A Quantitative Model for Replacement of Medical Equipment Based on Technical and Environmental Factors

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Abstract- Medical equipment operation state is a valid reflection of health care organizations performance, where such equipment's highly contribute to the quality of healthcare services on several levels in which quality improvement has become an intrinsic part of the discourse and activities of health care services. In healthcare organizations, clinical and biomedical engineering departments play an essential role in maintaining the safety and efficiency of such equipment's. One of the most challenging topics when it comes to such sophisticated equipment's is the lifespan of a medical equipment where many factors will impact such characteristic of a medical equipment through its life cycle. So far, many attempts have been made in order to address this issue where most of the approaches are kind of arbitrary approaches and one of the criticisms of existing approaches trying to estimate and understand the lifetime of a medical equipment lies under the enquiry of what are the environmental factors that can play into such a critical characteristic of a medical equipment. In an attempt to address this short coming the purpose of our study rises where in addition to the standard technical factors taken into consideration through the decision making process by a clinical engineer in case of medical equipment failure, the dimension of environmental factors shall be added.

The investigations, researches and studies applied for the purpose of supporting the decision making process by a clinical engineers and assessing the lifespan of healthcare equipment's in the Lebanese society was highly dependent on the identification of technical criteria's that impacts the lifespan of a medical equipment where the affecting environmental factors didn't receive the proper attention. The objective of our study is based on the need of introducing a new well-designed plan for evaluating medical equipment's depending on two dimensions. According to this approach, the equipment's that should be replaced or repaired will be classified based on a systematic method taking into account two essential criteria's, the standard identified technical criteria and the added environmental criteria.

I. INTRODUCTION

Health technologies are important for a functioning health system. Medical devices in particular are crucial in the prevention, diagnosis and treatment of illness and disease, as well as patient rehabilitation. Medical equipment's is extensively used in all these aspects where these days it is virtually impossible to provide health service without them. Unlike of other healthcare technologies including drugs, implants and disposable products, medical equipment requires maintenance both scheduled and unscheduled during its useful time. As the sophistication and the cost of medical equipment's rises and continue to escalate through our days, the complexity and the cost of its maintenance have also risen sharply through the last decades. The maintenance of medical equipment is as important of its design and development. Usually, much more money is spent on maintaining a piece of equipment over its lifespan than on its procurement [1]. As medical technology becomes more sophisticated and complicated, the assessment of medical equipment is increasingly becoming the main target of health care institutions [2]. In addition, as we witness a further advance in medical technology, a Medical Equipment Management program (MEMP) must be developed in health care facilities to ensure medical devices operate according to safety, reliability and efficiency where maintenance is one of the vital processes to improve equipment safety and decrease the risk of equipment failure [3]. Maintenance strategies and reliability engineering have been significantly improved in the last two decades for the purpose of improving the performance of medical equipment and supporting the equipment maintenance management, but most of hospitals and healthcare organizations do not profit from the maintenance excellence as much as other industries [4]. For several years starting 1989, a remarkable and important effort has been done regarding the study of reliability and maintenance of medical technology and the investigations of their disorders, in which a lot of researches, studies and papers tackled the maintenance problems including mathematical models, empirical studies on medical devices maintenance and prioritization of medical equipment's for their maintenance activities. The status of various studies on maintenance of medical equipment's is presented in different models. In paper [5], a risk assessment method is proposed to classified medical equipment's according to their equipment management numbers identified as the sum of the numbers assigned to the devices function, physical risks and required maintenance, in which medical devices was included in the maintenance plans and strategies if the summation of the included parameters was above an identified critical value. In paper [6], the researchers highly focused on the criticality of medical devices and the surrounding environment in which the study was dedicated to the classification of medical equipment's and the analysis of their preventive maintenance depending on the failure mode and effects analysis (FMEA).Other studies focused on the effectiveness of the measured maintenance with failure codes as an evidence based maintenance in which maintenance data is collected in various hospitals and specific failure codes was applied to measure maintenance effectiveness [7]. Moreover, paper [8] proposed a maintenance model for minimizing risks and optimizing the cost effectiveness of medical equipment's where both elements were evaluated together with the role of medical equipment suppliers. Other studies proposed programs to increase efficiency of the utilization of medical equipment's through a Medical Equipment Management Program (MEMP) [9]. Furthermore, study [10] developed a fuzzy healthcare failure modes and effect analysis (HFMEA) where such analysis is a systematic method that identifies and prevents equipment problems before they occur by ensuring a safe and desirable outcome.

All of the above studies discussed the importance of preventive maintenance and its contribution on the lifespan of a medical equipment and highlighted a proposed models that share a common target specified in the calculation of risks that is applied to lead safety, effectiveness and efficiency regarding the health care service deliver to patents through healthcare facilities where such models are simple to use and effective in reducing general risks that effects the lifespan of a medical equipment. However, an interesting approach in this issue has been proposed through a study related for preventive maintenance prioritization of medical equipment's. In paper [11], a new evaluation technique similar to Canadian technique which will be highlighted later on is proposed but with less data in which a simple investigation is applied focusing on the identification of five main technical criteria's including the function, age, mission criticality, the risks, and the maintenance requirements. Data collection for each identified criteria's is maintained by the application of a checklist questionnaire targeting data collection for each medical equipment. Such technique is applied as a case study on a Lebanese public hospital resulting in a list of equipment's that should be replaced after a period of time. As mentioned before , Novel Approach Study [11] is similar technique to the Canadian technique illustrated through an optimization and prioritization study done by Sharareh Taghipour in 2011 in which six main criteria's is assigned from which some of them are branched into sub criteria's [12]. Taghipour focused on recalls and hazard that may occur for medical equipment as well as he raised the attention to the operational and the non-operational consequences of a failure for the purpose of inspection the cost of repair

