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Using Analytical Hierarchy Process for Medical Equipment Maintenance and Replacement Decision in Malaysia Private Hospitals

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ABSTRACT

Medical equipment is any instrument, appliance, software, or material intended by the manufacturer to be used, alone or in combination for medical purpose. Further, medical equipment maintenance and replacement is a challenging procedure, especially for high-end equipment. This topic has been a long debate as the equipment will increase undesirable failure; where an early maintenance or replacement will result in high investment costs and premature disposal and late maintenance or replacement will lead to malfunctions that can pose serious risks to patient safety and healthcare operations. However, hospitals are unable to decide whether to maintain or replace the equipment especially when the equipment reaches its life and has a high repair cost. A few studies were conducted on the same research topic, but most of the findings emphasized maintenance and replacement methods rather than the criteria contributing to the decision. The criteria to maintain or replace medical equipment play an essential role to ensure the equipment is operating cost-effectively. Hence, the objective of this research is to apply Analytical Hierarchy Process (AHP) approach to prioritize important criteria that influence decision-makers to decide whether to maintain or replace medical equipment. Some of potential criteria for the decision-making include maintenance cost, support, and regulatory compliance. This research utilized a mixed method approach to gather preliminary data from medical equipment experts and surveys to prioritize the criteria. Findings suggested a list of criteria that are influenced in decision-making to maintain or replace the medical equipment. The prioritization of the criteria reveals the downtime, life cycle cost and beyond economical repair (BER) to be the most important criteria.

1. Introduction

Healthcare is one of the most dynamic, fast growing, and powerful engines for economic growth in most developed and developing countries [3]. This industry is an aggregation of sectors in the economic systems that provide goods and services to treat patients with curative, preventive,

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rehabilitative, and palliative treatment [21]. Additionally, as new and advanced technology exists, the quality rendered to patients becomes better related with medical equipment [9]. According to Ssekitoleko [24], medical equipment can be defined as indispensable tools for healthcare in prevention, diagnosis, treatment, and rehabilitation. Medical equipment can be categorized according to the level of risk and criticality in the event of absence or inability to function. Medical equipment with high risk and the possibility of being non-functional in operation may affect the safety of the users [15]. Medical equipment plays a significant role in the hospital especially to assist the medical professional assessing the patients' medical condition [7]. The domestic medical equipment market in Malaysia is to be worth US$2.0 billion in 2022, with a Compound Annual Growth Rate (CAGR) of 7.5% between 2018 and 2022. Further, the demand for private healthcare services locally and globally is expected to bode well for Malaysia's healthcare sector. Thus, maintaining medical equipment is required and a significant amount of money to be invested is needed, especially for those categorized as high-end medical equipment [24].

Huge amount of money has been invested in medical equipment industry with the cost of annual maintenance often increasing to 10% of the replacement value [6]. To have an appropriate working environment and the best quality of the equipment to be used, a comprehensive maintenance and replacement process of medical equipment is vital [5]. This is needed to guarantee the patient and end-user safety and prevent excessive loss of revenue to the hospital [13]. Medical Equipment Management Plan (MEMP) is widely used in hospital, as it becomes the platform to maintain medical equipment procedure in a secure operating environment and track the general process of equipment from procurement to disposal [24]. In Malaysia, medical equipment maintenance and replacement is made based on the age and functionality of the equipment rather than having the right mechanism to assist the decision-making process [2]. Most of the occupants prefer to use regular service calls that are typically based on contractual arrangements between service providers and hospitals [25]. Furthermore, there is a lack of scientific, realistic, and comprehensive assessment of medical equipment maintenance and replacement decisions, and most are very dependent on inadequate reliable information.

The awareness of the importance of the management and maintenance of healthcare facilities has not been emphasized explicitly and systematically, which has resulted in lower quality maintenance and remedial works [18]. In the healthcare industry, poor decision-making may lead to negative impacts such as premature replacement or over-maintained medical equipment [1]. Premature replacement is a renewal of medical equipment where the equipment being replaced though it is newly purchased and rarely faulty.

