Taylor & Francis
Taylor & Francis Group

Cogent Engineering

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/oaen20

An integrated multi-criteria decision-making framework for a medical device selection in the healthcare industry

Mohammad A. Shbool, Omar S. Arabeyyat, Ammar Al-Bazi & Wafa' H. AlAlaween |

To cite this article: Mohammad A. Shbool, Omar S. Arabeyyat, Ammar Al-Bazi & Wafa' H. AlAlaween | (2021) An integrated multi-criteria decision-making framework for a medical device selection in the healthcare industry, Cogent Engineering, 8:1, 1968741, DOI: 10.1080/23311916.2021.1968741

To link to this article: https://doi.org/10.1080/23311916.2021.1968741

PRODUCTION & MANUFACTURING | RESEARCH ARTICLE

An integrated multi-criteria decision-making framework for a medical device selection in the healthcare industry

Mohammad A. Shbool[1]*, Omar S. Arabeyyat[2], Ammar Al-Bazi[3] and Wafa' H. AlAlaween[1]

Received: 23 April 2021
Accepted: 22 July 2021

*Corresponding author: Mohammad A. Shbool, Industrial Engineering Department, School of Engineering, The University of Jordan, 11942, Amman, Jordan
E-mail: m.shbool@ju.edu.jo

Reviewing editor:
Zude Zhou and Kun Chen, Wuhan University of Technology, Wuhan, CHINA

Additional information is available at the end of the article

Abstract: Medical devices used in healthcare organizations are costly, and the process of selecting these devices requires considering multiple criteria such as effectiveness and ease of use. Careful selection of these devices is daunting since it entails the evaluation of various measures. This research investigates the selection process of the same type of medical devices, especially when alternatives are available, and the organization needs to make a good selection. A Multi-Criteria Decision-Making (MCDM) framework based on the integration of the Analytical Hierarchy Process (AHP) and *ELimination* Et *Choice* Translating *Reality* (ELECTRE) method is developed. The framework model includes 10 criteria, which are selected based on real-life inputs from professional physicians. Seven Ultrasound machines (referred to as alternatives) are evaluated using the developed

ABOUT THE AUTHOR

Mohammad A. Shbool

Mohammad A. Shbool is an assistant professor of industrial engineering at *The University of Jordan* in Amman, Jordan. He received his Ph.D. in industrial engineering from the University of Arkansas - Fayetteville, USA, in 2016. He mainly teaches Simulation, Logistic Engineering & Supply Chain Management, and Engineering Statistics classes for IE students. Dr. Shbool is mainly interested in doing research in Simulation Modeling (discrete, Agent-based, & system dynamics), multi-criteria decision analysis, and Machine Learning applied to healthcare and manufacturing systems. He published a journal article in healthcare decision-making entitled "*Decision Making Framework for Evaluating Physicians Preference Items Using Multi-Objective Decision Analysis Principles*." Dr. Shbool is an EFQM (European Foundation for Quality Management) certified, and he is a member of both the IISE Institution and Alpha Pi Mu American honor society.

Many MCDM techniques have been successfully utilized in the era of decision-making as selection and ranking problems. The integration between two or more techniques has also been investigated and implemented in different fields. However, the current work provides a hybrid framework that integrates both AHP and ELECTRE techniques to select medical devices such as Ultrasound Machines efficiently. This paper details the decision-making process in conjunction with physicians' input and expertise to validate the model and generate the best final ranking of high-quality different specifications ultrasound machines in Jordan. The hybrid approach can provide physicians, hospitals, and healthcare supply chain professionals with a generic decision-making tool that can be used to select medical devices.

PUBLIC INTEREST STATEMENT

Many MCDM techniques have been successfully utilized in the era of decision-making as selection and ranking problems. The integration between two or more techniques has also been investigated and implemented in different fields. However, the current work provides a hybrid framework that integrates both AHP and ELECTRE techniques to select medical devices such as Ultrasound Machines efficiently. This paper details the decision-making process in conjunction with physicians' input and expertise to validate the model and generate the best final ranking of high-quality different specifications ultrasound machines in Jordan. The hybrid approach can provide physicians, hospitals, and healthcare supply chain professionals with a generic decision-making tool that can be used to select medical devices.

framework. A case study is conducted on the best selection practice of an Ultrasound machine in a gynecology clinic based in the Kingdom of Jordan. Results revealed that the best and worst alternatives of ultrasound machines are identified and compared with all other options.

Subjects: Decision Analysis; Engineering Economics; Healthcare Administration and Management; Health Informatics and Statistics

Keywords: MCDM; integrated framework; AHP; ELECTRE; medical devices; healthcare industry

1. Introduction

In the last and current centuries, the global economy, pushed by innovations and progress in technology, has shown remarkable growth in the medical devices industry, which resulted in high competency among companies and manufacturers. Diversity of brands of products, different quality levels, and prices have made it difficult for customers to purchase a product. Buyers have always been facing the dilemma of selecting the best alternative at a reasonable price. With multiple criteria to be considered when alternatives exist, making a choice becomes complicated. This sort of problem complexity comes from the conflicting objectives, implying the need for a systematic procedure that tackles decision problems, guaranteeing the least amount of after-decision regrets. Therefore, Multi-Criteria Decision-Making (MCDM) methods have emerged to support decisions and enhance the selected solution's reliability and credibility (Marsh et al., 2017).