. In our model, a new technique will be proposed similar to the Novel Approach one in which a new criteria will be added to the identified technical criteria's. Here, the investigation will be simple and straight forward in which we will focus on a new effecting criteria identified as the environmental factors contributing in having an impact on the lifespan of a medical equipment, and thus effecting the decision making process to be made by a clinical engineer regarding the replace or repair of a medical equipment in case of failure. Identified environmental criteria's will include for effective criteria's including Society Economical situation , Government Regulations and support strategies , Geographic factor and the stringent environment in which medical equipment's are operating through , political stability stability where such factors impact will be identified depending on experts through the healthcare field in the Lebanese society. Actually, data collection regarding each environmental criteria is very hard and requires a long time where such factors are considered to be a new approach for health care experts in such society where the decision making process regarding medical equipment failures through the Lebanese societies highly depends on the identification of technical factors and specially the cost of repair of an equipment in comparison with its purchase cost. The data related to each environmental factor will be extracted using a survey questionnaire implemented through google forms where responses will be maintained from experts through the health care field in the Lebanese society including Hospitals, Medical Companies and specifically targeting clinical and biomedical engineers operating within these organizations. Furthermore, obtained data shall be applied in Microsoft Excel ® in which data will be analyzed and calculation of the needed Parameters for equipment prioritization and classification is maintained similar to the Novel Approach Study [11] where classification process depends on two dimensions, the identified technical factors in paper [11] and the added Environmental Factors through our study.

In this paper, the problem statement regarding our topic is presented in Section II. The proposed methodology is presented in Section III. The results obtained discussed in Section IV. Finally, a conclusion and our further expectations are presented in Section V.

II. PROBLEM STATEMENT

The essentiality of having a scientific strategy or plan that helps the biomedical engineer in taking the right decision in case of medical equipment failure and mainly support the basic goal of delivering the best health care service to patients that lies within safety , efficiency and effectiveness rises . Currently, the adopted method of taking decisions by biomedical or clinical engineers working in hospitals through the Lebanese society regarding the replacement or repairing of a medical equipment in case of failure is highly based on cost, where the engineer proceeds in repairing the machine if the repair cost is less than 25 % of the medical equipment cost and takes the decision of replacement and getting a new equipment if the repair cost is greater than 25 % of the equipment cost. Starting from this point our problem arises, neglecting other factors affecting the equipment failure would put the decision under serious doubt. Missing and neglecting other factors and taking into consideration the method related to cost and not having a well-studied plan and a scientific formula to depend on through the decision process results in a problematic issue. Although, many approaches have been done so far in order to assess the lifespan of a medical equipment including the technical factors affecting such critical characteristic such as frequency of failure , cost of repair, maintenance requirements and many others, but missing an essential dimension regarding the environmental factors affecting the life span of an equipment such as society economics, geographic, government regulation and political stability that contributes in affecting the decision process in case of medical equipment failure will open the chances for monopoly, which in return will affect the decision process regarding equipment failure in specific and patient safety in general. It is essential to establish a systematic model and a scientific strategy among all Lebanon taking into consideration the factors that affects medical devices and help clinical engineers to take the right decision in case of failure where the equipment's that shall be replaced or repaired can be classified depending on a scientific method focusing on two dimensions, the technical dimension and the environmental dimension in order to perform at the same level and deliver the same quality of healthcare service.

Although, many well-designed techniques and studies have been done so far regarding preventive maintenance of medical equipment’s and applied models targeting risks calculations and reduction but a major problem lies behind the fact that the decision process making regarding medical equipment’s failure through the Lebanese healthcare organizations and specially hospitals is highly dependent on the cost of repair in comparison with total cost of a medical equipment. It’s Important to support the decision making process regarding medical equipment’s failure through the Lebanese society and maintain a technique to depend on based on identified scientific factors including technical part and environmental part.