Thus, a better mechanism for managing assets, especially in the healthcare industry is essential. If this issue is not addressed, lower quality maintenance, premature failure, and the severity of failure and mitigation might happen which may affect the long-run overall cost of the equipment. These consequences may jeopardize the quality of health services. Further, the safety of patients and smooth course of intervention largely depends on the perfect functioning of the equipment and the operative environment. Few studies have investigated key maintenance and replacement criteria especially in deciding whether to maintain or replace of medical equipment [21]. For example, salvage value or estimated resale value and the condition of the equipment are among key criteria that need to be considered for this type of decision-making [26]. However, studies on asset management in Malaysia's healthcare industries are still lacking and there is limited study on assessing the criterion decision-making either to maintain or replace of the equipment [21]. Lack of data and information on the real condition of the equipment are among difficulties facing Biomedical and Clinical engineering in deciding the plan for the medical equipment [22]. Aligned with the Health Malaysia Plan Action for the year 2021-2025 in strengthening the healthcare system to ensure the

society is healthy and productive, this research aims to propose a prioritization decision-making framework, particularly for medical equipment maintenance and replacement [12].

2. Literature Review

2.1 The Overview of Medical Equipment in Healthcare Industry

In general, there are more than 50,000 different kinds of medical equipment used on patients every day in hospitals [24]. Despite the importance of medical equipment in supporting healthcare services, the appropriate maintenance management remains challenges [8]. The equipment also needs to be properly handled and maintained to produce an efficient healthcare management system [21]. All equipment either medical or non-medical is necessary to give sufficient service as well as fulfil the requirement adjusted in the healthcare management system. Therefore, the use of a medical equipment management plan (MEMP) is compulsory to ensure excellent operation of diagnosis, monitoring and taking care of patients [20].

On average, one-third of the total operating costs in hospitals are used to maintain and purchase medical equipment [4]. Hence, medical equipment needs to be in a good condition and to prevent injuries from happen [10]. According to a report from World Health Organization (WHO), most of medical equipment in developing countries is not operated and have proper maintenance due to inappropriate management policy. Further, Bahreini [6] described two common approaches for medical equipment maintenance which include preventive and corrective strategies. Preventative Maintenance (PM) is a scheduled process of ensuring medical equipment is kept in perfect working conditions [5]. Meanwhile, Corrective Maintenance (CM) is repairing and restoring medical equipment that failed to function [6].

2.2 Decision-Making to Maintain or Replace

The process of maintaining medical equipment is very essential to enable the confirmation of normal operation, the productivity of the system, extending the life span of medical equipment, retain medical equipment in proper condition and upgrading the overall performance of the organization [11]. It is reported that part of the overall budget came from the maintenance of the equipment [14]. However, as there is no novel approach of maintenance and replacement medical equipment; thus, there is a need for tailored maintenance and replacement concepts for the healthcare industry.

The World Health Organization (WHO) has reported that few issues occurred where medical staff or administrative staffs are incapable to implement the right management on the medical equipment due to lack of understanding on equipment maintenance and replacement. According to a study by Jarikji and Hussein [10], the maintenance and replacement of medical equipment is based on technical and economic. Nevertheless, the objective of medical equipment replacement is to create a balance between the cost of equipment, performance, and risks [14]. Several criteria contribute to the maintenance and replacement of medical equipment, and these criteria could also vary from one hospital to another. Despite few research being focusing on the medical equipment maintenance approach, the focus on prioritization of the decision-making criteria is still very limited and at should be explore more. As there are limited studies available in focusing on assessing criteria in the decision-making process either to maintain or replace the equipment, this research had put forward to propose a decision-making framework, particularly for medical equipment maintenance and replacement.

A study by Salim *et al.,* [21] has identified criteria that influence decision makers to decide whether to maintain or replace of the equipment based on critical criteria. This study is a preliminary finding based on systematic review where some of the criteria that contribute to the final decision include salvage value, usability, technology implication and maintaining cost. Moreover, some equipment maintenance and replacement criteria may vary from one hospital to another. However, they are frequently the same as hospital institutions have a common interest in maintaining the medical equipment at the utmost minimal cost and minimizing the safety risks. The 15 decision-making criteria to maintain or replace medical equipment in the hospital including:

i. Support
ii. Condition
iii. Beyond Economical Repair
iv. Hardware and Software Obsolete
v. Health, Safety and Environment (HSE)
vi. Lifespan
vii. Maintaining and Operational Cost
viii. Purchase Cost
ix. Regulatory Compliance
x. Replacement Cost
xi. Risk and Failure
xii. salvage Value
xiii. Support
xiv. Downtime
xv. Life Cycle Cost

Some criteria were independent of others and stood out as a single criterion and some were grouped. However, this study still lacks in providing a shortlisted criteria for decision makers to decide whether to maintain or replace medical equipment which is more accurate and reliable way.