In the healthcare industry, systems have always been an area of great interest in research and development. This interest attributes to the high expenditure of this industry and lack of performance measures compared to other leading industries such as retail and manufacturing. Authors in (Shbool, 2016) focused on healthcare expenditures and causes of physicians' preferences in medical item selection. Multi-objective decision-making on physicians' preference items based on value modeling principles is investigated by (Shbool & Rossetti, 2017), and an extension of the model is provided in (Shbool & Rossetti, 2020).

One of the problems that healthcare providers face is the selection of medical devices. The decision-maker, either an individual or a group, needs to decide which device is the best to purchase. The diversity of alternatives (models of the same functional equipment) available from manufacturers imposes a burden on the shoulders of decision-makers to decide the most suitable device. This problem becomes complex when many criteria should be considered when making such a decision, in which confliction of criteria is the central theme. This problem is significant for two main reasons; first, selecting items based on a structured method can cut costs. Second, the right decision may increase the acquisition rate of patients due to excellent device characteristics. Therefore, healthcare providers must spend more effort making accurate decisions, which should be based on a structured methodology, that otherwise would increase the risk of after-decision regrets.

Therefore, this research considers selecting a medical device out of many similar alternatives as a multi-criteria decision-making problem. This problem is to identify the best selection of Ultrasound device alternative out of many other competitive options of the same product. This paper aims to develop an MCDM framework that combines both the Analytical Hierarchy Process (AHP) and ELimination Et Choice Translating Reality (ELECTRE) method for the best selection practice of a medical device.

The main contributions of this study can be summarized as follows:

(1) To propose an MCDM framework based on integrating AHP and ELECTRE methods for best practice in selecting medical devices subject to conflict criteria.

(2) To formulate new relevant criteria necessary to the selection process of medical devices with professional physicians working in this field.

An illustration of selecting an Ultrasound device in a gynecology clinic will be presented to provide a complete structure of an MCDM framework.

2. Previous work

In this section, applications of MCDM techniques, including AHP, ELECTRE, and their hybrids in different healthcare areas, particularly in resource selection, are presented and categorized based on the environment type (deterministic and uncertain/vague).

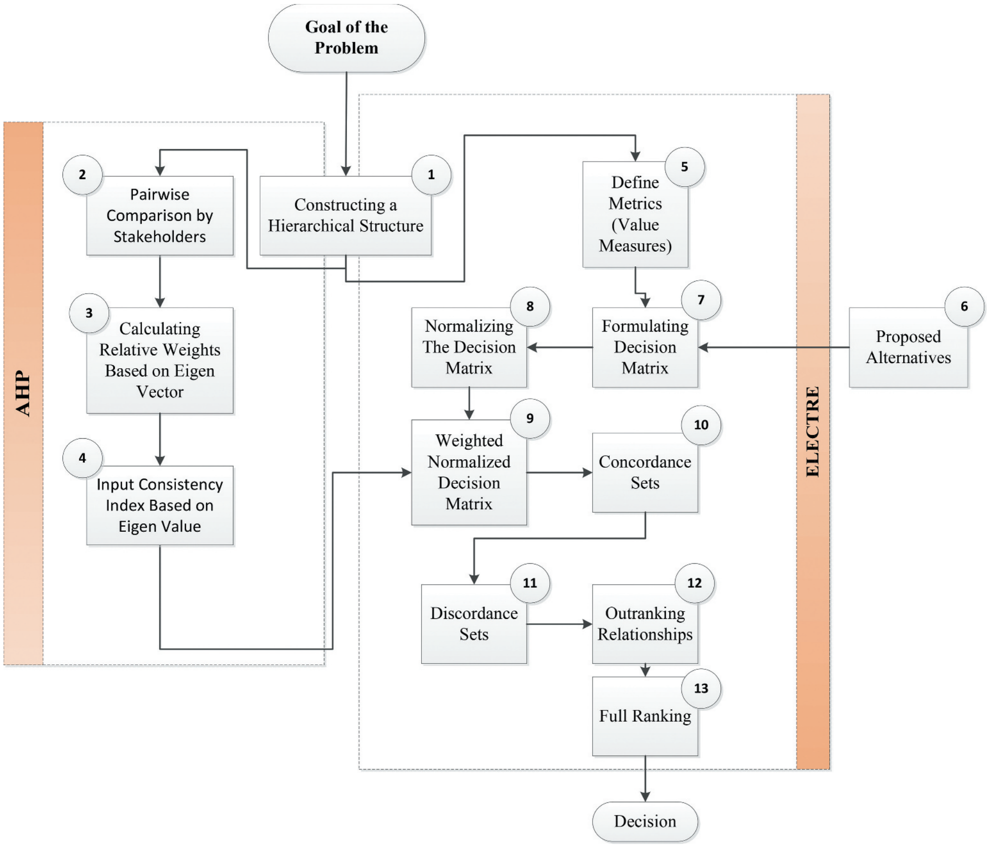
Multi-Criteria Decision Analysis (MCDA) methods were reviewed by (Glaize et al., 2019) to provide practical insights on how MCDA methods are applied in different healthcare areas in deterministic environments. Glaize et al. (2019) provided a structure for and practical insights on how MCDA methods are applied in different healthcare areas, including medical device selection. (Ivlev et al., 2015) presented a new MCDM model for medical device selection under conditions of uncertainty. Ivlev et al. (2016) identified the most suitable Magnetic Resonance Imaging (MRI) system for regional hospitals in the Czech Republic. They defined the most appropriate MCDA model for medical equipment selection by comparing various MCDA methods such as AHP and Technique for Order Preference by Similarity to Ideal Solution (TOPSIS), Preference Ranking Organization Method for Enrichment Evaluations (PROMETHEE II), and Simple Additive Weighting (SAW) method.