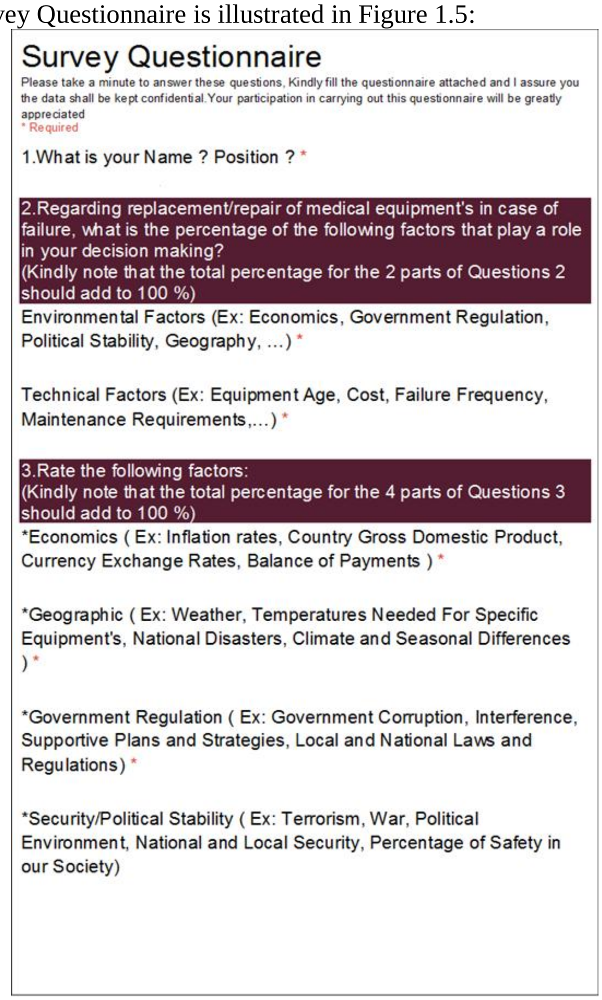
III. METHODOLOGY

Nowadays, Medical equipment’s are the basic source for healthcare service delivery through healthcare organizations in which such equipment’s are used to support patient care in terms of health and safety. Currently, as we witness a substantial advances in technology and a wide development in healthcare field, the complexity under which sophisticated medical equipment operates rises. The excessive use of such highly developed equipment’s shorten its lifespan which in return increase the impact on the quality of healthcare service deliver through such equipment’s. Clinical evaluation and decisions regarding the replacement or repair of such equipment’s in case of failure should be based on a scientific analysis that identifies criteria’s and quantitative parameters to increase the efficiency and enhance patient safety.

This paper proposes a model to classify and prioritize medical equipment’s according to measurable values that identifies time after which the medical equipment must be replaced. Here, a continuous pattern is followed through medical equipment’s classification and a technique similar to Novel Approach study [11], is applied in which a new criteria is added identified as the environmental factors impacting the lifespan of a medical equipment. To start with, we are going to identify the environmental factors identified as four effecting criteria’s which are: Society Economics, Security and political stability, Geographic and surrounding environment of a medical equipment and finally Government regulation.

After identifying the impacting environmental factors and as our study follow a continuous pattern regarding the scientific applied technique in the Novel Approach Study, the effecting technical factors are identified in which the Normalized Score Value (NSV) is computed for each medical equipment through the applied model on a public Lebanese hospital in this evaluation. Our main target is summarized in evaluating and collecting the impact of the identified environmental factors identified in four main criteria’s mentioned above. For this purpose, a survey questionnaire is implemented using google forms targeting the responses of experts in the healthcare field including Clinical engineers, biomedical engineers and physicians responsible for regular management for healthcare medical equipment’s. Here, for the purpose of calculating the intended parameters needed for equipment’s classification and ranking depending on both criteria’s; the technical and the environmental one and answering our questions , 30 hospitals and healthcare companies is taken into consideration. Hospitals and companies were chosen randomly by a higher percentage in Beirut and Mount Lebanon due to increased expertise in these two areas and the high ranked healthcare facilities in which the acquire

In our study, we used a survey questionnaire in which it’s divided into three main questions, the first one contains information about the name and the positon of the replier. The other questions include the healthcare expert opinions depending on their experience in the health care field regarding the percentage impact of the identified technical and environmental factors separately and the impact of each of the four identified environmental criteria’s including Economics, Government regulation, Geographic and Political stability. The applied Survey Questionnaire is illustrated in Figure 1.5:


Survey Questionnaire

Please take a minute to answer these questions, Kindly fill the questionnaire attached and I assure you the data shall be kept confidential.Your participation in carrying out this questionnaire will be greatly appreciated

* Required

1.What is your Name ? Position ? *

2.Regarding replacement/repair of medical equipment's in case of failure, what is the percentage of the following factors that play a role in your decision making?
(Kindly note that the total percentage for the 2 parts of Questions 2 should add to 100 %)

Environmental Factors (Ex: Economics, Government Regulation, Political Stability, Geography, ...) *

Technical Factors (Ex: Equipment Age, Cost, Failure Frequency, Maintenance Requirements,...) *

3.Rate the following factors:
(Kindly note that the total percentage for the 4 parts of Questions 3 should add to 100 %)

*Economics (Ex: Inflation rates, Country Gross Domestic Product, Currency Exchange Rates, Balance of Payments) *

*Geographic (Ex: Weather, Temperatures Needed For Specific Equipment's, National Disasters, Climate and Seasonal Differences) *

*Government Regulation (Ex: Government Corruption, Interference, Supportive Plans and Strategies, Local and National Laws and Regulations) *

*Security/Political Stability (Ex: Terrorism, War, Political Environment, National and Local Security, Percentage of Safety in our Society)

Figure 1: Proposed Survey Questionnaire

After filling the proposed questionnaire, the average percentage regarding each identified factor can be identified using Microsoft Excel ®. After that, Overall Normalized score value (NSV) in which each medical equipment can be ranked is computed depending on the identified (NSV) scores regarding technical criteria's as mentioned in Table III and the obtained (NSV) scores regarding environmental criteria's through our study. At this stage, the Overall (NSV) is expressed in the following equation:

$$Total_{NSV} = (Avr\ \%\ TF) \times NSV_{TF} + (Avr\%\ Ef) \times NSV_{EF} \quad (5)$$

The Parameter NSV_{TF} represent the computed NSV regarding each medical equipment depending on the identified technical criteria's as given in Table III. Moreover, the $Avr\ \%\ TF$ represent the average percentage of the maintained responses regarding the effect of technical factors on the decision making process. The parameter NSV_{EF} , represent the computed NSV regarding each medical equipment depending on the maintained responses regarding the effect of each identified environmental factor through the applied survey. Finally, the $Avr\%\ Ef$ represent the average percentage of the maintained responses regarding the effect of environmental factors on the decision process making.

