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A Framework for Medical Equipment Maintenance and Replacement in Private Hospitals

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Abstract
Maintenance and replacement are considered as a crucial process in the medical equipment life cycle management. However, most of the healthcare sectors, especially private hospitals, are still facing conflict in deciding whether to maintain or replace medical equipment, due to poor planning in the organization. Previous studies have found that irregular maintenance, poor equipment planning, and management are the main problems that often occur with medical equipment in hospitals. Thus, this study aims to identify decision-making criteria for medical equipment maintenance and replacement, to evaluate the important decision-making criteria for medical equipment maintenance and replacement, and to develop decision-making framework for medical equipment maintenance and replacement focusing on Malaysian private hospitals. This study has been conducted in three phases namely: identifying the criteria through systematic literature review (SLR); semi-structured interviews using qualitative approach; and pairwise survey using Analytical Hierarchy Process (AHP). From SLR, we found 15 criteria for medical equipment maintenance and replacement. While in the interview phase, we have refined the findings from SLR and concluded that there are only nine decision-making criteria for maintenance and replacement of medical equipment. In the last phase, the analysis from AHP pairwise survey has found that the consensus indicator (CI) was low with 59% while high consistency ratio (CR) was more than 10%.
Keywords: Decision-Making, Medical Equipment, Maintenance, Replacement, Multi-Criteria, Private Hospitals

Introduction
Healthcare is one of the fastest-growing sectors in the world with over 10% of the gross domestic product (GDP) in most developed countries (Karim & Haque, 2020). Healthcare services can be delivered through public and private providers (Kasthuri, 2018). According to the World Health Organization (2017), public healthcare is usually provided by the government through national healthcare systems; meanwhile, private healthcare can be

provided through 'profit-oriented' hospitals and self-employed practitioners, and 'non-profit' or non-government providers (Fernando & Wijewickrama, 2016). Private healthcare sector is the main context of this study, which can be defined as the individuals and organizations that are neither owned nor directly controlled by governments and is involved in provision of health services (Shi & Singh, 2022). In terms of medical equipment, private healthcare has similar equipment with the public healthcare, but still advanced in terms of technology and sophistication (Minopoulos & Memos, 2022). Medical equipment includes various diagnostic, laboratory, surgery, and dental medical instruments. High-risk medical equipment and possible malfunctions in the operation can affect user safety (Munsayac et al., 2021). Hospitals that provide better quality of medical equipment with good maintenance are able to sustain organization's reputations as well as patient's trust (Guyow, 2021). An appropriate and well-used medical equipment in the healthcare sector, primarily private hospitals, will boost to user's satisfaction (Yucesan & Gul, 2020). Nevertheless, it is still unclear in terms of the management perspective of medical equipment in hospitals to maintain quality and effectiveness involving maintenance and replacement processes (Reason & Hobbs, 2017). Thus, a systematic mechanism for managing assets is essential to make sure the medical equipment is well-maintained (Khumpang & Arunyanart, 2019). It is also important to have reliable medical equipment to increase the service quality provided by the healthcare industry (Hooda & Joshi, 2022). This related to maintenance and replacement process of medical equipment. Khider and Hamza (2022) stated that maintenance management is an orderly and systematic approach for planning, organizing, monitoring, and evaluating maintenance activities and the costs. Meanwhile, replacement of medical equipment means property acquired to take place of other equipment (Ghazal & Hasan, 2021).

Some issues need to be further discussed and get into the solutions, so that the medical equipment in maintaining or replacing the process is well-managed. The issues faced in decision-making of medical equipment whether to maintain or replace were: (1) poor systematic mechanism in managing medical equipment Liu & Tong (2022); (2) medical equipment maintenance made based on its age only (Salim & Mazlan, 2019); (3) lack of sources from previous study Zamzam (2021); (4) the information required for making decisions differ according to organization level Rahman (2019); and (5) errors related to medical equipment occurred (Torkzad & Beheshtinia, 2019). Hence, the multi-criteria decision-making (MCDM) approach has been used to prioritize maintenance requirements for medical equipment and establish guidelines for choosing the right maintenance strategy (Bragazzi & Mansour, 2020). Ivlev and Kneppo (2015) stated the suitable MCDM technique to prioritize and rank the influential criteria is Analytical Hierarchy Process (AHP). AHP is an approach through paired comparison that depends on experts' judgment to rank the level of priority (Pamučar & Puška, 2021). This method has been selected in this study as the result from this approach is reliable and has been used extensively by various industries in determining the priority selection that includes assessment experts on the proposed criteria (Pant & Kumar, 2022).