The AHP technique as one of the MCDA tools was used in a novel evaluation framework to select the optimal medical device by overcoming the limitations of previously confined assessments to the medical device cycle and the purpose of the specific assessment (Park et al., 2019). It has been shown that AHP can also be used in assessing selected medical devices and materials for grants by the Korean Ministry of Health and Welfare (Cho & Kim, 2003). Considering the time dependence of criteria, Improta et al. (2019) developed dynamic AHP by considering the evaluations associated with criteria as a function of time. They developed a system dynamic model for each criterion to capture the time behavior of the criteria. They implemented the proposed dynamic AHP framework in Health Technology Assessment. It is worth mentioning that the AHP was developed by (Saaty, 1980) based on the pairwise comparison of the relative importance of the on-hand criteria.

The ELECTRE as an outranking MCDA method that uses a weighted sum technique of multi-criteria based on agreement and disagreement indexes of the pairwise comparisons on each criterion has also been used. This method was initially introduced by (Roy, 1968), which was then analyzed and tailored by other researchers to other versions, including the ELECTRE method, ELECTRE I and subsequent extensions II, III, IV, and IS are outranking methods. These methods were developed to solve choice problems (Ishizaka & Nemery, 2013). A comprehensive review of the literature of ELECTRE methods and applications in various areas was made by (Govindan & Jepsen, 2016). Many studies applied the ELECTRE method in the research, which indicates this method's effectiveness. Examples of using ELECTRE in different areas are found in (Bari & Leung, 2007) and (Afshari et al., 2010). The ELECTRE methods have been successfully implemented in solving problems in various areas such as environmental management, energy, water management, transportation, military, and other topics (Figueira et al., 2005).

Under uncertain environments, MCDA tools were also used in medical device selection, including but not limited to (Buyukozkan & Gocer, 2019), who presented a novel approach for evaluating the smart medical device selection process in an uncertain decision environment. The intuitionistic fuzzy Choquet integral (IFCI) approach was applied to treat the uncertainty and vagueness. A fuzzy MCDM approach was proposed by (Tadic et al., 2014) to evaluate one kind of medical device supplier. A novel approach, including Neutrosophic with TOPSIS, was proposed by (Abdel-Basset et al., 2019) to estimate the smart medical devices (SMDs) selection process in a vague decision environment. Frazão et al. (2018) concluded that AHP and fuzzy logic dominate other methods in

Figure 1. Schematic view of the hybrid framework.



the literature. This conclusion was also confirmed by (IVLEV et al., 2014), who used the AHP approach to select sizeable medical equipment in resource-limited settings. Carnero and Gomez (2019) used both the MACBETH (Measuring Attractiveness by a Categorical Based Evaluation Technique) and FAHP (Fuzzy AHP) techniques for the optimal selection of medical gas supply devices. Both AHP and fuzzy VIKOR (VIekriterijumsko KOmpromisno Rangiranje) methods were utilized by (Emec et al., 2019) for the best selection of protein isolation devices used in a scientific research laboratory. The VIKOR-based fuzzy MCDM method was used by (Liu et al., 2013) to assess alternatives available for medical waste disposal. A hybrid fuzzy MCDM approach composed of the fuzzy AHP method and the fuzzy TOPSIS method was used for medical device manufacturer's selection (Lee et al., 2017). A multi-objective decision-making approach based on fuzzy AHP and fuzzy TOPSIS under a fuzzy multi-criteria decision-making environment was used to improve the supplier selection process in the healthcare sector (Goh et al., 2018).

Hybrid MCDM techniques in different environments were developed for medical device selection. An effective and efficient MCDM tool consisted of three different methods of AHP, Multi-Attribute Range Evaluations (MARE), and ELECTRE III was suggested to address equipment selection problems (Hodgett, 2016). Budak et al. (2016) proposed integrated TOPSIS (Technique for Order of Preference by Similarity to Ideal Solution) with an intuitionistic fuzzy set to select the appropriate Real-Time Location System technology for a hospital-based multi-criteria structure. A hybrid model consisting of the Analytic Hierarchy Process (AHP) and Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) method was developed by Barrios et al. (2016) to appropriate medical equipment. HMCDM (Hybrid MCDCM) methods were developed, mixing AHP, TOPSIS, ELECTRE, GRA (Grey Relational Analysis), and SAW methods for selecting the most suitable supplier in the healthcare sector (Akcan & Güldeş, 2019).

Table 1. AHP linear judgment scale

judgment value	Definition	Explanation
1	Equal importance	The two criteria contribute equally to the objective
3	Moderate importance	Experience and judgment slightly favor one criterion over another
5	Essential or Strong importance	Experience and judgment strongly favor one criterion over another
7	Very strong importance	A criterion is strongly favored, and its dominance is demonstrated in practice
9	Absolute importance	The importance of one criterion over another is affirmed and guaranteed on the highest possible order
2, 4, 6, 8	Intermediate value of the adjacent judgment	When compromise is needed (importance is neither one of two defined degrees)
Reciprocals of the above nonzero	The judgment value corresponds to the reverse relationship	If *v* is the judgment value when *i* is compared to *j*, then *1/v* is the judgment value when *j* is compared to *i*.