The calculation of the average percentages regarding each identified environmental factors in specific including Economic factor, Geographic, Government regulation and political stability can be expressed in the following equation and total effect of the Environmental and technical factors in general are expressed in the following equations:

$$Avr\%\ (ENV\ Criteria) = \frac{\sum Criteria\ Percentages}{Number\ of\ Repliers} \quad (5)$$

Equation (5), Illustrates the method of calculation of the average percentage of each identified environmental criteria in specific.

$$Avr\%\ (EF) = \frac{\sum EF\ Percentages}{Number\ of\ Repliers} \quad (6)$$

Equation (6), Illustrates the method of calculating the average percentage of the impact of the environmental factors in general

$$Avr\%\ (TF) = \frac{\sum TF\ Percentages}{Number\ of\ Repliers} \quad (7)$$

Equation (7), Illustrates the method of calculating the average percentage of the impact of the Technical factors in general.

After the calculation process of the mentioned factors above, the Overall (NSV) can be computed as mentioned in (5), from which the classification process for each item will be maintained depending on two effecting dimensions.

IV. Results

The obtained results and scores through our study for each medical equipment is based on the calculated score related to technical effect computed in the Novel Approach study [9], and the added environmental part through our study in which the final computed NSV (Normalized Score Value) will be based on the identification of both effecting criteria's, the technical criteria and the environmental one. Participation was 44 % from the chosen hospitals mainly distributed in Beirut and Mount Lebanon. Since this is an ethical study, names of hospitals won't be revealed.

Table 1 : Computed Scores and grades for each equipment through Novel approach

Nb.	**Name**	**Normalized Score**	**Transformed Score (%)**
1	Defibrillator	1	100
2	Blood Gas system	0.84776143	82.563644
3	Pulse Oximeters	0.83167396	80.721096
4	Infusion pump (CCU)	0.80675075	77.866563
5	Monitor (ICU)	0.76745621	73.400487
6	Oximeters	0.76154527	72.689039
7	Syringe pump (ICU)	0.75121329	71.505686
8	Dialysis	0.74112659	70.350424
9	Monitor (CCU)	0.69471468	65.034724
10	**Monitor (Endoscopy)**	**0.68912238**	**64.394221**
11	**Syringe pump**	**0.68817904**	**64.286177**
12	Refrigerator Pharmacy)	0.68541098	63.969142
13	Monitor (Dialysis)	0.68198543	63.576804
14	Incubator(PICU)	0.67304633	62.552981
15	Refrigerator (NICU)	0.66928522	62.122209
16	Refrigerator (PICU)	0.66928522	62.122209
17	Incubator (mobile)	0.66080627	61.151088
18	Syringe pump (floors)	0.65123852	60.055265
19	Incubator (Therapeutic)	0.64902559	59.801811
20	ECG (ICU)	0.62764624	57.353167
21	Fetal Monitor	0.62328606	56.853783

22	x-ray (ICU)	0.60806278	55.110213
23	Ultrasound Unit	0.59212049	53.284293
24	Reanimation & warming table	0.58451048	52.412695
25	ECG (CCU)	0.57761153	51.622536
26 *	**ECG (Dialysis)**	**0.56972919**	**50.719747**
27	**Infusion Pump (NICU)**	**0.56173091**	**49.80368**
28	**Infusion Pump**	**0.54855002**	**48.294032**
29	Lactina Electric pulse	0.52413795	45.498041
30	CPR	0.52413795	45.498041
31	ECG (NICU)	0.50133159	42.885958
32	Fetal Doppler	0.48090312	40.546222
33	Incubator (Delivery Unit)	0.43585151	35.386322
34	Auto scope	0.39837394	31.093899
35	Bairhugger	0.24364574	13.372397

For Hospital A in Beirut area, Professional replier provided us with a feedback on the percentage effect of the technical and environmental factors provided in Question 2 , and the percentage effect of the four identified environmental factors including economical factor , geographic factor , government regulation factor and Political stability factor provided in Question 3. Moreover, since we are dealing with an ethical study, the provided name and position of the replier in Question 1 won't be revealed. Please refer to Table 5.1 & Figures 5.1 & 5.2 for results where the percentages given for each applied question should add to 100 % in which results analysis will follow the same pattern for all hospitals included in our study from which results is maintained.