This study will provide a significant well-being to the society in the long run as medical equipment in hospitals is well-maintained and safe to be used. This effort will lead to high quality service in the healthcare industry. Furthermore, the Ministry of Health Malaysia (MoH) has desired to increase preparedness in the healthcare system to handle infectious diseases and any future health crisis. Therefore, this study will be the 'feature map' in providing efficient decision-making processes especially in managing complex medical equipment. The model proposed by this study will assist in realizing the effort. In addition, the outcomes of this study will give an understanding and explore the local healthcare services as it identifies the key role in the delivery process to the public. The findings of the study could support the MoH in mastering its knowledge in response to the unique needs and demands of society. This study may be one of the initiatives for the MoH and policymakers to develop and implement effective approaches in providing healthcare services in hospitals.

Methodology

This study has three phases including: (1) exploring phase using a systematic literature review; (2) the qualitative phase using semi-structured interviews; and (3) 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.

Phase 1: Structured Literature Review (SLR)

Process of Conducting SLR

In this study, three databases have been used to conduct article search including: (1) Web of Science: the most significant world-leading database in the world in terms of impact criteria that offers multi-discipline material (technology, astronomy, IT, medical science, etc.). This database is based on the indexing of multidisciplinary study in various science, social sciences, the arts, and the humanities; (2) ScienceDirect: the most important gateways for education and one of the most significant sources of information that offers access to various scientific and medical fields of science; (3) Scopus: a database that totals the citations and abstracts of many scholarly and peer-reviewed journals, trade journals, books, patent records, and scholarly conference publications. In these three databases, advanced search was applied to review papers, research papers, and conferences published from 2017 until 2023 during the author's searching process. This study has used mix keywords to search for the related articles as shown in Figure 1.

> ("medical equipment" OR "medical device" OR "equipment") AND (decision OR selection) AND (maintenance OR maintain OR replacement OR disposal OR condemn) AND (factor OR attribute OR criteria OR criterion)

Figure 1. Keywords for SLR Process

To accomplish a clear filtering process, the final set of papers were read, analyzed, and summarized by the author. The initial numbers of articles from three databases are 724 which are from: 9 articles from Web of Science, 701 articles from ScienceDirect, and 14 articles from Scopus. Next the screening process was carried out; and 58 articles were identified as duplicates, making the articles down to 666. The review of the title and abstract was carried out, leaving only 117 articles. After conducting a full reading and scanning process, only 60 articles remained, and all these articles are related to medical equipment in healthcare services in hospitals which is illustrated in Figure 2.