Moreover, AHP was also applied in modeling and solving many other real-life problems, including but not limited to assessing the energy credits to enhance the Egyptian Green Pyramid rating system. AHP provided a logical framework to determine the relative weight for the energy sector of each system (Abdel Aleem et al., 2015). A framework was proposed by (Elbasuony et al., 2018) to assess the overall PQ performance of different hybrid smart grid-connected DG systems, considering different interface-bus types and PQ criteria in various scenarios under normal operating conditions and a three-phase fault condition. A weighted sum strategy using the analytic hierarchy process (AHP) was used to convert the multi-objective problem into a normalized single-objective one to find the best solution of an Economic Technical Environmental Dispatch (ETED) problem (Rawa et al., 2021). (Abbas et al., 2018) developed a fuzzy knowledge-based model to select the best container storage location in a container yard with uncertain container departure times.

No previous work was found in the literature that used MCDM models, including both AHP and ELECTRE methods, to optimize the selection process of medical devices subject to conflicting criteria. Hence, this work aims to provide a structured hybrid framework for selecting the medical devices using both the AHP and ELECTRE methods together on a real-life medical device selection problem. AHP was used in this research to obtain criteria weights, while ELECTRE was used to select the best alternative based on their performance concerning the weighted criteria.

3. Research methodology

During recent decades, drastic medical devices and technological advancement raised the bar for aliveness, which is also considered a driver for increased healthcare expenditure (Willemé & Dumont, 2015). Healthcare problems have become more complex. Therefore, there is a solid need to elevate the decision-making process by incorporating Multi-Criteria Decision analytical approaches into the healthcare domain.

As cited before, this work's decision-making framework targets medical device selection in healthcare clinics. The problem is examined as a multi-criteria decision-making problem, where criteria were elicited from physicians who use such devices. The ELECTRE method will be explained step by step as summarized in (Yücel & Görener, 2016) and (Abdolazimi et al., 2015). Figure 1 is a schematic view of the developed methodology. The whole framework is explained in the following subsection in two parts, AHP and ELECTRE. Each step includes necessary formulas as well as corresponding calculations. The AHP method itself will be implemented to derive weights of the criteria, and consequently, it will be terminated at some point.

Table 2. Random index *(Saaty & Tran, 2007)*

Order of matrix *n*	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
RI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

Constructing a Hierarchical Structure is considered the core step. In this first step, the problem is decomposed into different levels to build the hierarchical structure. The core function of the hierarchy is the criteria.

3.1. The AHP steps

The first stage is to solicit weights of the criteria selected for evaluation; AHP was utilized in this study for this purpose. In the AHP part, the pairwise comparison will be conducted in the second step by stakeholders. Pairwise comparison is the heart of the AHP method to develop the judgment matrix. The criteria are compared two at a time by specifying a relative importance/preference on a scale of 1 to 9. Different judgment scales have been reviewed by (Ishizaka & Labib, 2011) besides the original linear scale proposed by (Saaty, 1980). The linear scale moderately keeps a balance between the two outputs of AHP, consistency of judicial decisions, and priority allocation. Pairwise comparison is either subjective based on stakeholders'/experts'/decision-makers' opinions and knowledge or objective based on quantitative measures. The judgment scale used in this research is shown in Table 1.

In general, for n criteria, the pairwise comparisons are shown in a square and reciprocal ($n \times n$) matrix as shown in Equation (1) (Gorener, 2012). A total of $\frac{n(n-1)}{2}$ comparisons are to be carried out, representing how each criterion (listed as row heading) is essentially relative to each of the remaining criteria (listed as column heading).

$$A_{n\times n} = \left[a_{11}a_{12}a_{21}a_{22}\cdots a_{1n}a_{2n}\vdots\vdots\ddots\vdots a_{n1}a_{n2}\cdots a_{nn} \right]$$

$$Wherea_{ij} = \begin{cases} Relative\ Prefernce\ of\ iover\ j \quad i<j \\ 1 \quad i=j \\ \frac{1}{Relative\ Preference\ when\ i<j} \quad i>j \end{cases} \tag{1}$$

From the pairwise comparison matrix, the normalized relative weights are estimated in step 3 by finding the sum of each column S_j (column j) and dividing each relative weight (a_{ij}) by the sum of that column; see Equation (2) (Saaty & Tran, 2007) below.

$$Norm_{n\times n} = \left[\frac{a_{11}}{S_1}\cdots\frac{a_{1n}}{S_n}\vdots\ddots\vdots\frac{a_{n1}}{S_1}\cdots\frac{a_{nn}}{S_n} \right] WhereS_j = \sum_{i=1}^{n} a_{ij} \quad j = 1\ldots n \tag{2}$$

Relative weight vector (w) can be set up from the normalized principal Eigenvector (a.k.a priority vector); that is, the first criterion's weight is simply the average of normalized weights. Relative weights for the ten criteria were calculated according to Equation (3) (Saaty & Tran, 2007).

$$Relativeweights = w = \left[w_1 = \sum_{j=1}^{n} a_{1j} \quad w_2 = \sum_{j=1}^{n} a_{2j} \vdots \quad w_n = \sum_{j=1}^{n} a_{nj} \right] \tag{3}$$

Estimating the Input Consistency Index is the fourth step. In this step, the whole process is based on judgments of priorities by pairwise comparisons. For example, if physicians preferred criterion 1 over 2 ($C_1 > C_2$) And criterion 2 over 3 ($C_2 > C_3$) and they have been asked to compare criterion 1 with 3, the expected answer should be ($C_1 > C_3$). This logic entails consistency, and it emerges from the transitive property. Measuring input judgments' consistency is based on the principal Eigenvalue (λ_{max}) that can be calculated using Equation (4) (Gorener, 2012).