Questions	Factors	Results
1) What is your Name? Position?	-	-
2) Regarding replacement/repair of medical equipment's in case of failure, what is the percentage of the following factors that play a role in your decision making?	Technical Factors	70 %
	Environmental Factors	30 %
3) Rate the following factors:	Economics	45 %
	Geographic	30 %
	Government Regulation	15 %
	Security/Political Stability	10 %

Table 2: Questionnaire results for Hospital A

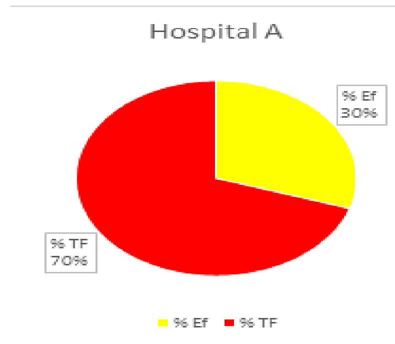


Figure 2: Percentages of environmental & technical factors for Hospital A

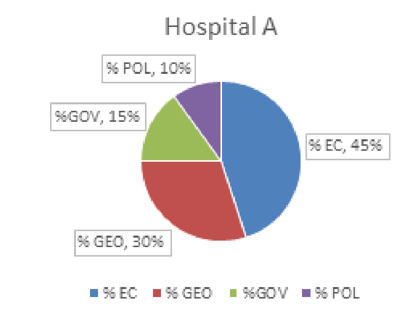


Figure 3: Percentages of the identified environmental factors for Hospital A

The Same procedure applied to Hospitals from A to K with different results. Hospitals Including Hospital L to reach Hospital Y refused to participate in our study where the distribution of the selected hospitals through our study was among Beirut and Mount Lebanon areas. Participated hospitals through our study included six hospitals in Beirut area, and five hospitals in Mount Lebanon. Hospitals are chosen randomly between areas or upon recommendations.

Microsoft excel tool is used for the calculation of the average percentages for each factor needed to be applied for the purpose of computing the needed scores for studied medical equipment's in the Novel Approach study [9].Please See Table 2 & Table 3 , figures 4 & 5 respectively.

Percentages	% AVR
% EF	**20.818182**
%TF	**79.181828**

Table 3: Computed Percentages for effecting technical and environmental factors.

Percentages	%AVR
% EC	26.818182
% GEO	20.454555
%GOV	27.272737
% POL	25.454545

Table 4: Computed percentages of the four effecting environmental factors .

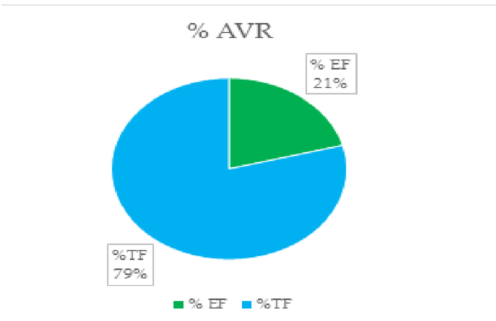


Figure 4: Average percentages of the effecting environmental and technical factors.

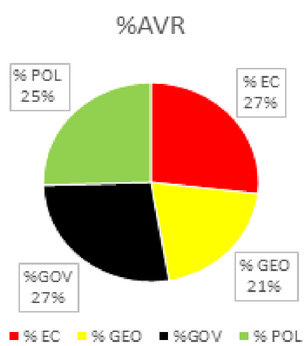


Figure 5: Average percentages of the four effecting environmental factors.

The weights can be assigned for each of the given factors in which needed scores for classification and evaluation of medical equipment's depending on both technical and environmental criteria's can be computed.Please see figure 6 and 7 respectively.

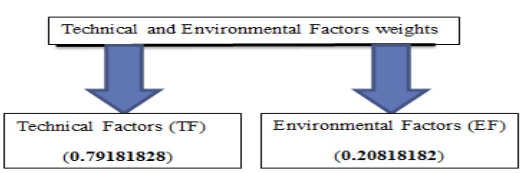


Figure 6: Resulted weights of effecting environmental and technical factors.

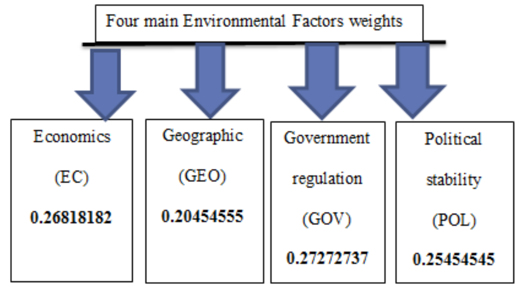


Figure 7: Resulted weights of the four effecting environmental factors.

After acquiring the weights through our survey, the needed parameters for classification of medical devices based on technical and environmental criteria's can be computed through the following equation.

$$Total_{NSV} = (Average\ \%\ TF) \times NSV_{TF} + (Average\%\ Ef) \times NSV_{EF}$$

The NSV_{TF} reflects the Normalized Score Value of each medical equipment depending on five main effecting technical criteria's resulted from the assessment process through the Novel Approach Study [9]. $NSV_{EF}$of each specific equipment can be maintained based on a qualitative approach , then such factor can be characterized as a Total score (X) which is the summation of the Weights × Intensities for the four environmental criteria's , that is illustrated in equation below:

$$Total\ Score\ (X) = \sum_{j=1}^{4} W_j S_j$$

$$Total\ Score\ (X) = W_{Economics} \times I_{Economics} + W_{Geographic} \times I_{Geographic} + W_{Govermental} \times I_{Govermental} + W_{Political} \times I_{Political}$$

In our proposed model, devices can have a $Total_{NSV}$ score between (0.19292315, 1.0) where 1.0 is the maximum $Total_{NSV}$a device gets when the NSV_{TF} is maximum and in our case its 1.0 for the Defibrillator, See table 5.16 and the Total Score (X) is maximum and in such case the device is getting the highest intensity from each environmental factor which is 1.0 for each environmental factor, resulting in a summation in which Total Score (X) is 1.0 and the $Total_{NSV}$is equal to 1.0. The calculation is shown below using :

Maximum $Total_{NSV}$

= 0.79181828 × (1) + 0.20818182 × [0.26818182 (1) + 0.20454555(1) + 0.27272737(1) + 0.25454545 (1)]

= 1.0.