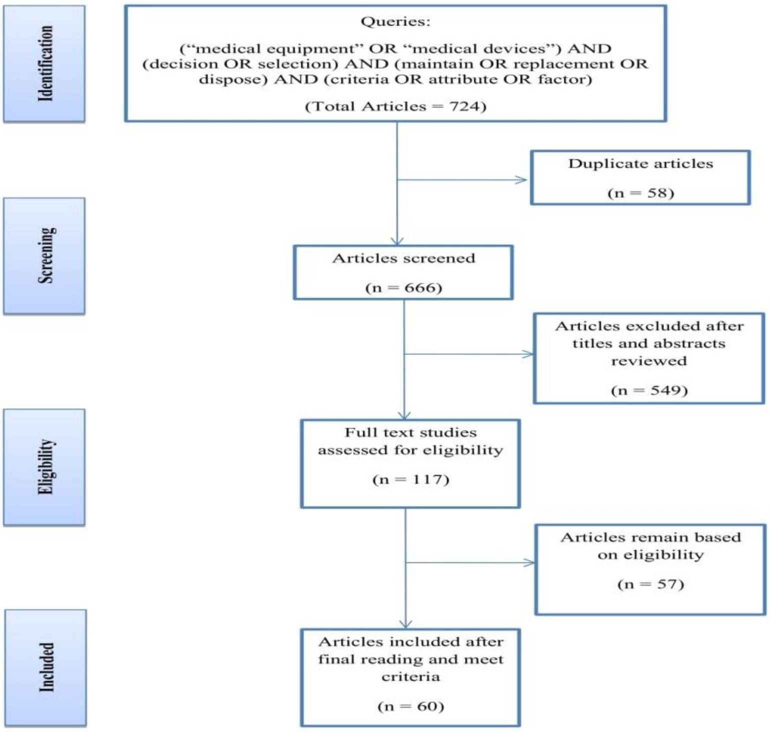

Figure 2. SLR Process Flow

Findings from SLR Analysis

In this study, the primary objective of SLR was to explore and identify the criteria for decision-making to maintain and replace medical equipment which was extracted from previous study and practices reports. As shown in Figure 3, a total of 60 sources from research papers, research articles, and standard operating procedure (SOP) were analyzed by using taxonomy analysis in the SLR phase. There were 33 criteria identified in the first stage of analysis from the sources obtained and later filtered into the final 15 by grouping criteria with the same category. The final 15 decision-making criteria for medical equipment maintenance and replacement were: (1) beyond economical repair; (2) condition; (3) downtime; (4) hardware and software obsolete; (5) health, safety & environment; (6) lifespan; (7) maintaining & operational cost; (8) purchase cost; (9) regulatory compliance; (10) replacement cost; (11) failure risk; (12) salvage value; (13) support; (14) technology; and (15) life cycle cost. The criteria identified from the SLR have then been compared with criteria extracted from the expert's interview, and the similarities were validated and finalized.

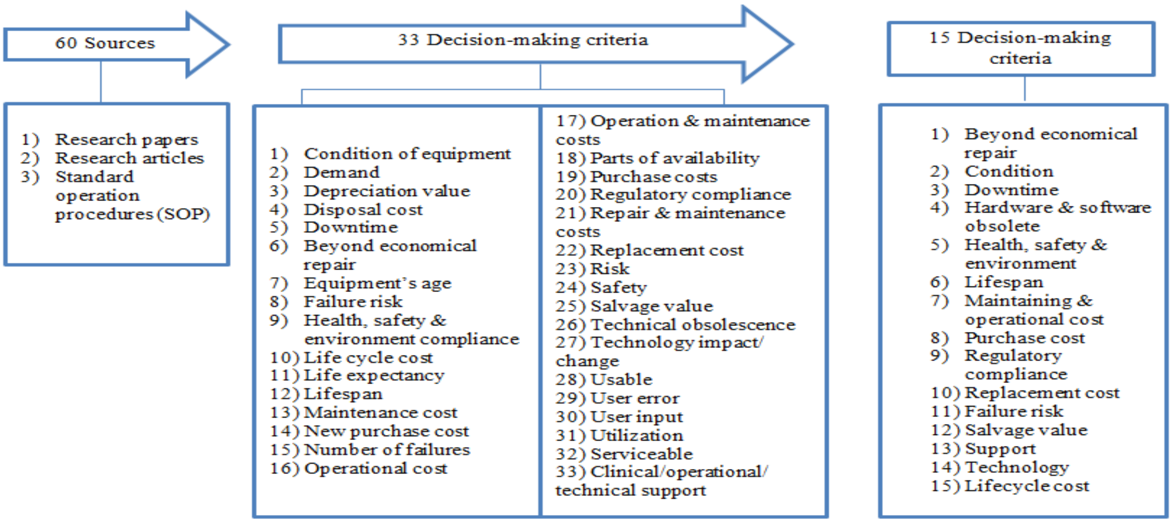

Figure 3. SLR Analysis

Phase 2: Semi-structured Interview

Process of Conducting Semi-Structured Interview

The second phase of this study is a qualitative approach consisting of semi-structured interviews conducted to verify the criteria obtained in phase 1. This phase is also important for extracting new criteria from interview sessions with experts. Respondents for this phase are experts from the healthcare industry; where most of them work in hospitals and have more than five years of working experience. Respondents are expertise in managing healthcare facilities especially related to medical equipment. As the respondents' working background were related to medical equipment management, their opinions and perceptions were relevant to be used as the data collection for this study. A total of six interviews were conducted with six respondents. Interviews were conducted through online platforms and face-to-face, where the interview sessions were recorded for subsequent analysis. Additional information was also taken into account during the interview session for further findings. Interview data were analyzed using framework methods that have been widely used to manage and analyze qualitative data, especially in medical and health research. The qualitative interviews were conducted to confirm the decision-making criteria identified through SLR (Roberts, 2020).