$$\lambda_{max} = \prod_{1}^{n} (S_j w_i) \tag{4}$$

Next, the consistency index (CI) and consistency ratio (CR) are calculated as indicated in Equation (5) (Yücel & Görener, 2016; Gorener, 2012, 11). Table 2 shows RI values (Saaty & Tran, 2007). If CR ≤10%, the inconsistency in the subjective judgments is acceptable, and if CR>10%, the judgments should be revised.

$$CI = \frac{\lambda_{max} - n}{n - 1} and CR = \frac{CI}{RI} \tag{5}$$

3.2. The ELECTRE steps

The second stage in the framework evaluates and ranks alternatives based on criteria weights; ELECTRE was utilized. In the ELECTRE part, Metrics (value measures) will be defined in step 5. This scale establishes the range of the valuation measure that determines each criterion for scoring in the decision matrix. It is like a rubric that describes what each score value means on this value measure on a scale explicitly defined for this value measure. Determining alternatives that should undergo the evaluation process is done in step 6.

The decision matrix will be formulated in step 7. It presents the criteria (n) as columns and (m) rows for the alternatives, with cells representing the alternatives scoring on the criteria. The general matrix represents the standard decision matrix that determines the process baseline in Equation (6) (Akcan & Güldeş, 2019; Supraja & Kousalya, 2016; Yücel & Görener, 2016).

$$r_{ij} = \left[r_{11} r_{12} \cdots r_{1n} r_{21} r_{22} \cdots r_{2n} \vdots r_{m1} . r_{m2} . \cdots \vdots r_{mn} \right] \tag{6}$$

where $i = 1, \ldots m, j = 1 \ldots n$ and r_{ij} = score of alternative i on criterion j

Normalizing the decision matrix will be step 8. Equation (7) (Akcan & Güldeş, 2019; Supraja & Kousalya, 2016; Yücel & Görener, 2016) below is used to normalize the decision matrix. The resulted normalized decision matrix is shown in Table 7, section 4.

$$X_{ij} = \frac{r_{ij}}{\sqrt{\sum_{i=1}^{m} r_{ij}^2}} \quad i = 1 \ldots m, j = 1 \ldots n \tag{7}$$

$$WhereX_{ij}isthenormalizedvalueforeachscore$$

Weighted Normalized Decision Matrix, step 9, is produced according to Equation (8) (Akcan & Güldeş, 2019; Supraja & Kousalya, 2016; Yücel & Görener, 2016). As explained earlier, the weights of the criteria were determined using the AHP method. Criteria's weights will be utilized to calculate the concordance and discordance (steps 10 & 11) for all possible criteria pairs.

$$v = w_j \times x \quad j = 1 \ldots n \tag{8}$$

Where *v* is the column weighted normalized value for all alternatives on criterion *j*, and *x* is the normalized column in the decision matrix on criterion *j*.

Determining the Concordance Sets is step 10. This step compares each pair of the alternatives in each criterion using the weighted normalized matrix. This process is done as follows: for every possible pair of alternatives $A_p \text{ and } A_q (p, q = 1 \ldots \mathrm{m}, \text{ and } p \neq q)$, if alternative *p* is better than or equal to *q* on that specific criterion, it is listed under the concordance set as follows in Equation (9) (Akcan & Güldeş, 2019; Supraja & Kousalya, 2016; Yücel & Görener, 2016).

$$C(p, q) = \{ j, \quad v_{pj} \geq v_{qj} \} \quad j = 1 \ldots \mathrm{n} \tag{9}$$

where v_{pj} is the weighted normalized score of alternative *p* on criterion *j*

Thus, C(*p, q*) represents the set of attributes where A_p is better than or equal to A_q $(A_p \rightarrow A_q)$. After determining the concordance set, the concordance index C_{pq} is generated by adding weights for the criteria in the concordance set according to Equation (10) (Akcan & Güldeş, 2019; Supraja & Kousalya, 2016; Yücel & Görener, 2016).

$$C_{pq} = \sum_{j^*} w_{j^*} \quad p \neq q and j^* \in C_{pq} \tag{10}$$

The average concordance index is calculated as shown in Equation (11) (Akcan & Güldeş, 2019; Supraja & Kousalya, 2016; Yücel & Görener, 2016); it helps determine if each alternative's concordance index is greater than or equal to the average.

$$\bar{C} = \frac{\sum_{\in p \neq q} C_{pq}}{n(n-1)} \tag{11}$$

Determining the Discordance Sets will be in step 11. The discordance set, D(*p,q*), is the collection of remaining criteria not included in the concordance set, i.e., $D(p, q) = \{j, \quad j \neq j^*\}$. In other words, all criteria for which A_p is worse than A_q compose D (*p, q*):

$$D(p, q) = \{j | v_{pj} < v_{qj}\} \quad j = 1 \ldots n$$

The degree of disagreement in $(A_p \rightarrow A_q)$ is called the discordance index D_{pq} and can be defined using Equation (12) (Supraja & Kousalya, 2016; Yücel & Görener, 2016).

$$D_{pq} = \frac{\max\limits_{j \in D(p,q)} \quad |v_{pj} - v_{qj}|}{\max\limits_{j} \quad |v_{pj} - v_{qj}|} \tag{12}$$

The average discordance value is calculated according to Equation (13) (Supraja & Kousalya, 2016; Yücel & Görener, 2016).