The $Total_{NSV}$ is minimum when the NSV_{TF} is minimum, and the Total Score (X) is minimum in which the device gets the lowest intensity effect from each environmental criteria which is zero.

$$\text{Minimum } Total_{NSV}$$

$$= 0.79181828 \times (0.24364574) + 0.20818182 \times [0.26818182\ (0) + 0.20454555(0) + 0.27272737(0) + 0.25454545\ (0)]$$

$$= 0.19292315.$$

In our study where the approach is a qualitative approach , an assumption can be applied regarding the intensities of each of the identified environmental criteria's , where our model can be applied based on two main cases where the first case illustrates a maximum effect from each environmental factor in which the intensity of each factor is equal to 1 and the second case in which our model will be applied illustrates that the intensity of each environmental factor is obtained by the division of each criteria weight with the maximum acquired weight of the four main criteria's [9].

$$Intenisty = \frac{W_i}{\max(W_i)}$$

Case I:

In such case , our model is applied in which each environmental factor acquired apply a maximum effect on each medical equipment , then the Total Score (X) will be the summation of the maintained weights through the hospitals included in our study. Please see Figure 5.33. As an example, let us apply our model on the Oximeters. Starting with the summation of the weights and intensities for obtaining the Total score (X), the score of such parameter add to 1.0. In the second mission, each of the parameters is subsisted through equation $Total_{NSV}$, in which the $Total_{NSV}$ (Oximeters) is calculated as follows:

$$Total_{NSV}(Oximeters) = 0.79181828 \times 0.76154527 + 0.20818182 \times [0.26818182\ (1) + 0.20454555(1) + 0.27272737(1) + 0.25454545\ (1)]$$

$$Total_{NSV}(Oximeters) = 0.81118728$$

Similarly, we computed the $Total_{NSV}$ score for each medical equipment in which the defibrillator scored the maximum value, its $Total_{NSV}$ is 1. Using such scores and the maintained maximum and minimum scores, the $Total_{TSV}$ is computed for each device through equation :

$$Total_{Tsv} = \frac{Total_{NSV} - Minimum}{Maximum - Minimum} \times 100$$

$$Total_{Tsv}\ (Oximeters) = \frac{0.81118728 - 0.19292315}{1 - 0.19292315} \times 100$$

Following the same procedure, we obtained a long list of medical equipment's with their Total Transformed Score Value.

Table 5: Scores and Grades for each medical equipment

Nb.	Name	$Total_{NSV}$ Score	$Total_{Tsv}$ (%)
1	Defibrillator	1	100
2	Blood Gas system	0.87945481	85.063977
3	Pulse Oximeters	0.86671646	83.485645
4	Infusion pump (CCU)	0.84698181	81.040443
5	Monitor (ICU)	0.81586767	77.185279
6	**Oximeters**	**0.81118728**	**76.605360**
7	Syringe pump (ICU)	0.80300623	75.591696
8	Dialysis	0.79501940	74.602096
9	Monitor (CCU)	0.75826960	70.048865
10	**Monitor (Endoscopy)**	**0.75384151**	**69.499994**
11	**Syringe pump**	**0.75309456**	**69.407444**
12	Refrigerator Pharmacy)	0.75090276	69.135871
13	Monitor (Dialysis)	0.74819035	68.799792
14	Incubator(PICU)	0.74111220	67.922782
15	Refrigerator (NICU)	0.73813409	67.553782
16	Refrigerator (PICU)	0.73813409	67.553782
17	Incubator (mobile)	0.73142030	66.721918
18	Syringe pump (floors)	0.72384438	65.783231
19	Incubator (Therapeutic)	0.72209214	65.566122
20	ECG (ICU)	0.70516358	63.468606
21	Fetal Monitor	0.70171111	63.040831
22	x-ray (ICU)	0.68965704	61.547285
23	Ultrasound Unit	0.67703364	59.983196
24	Reanimation & warming table	0.67100790	59.236583
25	ECG (CCU)	0.66554518	58.559731
26 *	**ECG (Dialysis)**	**0.65930380**	**57.786400**
27	**Infusion Pump (NICU)**	**0.65297062**	**57.001693**
28	**Infusion Pump (floors)**	**0.64253375**	**55.708524**
29	Lactina Electric pulse	0.62320383	53.313470
30	CPR	0.62320383	53.313470
31	ECG (NICU)	0.60514533	51.075952

32	Fetal Doppler	0.58896970	49.071727
33	Incubator (Delivery Unit)	0.55329970	44.651740
34	Otoscope	0.52362158	40.974838
35	Bairhugger	0.40110497	25.794547