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
Experts' Background

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

Findings from Semi-Structured Interview

All of the respondents in qualitative interviews had answered questions asked by the interviewer and depth elaboration on the topics chosen has been noted for further phases. As an example, the opening questions asked by the interviewer to the experts were to emphasize the importance of the Medical Equipment Management Plan (MEMP) implemented in hospitals; and the respond that we get from respondents are: Expert 1 mentioned, *"MEMP is necessary for every hospital, especially for future operations, management, and cost savings to avoid loss of results, poor performance, and frequent failures of medical equipment"*. According to Expert 2, *"A plan that involves prevention and maintenance in the management of medical equipment is important to prevent safety issues from occurring"*.

Experts were also asked about the medical equipment replacement process practiced in hospitals. Expert 3 explained, "*High considerations should be taken and decisions must be made on a case-by-case basis including equipment service history, performance, and reliability, overall condition of equipment, functional importance, any critical risks that the equipment may cause to be out of use, impact on productivity or quality, unscheduled downtime costs, decommissioning or disposal costs, costs related to research and purchase of replacements, capital costs of equipment replacement, and any training costs for equipment replacement".* On the other hand, Expert 4 has mentioned: "*The decision to repair or replace is not always easy. However, by working with a qualified specialist, it is possible to make an informed decision"*. Meanwhile, Expert 5 also mentioned "*Taking a long-term view will make good decisions in terms of cost, performance, and sustainability of hospital operations"*.

Deduction method was used in this study; where the results extracted from the literature review were confirmed and validated during semi-structured interview sessions. The comparison findings of decision-making criteria from SLR (phase 1) and semi-structured interview (phase 2) was as shown in Table 2.

Table 2
Comparison Decision-Making Criteria

No.	Through SLR	No	Through Qualitative Phase
1	Beyond economical repair (BER)	1	Life cycle cost (LCC)
2	Condition	2	Downtime
3	Downtime	3	Beyond economical repair (BER)
4	Hardware & software obsolete	4	Condition
5	Health, safety & environment (HSE)	5	Regulatory compliance
6	Lifespan	6	Failure risk
7	Maintaining & operational cost	7	Health, safety and environment (HSE)
8	Purchase cost	8	Hardware & software obsolete
9	Regulatory compliance	9	Support
10	Replacement cost		
11	Failure risk		
12	Salvage value		
13	Support		
14	Technology		
15	Utilization		

Extraction of fifteen criteria from the SLR process have found out that there were seven similar criteria with the listed obtained from the interview results: (1) beyond economical repair, (2) condition, (3) hardware and software obsolete, (4) health, safety, and environment, (5) regulatory compliance, (6) failure risk, and (7) support. Additional two criteria come out from the interviews: (1) life cycle cost (LCC), and (2) downtime. The new criteria identified from the interviews are important to be considered during the decision-making process for medical equipment maintenance and replacement because both criteria may lead to better durability, less maintenance, fewer risks, and lower operational spending and can even increase equipment lifespan. Based on the interview sessions, LCC are the most considered criteria for decision-making equipment maintenance and replacement mentioned by experts. LCC mainly involves the process of estimating the budget spent on an asset throughout its lifespan. LCC is commonly related with the criteria of purchase price, cost of maintenance as well as disposal. Even though the cost of maintenance and operation is a proportion of LCC, it still counts as LCC as highlighted by the experts. The next criteria are downtime, which the equipment has faced a period of malfunctions, or the equipment cannot be operated in a well condition.