$$\bar{D} = \frac{\sum_{\in p \neq q} D_{pq}}{n(n-1)} \tag{13}$$

Outranking Relationships will be determined in step 12. Every pair is compared, and the outranking relationships are built according to Equation (14) (Supraja & Kousalya, 2016; Yücel &

Table 3. Physicians information

Physicians Code	Sex	Age	Years of Experience	Clinic Location	Income level (In J.D. per visit)
HG	Male	57	27	Al-shumaysani	30
NH	Female	48	17	Abdun Al Shmali	30
IA	Female	46	15	Al-shumaysani	30
DA	Female	37	8	Fifth circle	20
QS	Male	46	14	AlAbdali	30
MS	Male	50	19	Tla Al-Ali	25
MQ	Male	67	38	Dakhliya Circle	40
WA	Male	45	18	Marj Al Hamam	20
AA	Male	41	13	Fifth circle	20
SA	Male	38	9	Umm Al Sumaq	20
LD	Female	44	14	Al-Shumaysani	25
MZ	Male	46	15	Fifth circle	25
TB	Male	64	33	Jabel Al Hussien	25
VN	Female	40	13	Marka	15
MZ	Male	65	34	Al Jandawil	20
EA	Male	54	22	Jabel Al Hussien	30
RM	Female	32	3	Fifth circle	20
RJ	Female	37	8	Al Jubeiha	20
AL	Female	34	5	Taburbour	20
BF	Male	35	6	Abdun	20

Görener, 2016). For example, A_1 beats A_3 based on the concordance index, while based on the discordance, it does not so that the A_1A_3 cell will be indicated with “False.”

$$A_p \text{ outranks } A_q,\ (A_p \rightarrow A_q), \text{if } C_{pq} \geq \bar{C}\ \&\ D_{pq} < \bar{D} \tag{14}$$

The full ranking list of all alternatives is determined in step 13 by calculating net concordance and discordance matrices, Equations (15) and (16) (Supraja & Kousalya, 2016; Yücel & Görener, 2016). Then, sort the alternatives in descending order in terms of the net concordance, and another list sorted in ascending order in terms of the net discordance.

$$C_p = \sum_{\substack{k=1 \\ k\neq p}}^{m} C_{pk} - \sum_{\substack{k=1 \\ k\neq p}}^{m} C_{kp} \tag{15}$$

$$D_p = \sum_{\substack{k=1 \\ k\neq p}}^{m} C_{pk} - \sum_{\substack{k=1 \\ k\neq p}}^{m} D_{kp} \tag{16}$$

Table 4. Criteria list and value measures

Criteria List (10 Criteria)		Definition of Value Measure Scale (1–5) for Each Criterion (Step 5)				
Code	**Criterion**	**1**	**2**	**3**	**4**	**5**
C_1	Imaging	2D, Black & White	2D, Colored	3D, Black & White	3D, Colored	4D Emulated, Colored
C_2	Size	Portable	N/A	Large	Medium	Small
C_3	Ease of Use	Hard to use OS	Easy to use OS/ Touchpad Nav.	Easy to use OS/ Trackball Nav.	Windows/ Touchpad Nav.	Windows/Trackball Nav.
C_4	Durability	Poor Brand Name or No Surge Protection or Bad Build Quality	Surge Protection/ Good Build/ Reputable Brand Name	Surge Protection/ Heavy Duty/ Reputable Brand Name	Surge Protection/ Good Build/Top Brand Name	Surge Protection/ Heavy Duty/Top Brand Name
C_5	Connectivity	None	Printer	USB	PC	Network
C_6	Storage	0–4 GB	5–9 GB	10–19 GB	20–49 GB	50–80 GB
C_7	Price (in Thousands)	41–50	31–40	21–30	11–20	0–10
C_8	# of Probes	1 Probe	N/A	2 Probes	N/A	3+ Probes
C_9	Warranty (Years)	1 Year	N/A	2 Years	N/A	3+ Years
C_{10}	Years of Service	1–3 Years	4–5 Years	N/A	6–10 Years	11–20 Years

Table 5. Criteria weights

Criteria	Principal Normalized Eigen Vector (Priority Vector)	Criteria	Principal Normalized Eigen Vector (Priority Vector)
C1	0.12670	C6	0.02052
C2	0.02181	C7	0.28098
C3	0.03187	C8	0.10419
C4	0.23233	C9	0.04836
C5	0.02904	C10	0.10420

4. Case study

The on-hand problem is selecting a medical device in general and in the specific Ultrasound device. The goal will be to choose the device that outranks all other devices on the listed criteria. This goal leads to the next (first) step; defining criteria based on which the devices will be evaluated and compared.

The researchers suggested the criteria based on some readings and, more importantly, from 20 physicians after visiting their gynecology clinics based in Jordan. The physicians agreed on some of the proposed criteria and added them to the list, which reached ten criteria. They were able to provide information about seven Ultrasound Machines for this case study. Table 3 summarizes the physicians' list who participated in this study based on their name's initials (Coded for data privacy purposes).

Seven ultrasound machines are mainly used in this paper. These machines used in Jordan are coded for legal declaration issues. The codes of these machines are GV, MM, AP, SS, GL, ST, and MD. From now on, alternatives will be referred to as A_i and criteria as C_j for simplicity. For example, A_1 is the first ultrasound machine brand (GV), and C_1 is the "Imaging" criterion.