Case II

In such case, our model is applied in which each environmental factor acquire an effective intensity the is equal to the division of each criteria weight with the maximum weight of the four maintained environmental criteria's.In the first mission, the Total Score (X) will be calculated as follows:

$$Total\ Score\ (X) = W_{Economics} \times I_{Economics} + W_{Geographic} \times I_{Geographic} + W_{Govermental} \times I_{Govermental} + W_{Political} \times I_{Political}$$

In the second mission, each of the acquired weights for the four main effecting criteria's will be substituted in the given equation. Moreover, Intensity of each criterion will be calculated through the following equation:

$$Intenisty = \frac{W_i}{\max(W_i)}$$

After the Total Score (X) is acquired, all acquired parameters will be substituted through equation (8), in which the $Total_{NSV}$ of each device will be acquired. Similarly to case one, the $Total_{Tsv}$ of each device will be computed.

As an example, let us apply our model on the Monitor of CCU. Starting with the calculation of the needed intensities of each of the effecting environmental criteria's using equation (12), the intensity of the Economical factor is acquired as follows:

$$I_{Economics} = \frac{W_{Economics}}{\max(W_i)}$$

Analyzing the obtained weights through our study, the max (Wi) is equal to the highest acquired weights which is for the government regulation factor in which, max (Wi) = $W_{Govermental}$ which is equal to 0.27272737. Then $I_{Economics}$ can be computed as follows:

$$I_{Economics} = \frac{0.26818182}{0.27272737} = 0.98333298$$

Similarly, the intensity of each factor is computed in which the acquired parameters are substituted for the purpose of calculating the Total Score (X) where calculation is done as follows:

Total Score (X)= 0.26818182 ×(0.98333298)+ 0.20454555×(0.75)+ 0.27272737×(1)+ 0.25454545 ×(0.93333298) =0.92742421

$$Total_{NSV}(Monitor\ CCU) = 0.79181828 \times 0.69471468 + 0.20818182 \times 0.92742421 = 0.74316064$$

Similarly, we computed the $Total_{NSV}$ score for medical equipment's in which the defibrillator scored the maximum value, its $Total_{NSV}$ is 0.98489114.Then the Maximum $Total_{NSV}$ is 0.98489114 and the Minimum $Total_{NSV}$ is maintained as mentioned before through Case one, then the $Total_{TSV}$ is computed for each device as follows:

$$Total_{Tsv} = \frac{Total_{NSV} - Minimum}{Maximum - Minimum} \times 100$$

$$Total_{Tsv}\ (Monitor\ CCU) = \frac{0.74316064 - 0.19292315}{0.98489114 - 0.19292315} \times 100 = 69.477238\ \%$$

Following the same procedure, we obtained a long list of medical equipment's with their Total Transformed Score Value ($Total_{Tsv}$).Please see table 6.

Table 6: Scores and values for medical equipment's

Nb.	**Name**	**$Total_{NSV}$ Score**	**$Total_{Tsv}$ (%)**
1	Defibrillator	0.98489114	100
2	Blood Gas system	0.86434585	84.779019
3	Pulse Oximeters	0.85160750	83.170577
4	Infusion pump (CCU)	0.83187285	80.678727
5	Monitor (ICU)	0.80075871	76.750016
6	**Oximeters**	**0.79607832**	**76.159033**
7	Syringe pump (ICU)	0.78789727	75.126031
8	Dialysis	0.77991044	74.117552
9	Monitor (CCU)	0.74316064	69.477238
10	**Monitor (Endoscopy)**	0.73873255	68.918113
11	**Syringe pump**	0.73798560	68.823798
12	Refrigerator Pharmacy)	0.73579380	68.547044
13	Monitor (Dialysis)	0.73308139	68.204554
14	Incubator(PICU)	0.72600324	67.310812
15	Refrigerator (NICU)	0.72302513	66.934773
16	Refrigerator (PICU)	0.72302513	66.934773

17	Incubator (mobile)	0.71631134	66.087038
18	Syringe pump (floors)	0.70873542	65.130444
19	Incubator (Therapeutic)	0.70698318	64.909192
20	ECG (ICU)	0.69005462	62.771662
21	Fetal Monitor	0.68660215	62.335726
22	x-ray (ICU)	0.67454808	60.813686
23	Ultrasound Unit	0.66192468	59.219758
24	Reanimation & warming table	0.65589894	58.458901
25	ECG (CCU)	0.65043622	57.770071
26 *	**ECG (Dialysis)**	0.64419468	56.981031
27	**Infusion Pump (NICU)**	0.63786166	56.181375
28	**Infusion Pump (floors)**	0.62742479	54.863914
29	Lactina Electric pulse	0.60809487	52.422790
30	CPR	0.60809487	52.422790
31	ECG (NICU)	0.59003637	50.142584
32	Fetal Doppler	0.57386074	48.100124
33	Incubator (Delivery Unit)	0.53818805	43.595815
34	Otoscope	0.5085126	39.848766
35	Bairhugger	0.3859901	24.378871

The list of obtained total transformed score values ($Total_{Tsv}$) for the assessed medical equipment's through our study, allow the criticality classification of these equipment's into three main categories, where each equipment can fall into a specific category depending on the computed ($Total_{Tsv}$) of each equipment. Such score reflects the criticality of replacing or repairing medical equipment based on two effecting criteria's, the established technical factors through a previous study, and the identified environmental criteria's through our study. The first category is for medical equipment's that must be replaced urgently where such equipment's may impose a negative effect on healthcare service and patient safety. The Second category is for medical equipment's that can be replaced after a year and a half where deadline period of replacement can be identified by hospital, where such equipment's can be managed through specific strategies and management processes applied by the hospital. Finally, the third category is for those equipment's that can work for several years to come and can be changed later on.