Phase 3: Quantitative Approach

Process of Pairwise Survey and AHP Analysis

The third phase is a quantitative approach where a pairwise questionnaire survey was used to collect the data. By using pairwise questionnaire, it allows for a detailed determination of nature in relationship between more than two criteria. Thus, an effective test design with optimal number of test cases was used for this study. Respondents for this phase are experts with a standard of minimum two years' experience in the biomedical engineering field. The experts are required to evaluate the importance of the criteria according to their knowledge, experiences, and perceptions. The evaluation was conducted using Saaty's Scale (Sonker, 2021). The survey was conducted in two-way methods; the first approach was by distributing the survey questionnaire in a paper form. The second method was via an online platform. In this study, 25 pairwise questionnaires surveys were distributed related to decision-making criteria. The outcome has then been analyzed using AHP with the consistency ratio (CR) and consensus indicator (CI). In this study, the priority vector was used to obtain the weights for each of decision-making criteria. According to Kazibudzki (2022), the reason to conduct priority vector process is to complete the criteria ranking steps based on the weights and to conclude the priority on each criteria. Thus, ranking of the criteria is based on the weighting method used in this study. In this study, two methods were used which are (1) the method proposed by SCB Association Ltd (Ltd, 2016) and (2) BPMSG diversity analysis-Shannon alpha and beta distribution method Goepel (2019) using Microsoft Office Excel templates.

Consensus is a collaborative process among all group members to develop and agree to support decisions for the common interest. During the evaluation stage, the aggregation of individual judgments counted. As stated in Table 3, consensus indicators can be classified into three categories including: low, moderate and high. If the consensus percentage is low, it represents a low agreement among the group members for decision-making maintenance and replacement of medical equipment. Meanwhile, if the consensus percentage is high, it represents a high agreement among the group members for the decision-making.

Table 3
Consensus Indicator

Consensus Indicator, S*	**Description**
Below 50%	Very low consensus
50% to 65%	Low consensus
65% to 75%	Moderate consensus
75% to 85%	High consensus
Above 85%	Very high consensus

A consistency ratio (CR) is calculated after each set of pairwise comparisons including the criteria comparison, sub-criteria between each group, and comparison between alternatives of each-sub-criteria were conducted (Pant & Kumar, 2022). The CR shows the degree to which the pairwise judgments resemble a purely random set of pairwise comparisons. The judgment of CR is indicated as in Table 4. The CI value was determined by the random consistency index (RCI) by using the above equation 3.1:

$$CI = \frac{\lambda \max - n}{n-1} \qquad CR = \frac{CI}{CR} \qquad (3.1)$$

Table 4
Scales of CR

CR Scales	**Description**
<0.1	Reasonable
<0.2	Tolerable
>0.2	Revised or discarded

Findings from AHP Analysis

This section will elaborate the result obtained from the AHP analysis from the pairwise comparison survey. After the pairwise comparison survey was completed, the priority vector for decision-making criteria was calculated for each expert. This method has been conducted to rank the medical equipment replacement criteria according to the weightage.

The average of priority vectors for each criterion was calculated for the prioritization of decision-making criteria purposes. As illustrated in Table 5, the results showed that downtime (D) criteria have the highest percentage, followed by life cycle cost (LCC). This showed that the criteria stated were the most agreed by experts. Almost 70% of the experts agreed with the result in the qualitative interview in which life cycle cost (LCC) and downtime are the two priorities in decision-making of medical equipment maintenance and replacement.

Table 5
Priority Vector Average of Decision-Making Criteria

No.	Decision-Making Criteria	Priority Vector Average (%)
1	Downtime (D)	14.28
2	Life Cycle Cost (LCC)	13.75
3	Beyond Economical Repair (BER)	13.65
4	Health, Safety & Environment (HSE)	12.97
5	Hardware & Software Obsolete (HSO)	11.29
6	Regulatory Compliance (RC)	9.85
7	Condition (C)	8.53
8	Support (S)	8.38
9	Failure Risk (FR)	7.30

Based on nine criteria, the AHP consensus obtained from the pairwise comparison survey is 59%. This indicated that the CI for this study is low as the percentage falls between 50% to 65%. The value of 59% of consensus reflected that 59% of experts agreed to most of the criteria. The equation of CI as illustrated below was used to get the result.

$$S^* = \left(\frac{1}{D_\beta} - D^*_{\alpha\ min} D^*_{y\ max}\right) / \left(1 - D^*_{\alpha\ min} / D^*_{y\ max}\right) \qquad (3.2)$$

***S** = 59%**

The consistency is hard to achieve in real-life decision situations. Liang and Brunelli (2020) further mentioned if the inconsistency were high; a random entry of information can be used from the comparisons. In this study, the result shows a high inconsistency of the questionnaire survey. However, the inconsistency results can be minimized if the number of criteria was reduced to 6-8 (Goepel, 2019).