2.4 Medical Equipment Management Cycle

The medical equipment management cycle is divided into four phases and nine themes as shown in Figure 1 (*Source:* Tropical Health and Education Trust, THET). The first phase is 'Planning' where it consists of planning and assessment of the needs in the health facility in terms of the environment, equipment users, and patients, as well as budgeting and financing, in which the appropriate budgets for purchase and 'operating costs' are prepared and estimated [11]. The second phase is 'Procurement' which involves the evaluation and selection, i.e., deciding which equipment meets the previously identified needs. Specifications are drawn up, and the procurement and logistics phase are where a bid is made, a less complicated purchase is made, or a donation is arranged. The responsibilities and practical aspects of logistics are prepared and executed. In the installation and commissioning phase, the equipment is unpacked, installed and commissioned after it arrives at the health facility [11].

After these two preparatory phases, the third phase is the actual 'lifetime'. It begins with training users and maintenance personnel in competence development and training. The daily operation and safety for and by the users, as well as maintenance and repair, are mostly performed by biomedical device professionals [11]. The final phase 'end of life' is about decommissioning and disposal of medical equipment. As indicated in the figure, awareness, monitoring, and evaluation is constant

throughout the life cycle. Creating awareness among all stakeholders, whether they are users, maintenance personnel, administrators, or policy makers, is critical to improving systems and contributing to better biomedical and health practices. Monitoring and evaluation help keep track of the equipment life cycle and create opportunities to review and improve processes and share successes and lessons learned.

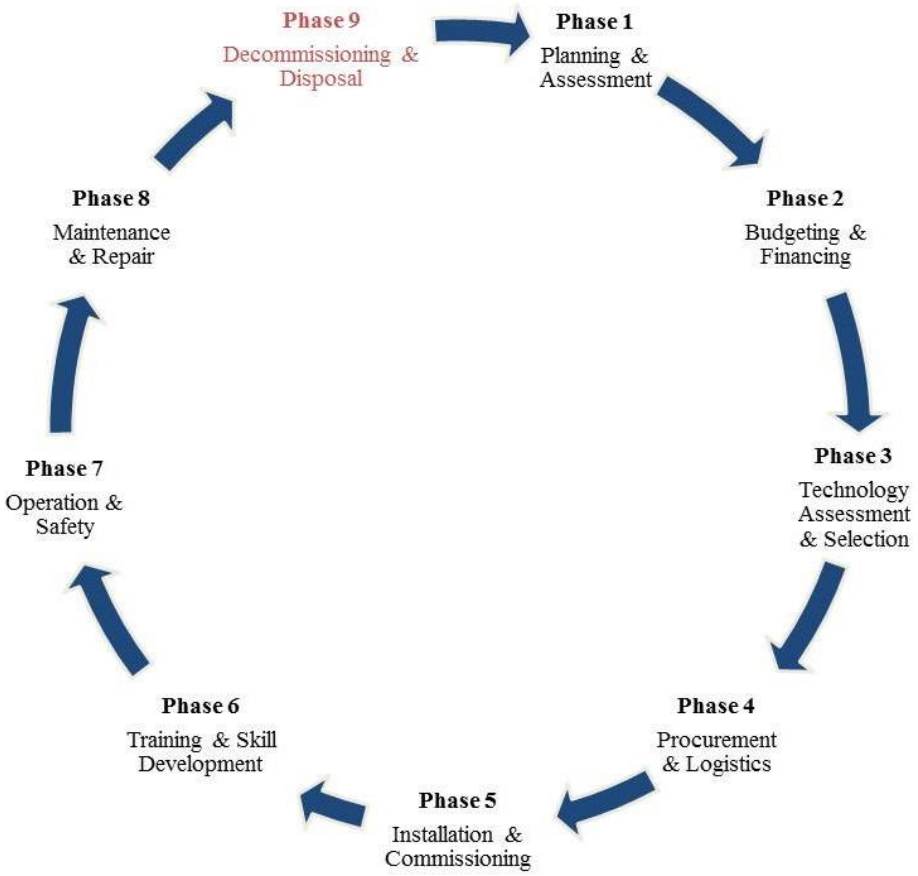

Fig. 1. The medical equipment life cycle

As the medical equipment management cycle will assure continual available of safe and effective equipment through a program of planned maintenance, a right process of decision-making should be conducted systematically to ensure accurate criteria will be chosen in the purpose of maintain or replace the equipment. Thus, in this study, Analytical Hierarchy Process (AHP) approach has been applied to obtain results of final criteria for decision-making to maintain or replace medical equipment by ranking the priority of the criteria.