Table 6. Decision matrix

Seven Alternatives (Ultrasound Machines)	**Criterion C_j**									
Alternative	**Imaging C_1**	**Size C_2**	**Ease of Use C_3**	**Durability C_4**	**Connectivity C_5**	**Storage C_6**	**Price C_7**	**# of Probes C_8**	**Warranty C_9**	**Service Years C_{10}**
A_1	4	4	4	3	3	1	2	1	1	2
A_2	2	4	5	4	1	2	3	3	5	2
A_3	3	5	3	2	3	2	3	3	1	2
A_4	4	3	4	5	3	3	4	5	3	5
A_5	1	1	2	1	3	2	3	1	1	4
A_6	5	3	5	4	5	5	1	5	1	2
A_7	2	3	3	2	4	4	4	3	3	4

A list of 10 criteria, shown in Table 4 (C_1—C_{10}), were defined using the opinion and assessment of the professional physicians who took part in this study. Detailed explanations on how to build a value hierarchy and the process of building value measures (step 5) can be found in (Parnell et al., 2013). In this work, criteria listing was done in two phases; in the first phase, physicians were asked about relevant criteria when selecting the device. The second phase was to get consensus on any irrelevant criterion or merge any two criteria due to dependency. By applying **Step 1**, the hierarchical structure was constructed.

The judgment matrix was obtained by applying **Step 2**. The criteria are compared two at a time by specifying a relative importance/preference on a scale of 1 to 9. In our problem, an aggregate of 10 criteria was considered resulting in 45 comparisons. Relative weights were calculated by applying **Step 3**; Table 5 shows the final results. Input consistency index was measured as in **Step 4**. In our medical devices' selection problem, $\lambda_{max} = 10.3$, Thus $CI = \frac{10.38-10}{10-1} = 0.0381 \rightarrow CR = \frac{0.0381}{1.49} = 2.55\%$ Which is < 10%, Thus physicians' subjective judgments of the 10 criteria preferences are consistent.

After applying Step 5, a detailed listing of criteria and their value measures with corresponding scales rubrics were obtained, as shown in Table 4. For example, criterion C1 (Imaging) has a scale of 5 value measures on which each option will be categorized. Suppose a Gynecology has a device X with 2D colored imaging capability; it should be assigned a value of 2 regarding this criterion. The physicians determined these scales.

The framework of this research was illustrated with an example of medical devices, precisely Ultrasound machines. By applying **Step 6**, Seven Ultrasound functional equivalent devices were proposed as alternatives for evaluation.

The Decisions matrix, the result of **step 7**, was obtained by scoring the seven Ultrasound devices on the ten criteria. Scores were gathered from the participated physicians and organized in a decision matrix, as shown in Table 6. **Step 8** was applied to obtain the Normalized decision matrix; results are shown in Table 7.

The weighted normalized decision matrix was obtained by applying **Step 9**; each alternative's normalized score on each criterion was multiplied by that criterion weight. Resulted matrix is shown in Table 8.

Table 7. Normalized decision matrix

Alternatives	**Criterion C_j (Weight)**									
	C_1 (0.15)	**C_2 (0.02)**	**C_3 (0.05)**	**C_4 (0.20)**	**C_5 (0.03)**	**C_6 (0.01)**	**C_7 (0.20)**	**C_8 (0.13)**	**C_9 (0.08)**	**C_{10} (0.13)**
A_1	0.4619	0.4339	0.3922	0.3464	0.3397	0.1260	0.2500	0.1125	0.1459	0.2341
A_2	0.2309	0.4339	0.4903	0.4619	0.1132	0.2520	0.3750	0.3375	0.7293	0.2341
A_3	0.3464	0.5423	0.2942	0.2309	0.3397	0.2520	0.3750	0.3375	0.1459	0.2341
A_4	0.4619	0.3254	0.3922	0.5774	0.3397	0.3780	0.5000	0.5625	0.4376	0.5852
A_5	0.1155	0.1085	0.1961	0.1155	0.3397	0.2520	0.3750	0.1125	0.1459	0.4682
A_6	0.5774	0.3254	0.4903	0.4619	0.5661	0.6299	0.1250	0.5625	0.1459	0.2341
A_7	0.2309	0.3254	0.2942	0.2309	0.4529	0.5040	0.5000	0.3375	0.4376	0.4682

Concordance sets C(*p, q*), as shown in Table 9, were obtained by applying **Step 10**. Every possible pair is listed with corresponding criteria for which the predecessor alternative dominates the successor. The sum of weights in the concordance sets is referred to as the concordance index. Concordance indices are shown in Table 10.

Highlighted cells in Table 10 represent the alternatives concordance index that is greater than the average concordance index. From Table 10, $\bar{C} = 0.5966$ and highlighted cells indicate that $\mathbf{C_{pq}} \geq \bar{\mathbf{C}}$.

In **Step 11**, the discordance set, D(*p*,*q*), was determined by determining all criteria for which A_p is worse than A_p. The discordance indexes D_{pq}, which represent the degree of disagreement in $(A_p \rightarrow A_q)$ are shown in Table 11. The average discordance value is used to determine outranking sets, i.e., the alternatives for which the discordance index is less than average.

Outranking relationships are determined by applying **Step 12**. Table 12 shows the result outranking relations, where "True" means that the alternative in the leftmost column outranks the corresponding alternative in the top row. Alternative *p* outranks alternative *p* if and only if their concordance index is greater than average and discordance index is greater than average. For example, A_4 dominates A_1 based on both concordance as well as discordance, so the A_4A_1 cell is indicated as "TRUE."