After analyzing the obtained scores for each of the mentioned cases above, in which two different assumptions is set for the intensity effect of each of the identified environmental factors, and after comparing the results obtained through our study in which a new criteria is added defined as the effecting environmental factors on the replacement and classification process of medical equipment's with the obtained results through the Novel approach study [9], an increase in the obtained total score values for each medical device is observed in which such increase allow us to set a new intervals of criticality and using the new transformed score values to sort medical equipment according to their urgency of replacement.

In general, we can classify the equipment's of a hospital in order of their urgent need to be replaced, where such classification is based on two effecting criteria's, the technical criteria and the environmental one. If the equipment's score is between 60% and 100 %, then the equipment should be replaced directly. If the scores range between 50% and 60 %, then the equipment should be replaced after a while. Finally, if the score is less than 50 %, then this means that the replacement should not be done in the near future. Such classification can be taken as an example, in which other intervals of criticality can be set depending on the hospital planned maintenance programs and financial contribution. The interval of criticality in which medical equipment's can be sorted depending on the obtained transformed score values is shown in Table 7.

Table 7: Criticality interval of equipment's according to obtained $Total_{Tsv}$

Criticality class	$Total_{Tsv}$	Maintenance Strategy
High	60% <TSV< 100%	To be changed Urgently
Medium	50% < TSV < 60%	To be changed after a year and a
Low	0% :5 TSV < 50%	To be changed after three years

Based on the given ranges of grades, medial equipment's can be summarized in three groups as shown in Table 8.

To be changed urgently	To be changed after a year and a half	To be changed after three years
High **60%** <TSV **100%**	**Medium** **50%** < TSV < **60%**	**Low** **0%**TSV < **50%**
Defibrillator	Reanimation & warming table	Fetal Doppler

Blood Gas System	ECG (CCU)	Incubator (Delivery Unit)
Pulse Oximeters	ECG (Dialysis)**	Auto scope
Infusion pump	Infusion Pump (NICU) *	Bair Hugger
Monitor (ICU)	Infusion Pump (floors) *	
Oximeters	Lactina Electric pulse	
Syringe pump (ICU)	CPR	
Dialysis	ECG (NICU)	
Monitor (CCU)		
Monitor (Endoscopy) *		
Syringe pump (PICU)		
Refrigerator (Pharmacy)		
Monitor (Dialysis)		
Incubator(PICU)		
Refrigerator (NICU)		
Refrigerator (PICU)		
Incubator (mobile)		
Syringe pump (floors)		
Incubator (Therapeutic)		
ECG (ICU)		
Fetal Monitor		
x-ray (ICU)		
Ultrasound Unit		

As a conclusion, much more studies must be done to support the healthcare service quality in our society and enquire more about the environmental factors and its effect not only on medical equipment's classification process but also its effect if found on accreditation processes through hospitals and its contribution if found in having a more socially responsible healthcare organization in which recently such organizations are becoming more increasingly aware of the needs and benefits of socially responsible behavior and especially in health care field. Moreover, such studies and enquiry can be done through other areas and provinces in Lebanon supporting the patients right to take the same health service from any place in Lebanon and not only through the areas of Beirut and Mount Lebanon.

V. Conclusion

The rapid advance in technology and wide development in health care field and the highly sophisticated medical equipment's, puts a huge impact on the improvement and rapid progress of medical services. Medical equipment open the chance for a better medical service where its hard nowadays to diagnose , treat and mitigate an illness or disease without the help of such important healthcare equipment's. Currently, medical devices are expected to operate according to safety, accuracy, reliability to ensure effective and efficient contribution in the healthcare field. As such, this research provided a new evaluation technique and classification process for medical equipment's where it provides a new model for assessing the life span of a medical equipment based on identified technical and environmental factors. Moreover , this method will support the accuracy of the decision making process to be taken by a clinical engineer in case of equipment failure where it targets two effecting dimensions ; the usual impacting technical factors and the newly identified environmental ones. Such method can be used as an assessment tool based on criteria decision-making approach resulting in a more precise, accurate and suitable decision regarding medical equipment failure where monition equipment's depending on scientific identified criteria's would be a huge step towards safety, efficiency , quality improvement and accountability. In order to reach a high decision status regarding medical equipment failure , the proposed approach can be further enhance in which responses about the impact of effecting technical and environmental factors can be further investigated throughout Lebanon major provinces where responses can be gathered from experts from the health care field , and further investigation can be done by taking the top ranked hospitals through the Lebanese societies where a survey analysis and audit interviews can be applied targeting top ranked hospitals Chief Executive officers

(CEOS) of each hospital , stakeholders, Employees all over the organization resulting in more accurate percentages where percentages can be classified depending on the repliers experience , age , gender and education level.

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