2.5 Analytical Hierarchy Process (AHP)

In this study, AHP will be used to analyse the pairwise comparison questionnaire survey. AHP are commonly used for the decision-making process. AHP is frequently applied in various decision-making scenarios such as prioritization and evaluation, selecting one alternative from a set of alternatives, resource allocation, benchmarking, and quality management [17]. AHP has been widely used in many industries for many purposes as shown in Figure 2. AHP has also been applied in healthcare industry research specifically in replacing medical equipment in hospitals as it has been

proven to work best in the decision-making process. This study implemented AHP to prioritize decision-making criteria to maintain or replace medical equipment in private hospitals.

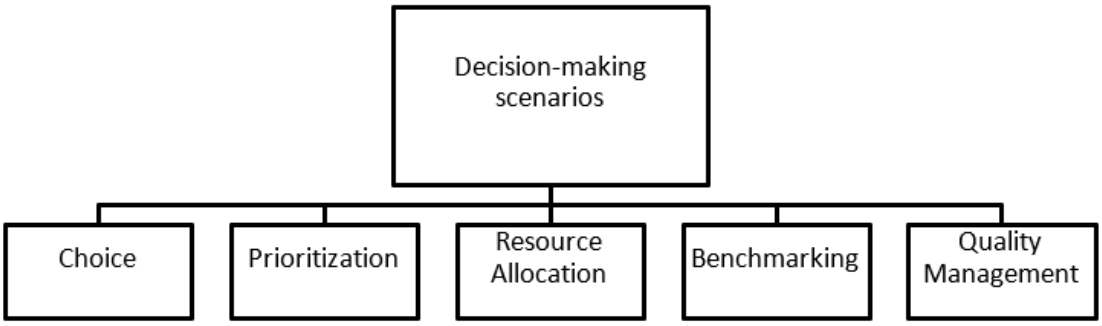

Fig. 2. Phases of AHP in Industry

3. Methodology

3.1 Target Population

The target respondents for this study are those who are working in the healthcare industry in Malaysia. The targeted experts were mostly professionals working in the hospital, or experts with various experiences in the healthcare industry. Thus, the unit of analysis of the research is individual level. However, the decision made by this single person represents the firm wholly.

3.2 Methods

This research utilizes a mixed-method approach including three phases:

i. exploring phase where a systematic literature review was conducted
ii. the qualitative phase using semi-structured interviews
iii. the quantitative phase using a pairwise comparison survey. The next section provides a discussion on the phase of systematic literature review (SLR) applied as the preliminary set of criteria for decision-making of medical equipment maintenance and replacement process.

3.2.1 Qualitative study: Semi-structured interview

A semi-structured interview is developed based on the literature review and preliminary framework. Six experts with working experience more than 5 years in the healthcare industry were involved as participants. One of the objectives of conducting qualitative research is to validate findings from the SLR phase [17]. The results from the interview showed a similarity answer with the criteria identified through extensive literature review. A semi-structured interview is in-depth interviews where the respondent needs to answer the pre-set open-ended questions which are widely employed. The interview is based on schematic presentation of questions or topics which need to be explored during the interview [16]. Using this approach, the interviewer will lead the interview session to obtain necessary information from the respondent at the same time the respondent is free to express their ideas. Respondents can give their opinion apart from answering questions from the interviewer. Respondents are allowed to suggest and elaborate additional criteria

that might not be in the list; but greatly significant to the decision-making process. The results from the interviews will then be analysed in the next phase.

The experts' background represents experts' profile and their job scope in private healthcare industry. Experts' background was compiled together as in Table 1:

Table 1
Background of Respondents

Respondent	Job Position	Area of Expertise	Respondent	Job Position	Area of Expertise
Expert 1	Project Manager	Project and equipment management	Expert 4	Chief Engineering of Biomedical Engineering	Medical equipment management
Expert 2	Biomedical Engineer	Medical equipment, safety and utilities	Expert 5	Corporate Executive Officer	Hospital management in clinical, financial and technical
Expert 3	Head of Biomedical Engineer	Medical equipment management	Expert 6	Executive Medical Equipment	Equipment management, purchasing and supplier management

3.2.1.1 Data analysis for qualitative method

Once consensus is achieved, the findings are analysed and finalized using the Framework method. Framework method organizes a set of codes into categories that have been jointly developed and creates new structures for the data to summarize the data in a way that can support answering each question [18]. The next step is to code the data into themes. The categorization of codes reflects themes. In this step, codes will be further aggregated into themes to form a common idea [23].

