piece of medical equipment should be assessed regarding the criteria/sub-criteria connected to the alternatives to assign an appropriate score.

The score of medical equipment at a specific criterion which has sub-criteria is the sum product of the sub criteria's weights and their grades' intensities that assigned to the intended equipment. This process is called 'synthesizing' of AHP. Therefore, the total score can be obtained as an absolute value from the weighted sum of the criteria/ sub-criteria and their assigned intensities. In order to easily prioritize and classify equipment according to their score values, the absolute total score values should be normalized. The transformed score value (TSV) is mapped to a hundred percent value as in (2). After that, the selected optimum threshold is determined to get the best choice with minimum decision error. The mean threshold range derived from expertise opinions of medical equipment failure decisions in hospitals.

$$TSV = (score\ value - min) / (max - min)\ 100\% \qquad (2)$$

III. Results and Discussion

The proposed model is tested through a case study on a real investigated data of 50 pieces of medical equipment (33 different types) from different departments within different public hospitals in Egypt. A field online survey is performed to collect experts' opinions, 58 CEs with average of (8 ± 6.27) years of experience, for parameters weights and grades judgment. By using the absolute technique for setting up the grades and intensities of all criteria, the weights are obtained as shown in Table I. Thus, the total criticality score is calculated using AHP synthesis as well as TSV using (2).

The selected threshold plays a role in decision making. If the assessed equipment score is equal or greater than this value, it should be repaired, else it should be scrapped. The numbers of experts are chosen to be five consultant engineers with average of (12 ± 5.09) years of experience as a reference guide for selecting threshold range. As shown in figure (2), the optimum threshold is 30% to get the minimum error of 12%. Above and below this value the error increases. The error is a measure of how far decision from experts' opinions.

TABLE I. CRITERIA AND SUB CRITERIA FOR MEDICAL EQUIPMENT FAILURE MODEL WITH OBTAINED WEIGHTS

Main criteria (weight)	*Sub-criteria (weight)*	*Sub-criteria (weight)*
C1-Equipment usage and importance (0.307)	C11- Effective number of equipment (0.378) C12- Equipment criticality (0.425) C13- Back-up availability (0.056) C14- Area criticality (0.141)	C131- Yes (0.3) C132- No (0.7) C141- Type (0.3) C142- Flow rate (0.7)
C2- Equipment lifespan (0.337)	C21- Equipment technology (0.57) C22- Life ratio (0.43)	---
C3- Failure times (0.066)	C31- Failure rate (0.51) C32- Down time (0.49)	---
C4- Financial issues (0.29)	C41- Costs ratio (0.514) C42- Repair cost (0.237) C43- total budget (0.249)	---

In our proposed model, any equipment has a score ranges from 0.178 to 1.0. Where, score value 1.0 is given for any equipment has the highest intensity when assessed against every single criterion. On the other hand, score value 0.178 is obtained when a piece of equipment gets the lowest intensity from all criteria. Therefore, the obtained score in the proposed model is always between 0.178 and 1.0. Therefore, TSV can be calculated as in (3).

$$TSV = (score\ value - 0.178) / (0.822)\ 100\ \% \qquad (3)$$

Table II shows samples for the main criteria values and final scores for 5 pieces of equipment when tested in our model.

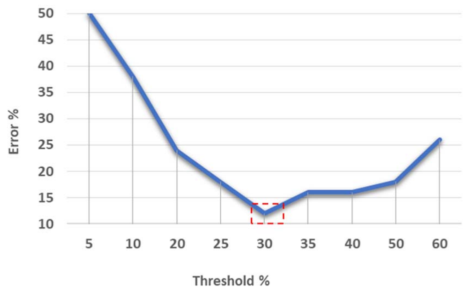

Fig. 2. Distribution of equipment selected thresholds with decisions errors

TABLE II. SAMPLE DATA OF INVESTIGATED MEDICAL EQUIPMENT FOR FAILURE DECISIONS

No.	**Equipment data (Name / Manufacturer / Model)**	**Equipment usage and importance**	**Equipment lifespan**	**Failure times**	**Financial issues**	**Total score**	**Transformed score %**
1	Centrifuge / Jouan / C3.12	0.224	0.164	1	0.216	0.253	9.16
2	Heart lung Machine / Stockert / SIII	0.816	0.164	0.658	0.340	0.448	32.83
3	Phacoemulsifier / Megatron / G 28101	0.251	0.164	1	0.386	0.310	16.09
4	Intra-Aortic Balloon / Datascope / CS300	0.812	0.620	0.592	1	0.787	74.13
5	Computed Tomography (CT) / Philips / MX4000 Dual	0.233	0.164	0.632	0.216	0.231	6.49

IV. CONCLUSIONS

Decision making for failed medical equipment to consider whether repair or scrapping is a critical issue. The study provides a decision support tool (AHP) by giving a consistent decision for failed medical equipment. The model highlights a set of criteria that could be considered in decision making. Among the proposed criteria, equipment usage and importance and equipment life span have great impacts on decision making. Tracking history of the equipment is essential in order to utilize the proposed criteria. The model was consistent by 88% with experts' opinions.

REFERENCES

[1] Joint commission on accreditation of healthcare organizations (JACAHO), hospital accreditation standards, Joint commission on accreditation: Oakbrook Terrace, IL, 2004.

[2] T. L. Saaty, "How to make a decision: the analytic hierarchy process", Interfaces, vol. 24, no. 6, p. 19-43, 1994.

[3] L. C. Leung, D.CAO, "On the efficacy of modeling multi-attribute decision problems using AHP and sinarchy", European Journal of Operational Research, 2001, v. 132, n. 1, p. 39-49.

[4] E.B. Sloane, M. J. Liberatore, and R. L. Nydick, "Medical decision support using the analytic hierarchy process", Journal of Healthcare Information Management, 2002, vol. 16, no. 4.

[5] E. B. Sloane, M.J. Liberatore, R.L. Nydick, W. Luo, and Q.B. Chung, "Using the analytic hierarchy process as a clinical engineering tool to facilitate an iterative, multidisciplinary, microeconomic health technology assessment", Computers & Operations Research, vol. 30, pp. 1447–1465, 2003.

[6] S. Taghipour, D. Banjevic and AKS. Jardine, "Prioritization of medical equipment for maintenance decisions", Journal of the Operational Research Society, 2011, vol. 62, no. 9, pp. 66–87.

[7] A. A. Kamel, B. S. Tawfik, "Decision support systems in clinical engineering, "5th Cairo International Biomedical Engineering Conference, Proceeding of the IEEE, Cairo, Egypt, December 16-18, 2010.

[8] T. L. Saaty, "Absolute and relative measurement with the AHP". The most livable cities in the United States. Socio Econ Plan Sci 20: 327–331, 1986.

[9] L. Fennigkoh, B. Smith, "Clinical equipment management", Jcaho Ptsm Ser 2: 5–14, 1989.

[10] J. DeRosier, E. Stalhandske, JP Bagian and T Nudell, "Using health care failure mode and effect analysis": The VA national center for patient safety's prospective risk analysis system. Joint commission 28: 248–267, 2002.