$$CI = \frac{\lambda\max - n}{n-1} \qquad CR = \frac{CI}{CR} \qquad CR = \frac{0.25392}{1.45} = 0.175$$

Further, a proportional distribution of all nine criteria was calculated and presented in a pie chart, as shown in Figure 4. The proportional distribution indicates the distribution of experts' answers. A high number of distributions demonstrated a condition of being highly selected by respondents. Consensus degree was measured to check the consistency of individuals' perceptions. In this study, downtime has the highest percentage for proportional distribution which is 19%, followed by the life cycle cost 16% and beyond economical repair which is 13%. Criteria with the lowest percentage of proportional distribution are condition, support, and failure risk with 7% each.

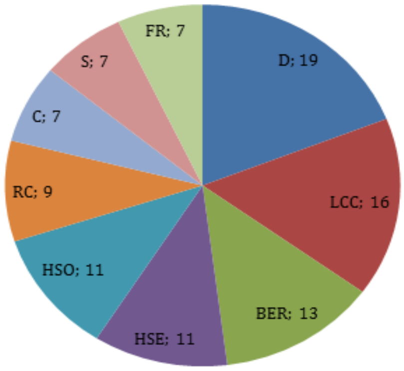

Figure 4. Proportional of Nine Criteria from 25 Experts

Flow of Developing a Decision-Making Framework for Medical Equipment Maintenance and Replacement

Figure 5 indicates the overall process to obtain the decision-making criteria to maintain and replace medical equipment in private hospitals. The process of developing starts with SLR analysis from previous study on equipment 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 criteria. The total weight for each criteria 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.

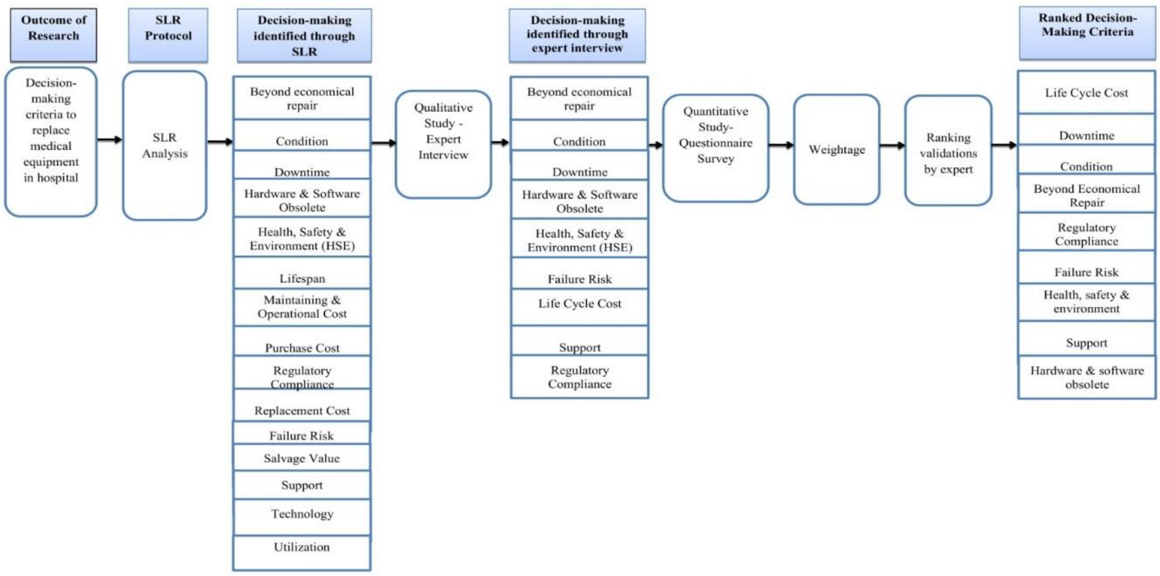

Figure 5. Decision-Making Flow to replace Medical Equipment in Hospitals

Conclusions

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 maintenance or replacement. Suitable criteria involved in decision-making for maintenance or replacement of medical equipment helps decision-makers to decide the right choice for this process and resulted to better performance provided in the healthcare management. Hence, this study is suitable to be used by healthcare organizations in the purpose of medical equipment management.

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