3.2.2 Quantitative study: Pairwise comparison questionnaire survey

A quantitative research method applies in this research using surveys. 25 experts with working experience more than 2 years in the healthcare industry are involved in this research. Questionnaire survey enables the data collected in a standardized way so that the data are internally coherent and consistent for analysis [19]. Survey questions will be constructed based on the assessment index from the interview's result in a pairwise comparison manner. Quantitative study is used in this study to validate the outcome from the semi-structured experts' interview. This approach aims to gather numerical data to support results obtained from qualitative research methods. Pairwise comparisons questionnaire will be used to apply the AHP approach that will be selected later. The evaluation was conducted using Saaty's Scale [23]. The outcome of this analysis will prioritize the decision-making criteria as well to determine the consensus and consistency in the final findings.

3.2.2.1 Data analysis for quantitative method

A suitable AHP technique has been applied to prioritize and rank the influential criteria found from the previous phase. A comprehensive multi-criteria decision-making framework for medical equipment maintenance and replacement will be developed. The fundamental terms in multiple attribute decision-making need to be defined particularly, Criteria, Evaluation Matrix (EM) and Alternatives. Evaluation matrix is a matrix of two dimensions that are alternatives (m) and criteria (n).

The intersection of the criteria and the alternatives are given as ^{X}ij. Therefore, Evaluation Matrix ($^{X}ij)m*n$ *is as* Eq. (1).

$$D = \begin{array}{c} \\ A_1 \\ A_2 \\ \vdots \\ A_m \end{array} \begin{array}{c} \begin{array}{cccccc} W_1 & W_2 & & W_n \\ C_1 & C_2 & \cdots & C_n \end{array} \\ \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1n} \\ x_{21} & x_{22} & \cdots & x_{2n} \\ \vdots & \vdots & & \vdots \\ x_{m1} & x_{m2} & \cdots & x_{mn} \end{bmatrix} \end{array} \quad (1)$$

Where $A_1, A_2, \ldots, A_m$ are the possible solutions (alternatives) that the decision maker can select, $C_1, C_2, \ldots, C_n$ are criteria to measure the performance of the alternatives, and finally, ^{x}ij is the performance of alternative A_i measured by criterion ^{C}i and ^{W}j is the importance weight of criterion ^{C}i. Different processes are required to perform the alternatives ranking such as normalization, maximization and minimization, closeness measurements, weights, and other processes. The Figure above represents the taxonomy for Multiple Attribute Decision Making methods [17].

3.3 Flow of Decision-Making Framework Development

As illustrated in Figure 3, the process of developing the framework starts with SLR analysis from previous study on equipment maintenance or replacement. From the SLR phase, a list of maintenance and replacement criteria was identified. The criteria from the SLR were then validated using a qualitative approach; where the criteria from the SLR process are compared with the criteria extracted during the interview session. While in third phase, which is the pairwise survey, the list of criteria was amended by calculating the priority vector obtained in the phase where it gives the weightage of importance of each criterion. The total weight for each criterion can be used as a benchmark to determine the priority of medical equipment that needs to be maintained or replaced. The weightage obtained from the quantitative study was validated again by the experts to ensure the accuracy of the result. This framework was developed to assist the hospital in the decision-making process to maintain or replace medical equipment.

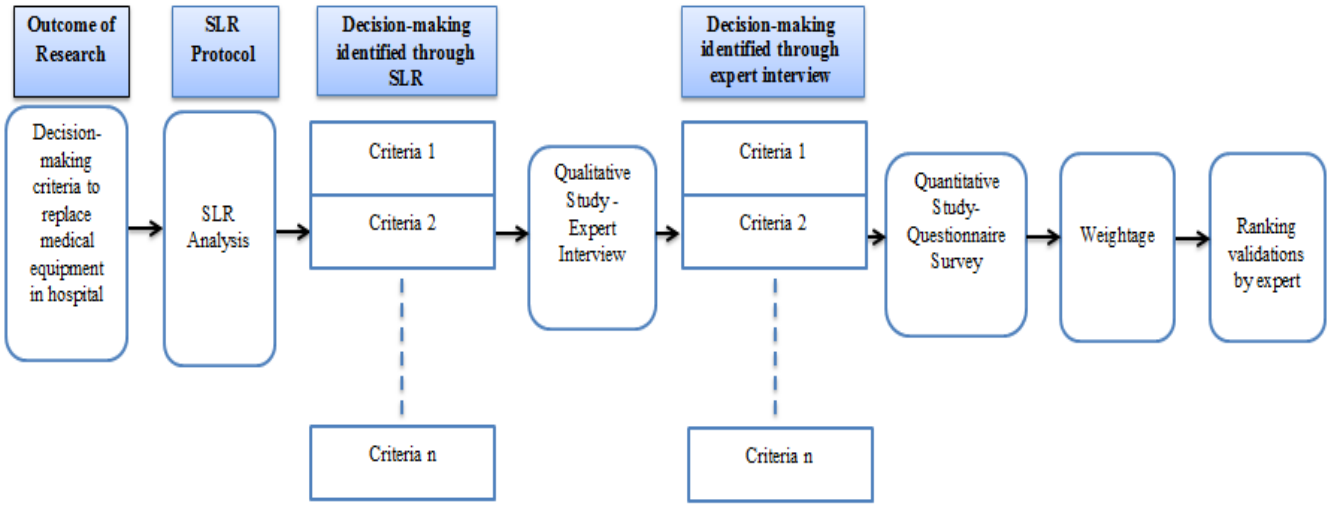

Fig. 3. Decision-Making Flow to Maintain or Replace Medical Equipment

The initial research decision-making framework is developed to effectively design the environmental assessment methods and tools. The development of the framework is to clarify how

and when the many different parties become involved in decisions, the scope of the decisions, the terms used for evaluating decisions and the types of decision-support that may be beneficial.

4. Findings and Discussion

Few analyses have been done in this research. In first phase, we have conducted a structure literature review (SLR) to retrieve the potential criteria to develop the AHP decision-making framework as illustrated in Figure 3. However, the process of retrieving has not been discussed in this paper since the objective of this paper explaining the qualitative and quantitative phase. From SLR phase, fifteen criteria were identified and later being merged into the similar and redundant meanings before being finalized into final nine. Final nine criteria were selected after been filtered during the interview sessions. The final nine criteria are:

i. beyond economical repair (BER) which means an asset is considered beyond economical repair when it is more cost-effective to replace the asset than repair it
ii. condition of the equipment defined as whether it is functional or physically fit
iii. hardware and software obsolescence
iv. health, safety, and environment compliance which means aspect that cover safety from the environment that may affect an individual's health and the general population
v. lifespan or life expectancy defines the time between a given point in an asset's life and when it must be replaced or removed
vi. regulatory and standard requirements for medical equipment are usually established for clinical and technical compliance. These regulations are imposed on the healthcare sector to ensure the safety in touch with the medical equipment
vii. failure risk criteria can result from lack of maintenance, incompatibility, and failure to integrate with other systems, and equipment exceeds lifespan
viii. support in medical equipment management includes technical support, system support, and clinical support
ix. salvage value also known as resale value of equipment at the end of its useful life.

In quantitative phase, all these nine criteria were ranked to validate findings from the qualitative phase. We have used a pairwise comparison method to distribute the survey. The questionnaires were analysed using Analytical Hierarchy Process (AHP) approach. AHP was used to derive the ratio scales from the paired comparison. From the value, the criteria were ranked according to the weightage. Based on the result, downtime criteria have the highest percentage, followed with life cycle cost.

5. Conclusion

A well-maintained and systematic mechanism for managing medical equipment has become one of the important elements in controlling the sustainability of medical equipment. A systematic healthcare mechanism may increase health outcomes and work performance to deliver the services in the healthcare industry. Thus, a proper decision-making framework is necessary to overcome any issues regarding the decision-making in medical equipment replacement. The framework proposed by this research will assist in realizing the effort. The aim of this study is to develop optimized medical equipment maintenance and replacement plans to support decision-makers and extend the effectiveness of equipment maintenance and replacement practices in hospitals. The findings will

guide the Ministry of Health (MoH) as well as the administrative and medical staff to better understand the ultimate criteria involved in medical equipment maintenance and replacement decision-making. Thus, this research will provide an overview to enhance the development of the healthcare services to the society.

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