The outranking relationships matrix shown in Table 12 is used to build the outranking diagram depicted in Figure 2. Each "True" is represented by an arrow starting from the alternative in the leftmost column, pointing to the top row's alternative. For example, an arrow should be drawn from A_1 to A_5, meaning that A_1 outperforms A_5. In cases where no one outranks the other in both concordance and discordance, i.e., False for $A_p \rightarrow A_q$ and False for $A_q \rightarrow A_p$ as well, then no arrow will be drawn between this pair. For example, neither A_1 outperforms A_3 nor A_3 outperforms A_1.

The dominant alternative that outranks all other alternatives is the best selection, which is, in our case, the Ultrasound device alternative A4. The least preferable alternative is alternative A5. These two devices' brands are the most common ultrasound machines used by physicians in gynecologist clinics in Jordan. A full ranking of all alternatives was done, as seen in the next step.

The final step, **Step 13**, was applied to determine the full outranking list. For example, net concordance for A_1 = 2.73–4.34 = −1.61, and net discordance = 1.897. Full ranking based on net concordance as well as net discordance is shown in Table 13. It can be seen that both rankings agreed on the 1st, 3rd, 5th, 6th, and seventh places.

Table 8. Weighted normalized decision matrix

Alternative (Ultrasound Machine)	**Criterion C_j**									
	C_1 (0.15)	**C_2 (0.02)**	**C_3 (0.05)**	**C_4 (0.20)**	**C_5 (0.03)**	**C_6 (0.01)**	**C_7 (0.20)**	**C_8 (0.13)**	**C_9 (0.08)**	**C_{10} (0.13)**
A_1	0.0693	0.0087	0.0196	0.0693	0.0102	0.0013	0.0500	0.0146	0.0117	0.0304
A_2	0.0346	0.0087	0.0245	0.0924	0.0034	0.0025	0.0750	0.0439	0.0583	0.0304
A_3	0.0520	0.0108	0.0147	0.0462	0.0102	0.0025	0.0750	0.0439	0.0117	0.0304
A_4	0.0693	0.0065	0.0196	0.1155	0.0102	0.0038	0.1000	0.0731	0.0350	0.0761
A_5	0.0173	0.0022	0.0098	0.0231	0.0102	0.0025	0.0750	0.0146	0.0117	0.0609
A_6	0.0866	0.0065	0.0245	0.0924	0.0170	0.0063	0.0250	0.0731	0.0117	0.0304
A_7	0.0346	0.0065	0.0147	0.0462	0.0136	0.0050	0.1000	0.0439	0.0350	0.0609

Table 9. Concordance sets

$(A_p \rightarrow A_q)$	C (*p*, *q*)	$(A_p \rightarrow A_q)$	C (*p*, *q*)	$(A_p \rightarrow A_q)$	C (*p*, *q*)
1→2	1,2,5,10	3→4	2,5	5→6	7,9,10
1→3	1,3,4,5,9,10	3→5	1,2,3,4,5,6,7,8,9	5→7	10
1→4	1,2,3,5	3→6	2,7,9,10	6→1	1,3,4,5,6,8,9,10
1→5	1,2,3,4,5,8,9	3→7	1,2,3,4,8	6→2	1,3,4,5,6,8,10
1→6	2,7,9,10	4→1	1,3,4,5,6,7,8,9,10	6→3	1,3,4,5,6,8,9,10
1→7	1,2,3,4	4→2	1,4,5,6,7,8,10	6→4	1,2,3,5,6,8
2→1	2,3,4,6,7,8,9,10	4→3	1,3,4,5,6,7,8,9,10	6→5	1,2,3,4,5,6,8,9
2→3	3,4,6,7,8,9,10	4→5	1,2,3,4,5,6,7,8,9,10	6→7	1,2,3,4,5,6,8
2→4	2,3,9	4→6	2,4,7,8,9,10	7→1	5,6,7,8,9,10
2→5	1,2,3,4,6,7,8,9	4→7	1,2,3,4,7,8,9,10	7→2	1,5,6,7,8,10
2→6	2,3,4,7,9	5→1	5,6,7,8,9,10	7→3	3,4,5,6,7,8,9,10
2→7	1,2,3,4,8,9	5→2	5,6,7,10	7→4	2,5,6,7,9
3→1	2,5,6,7,8,9,10	5→3	5,6,7,9,10	7→5	1,2,3,4,5,6,7,8,9,10
3→2	1,2,5,6,7,8,10	5→4	5	7→6	2,7,9,10

Table 10. Concordance matrix (indices C_{pq})

Highlighted cells point out the outranking set based on concordance ($C_{pq} \geq \bar{C}$)

	A1	A2	A3	A4	A5	A6	A7	Number of Values in matrix = (7*7)—7 = 49–7 = 42 (Zeroes are not counted)	Adding weights **IF** the value in the weighted matrix is greater than of the other alternative, for example, A1/A2 in Concordance Matrix is (0.33) that is (0.15 + 0.02 + 0.03 + 0.13)
A1	0.00	0.33	0.64	0.25	0.66	0.43	0.42		
A2	0.82	0.00	0.80	0.15	0.84	0.68	0.63		
A3	0.60	0.67	0.00	0.05	0.87	0.43	0.55		
A4	0.98	0.85	0.98	0.00	1.00	0.76	0.96		
A5	0.58	0.37	0.45	0.03	0.00	0.41	0.13		
A6	0.78	0.70	0.78	0.39	0.67	0.00	0.59		
A7	0.58	0.65	0.83	0.34	1.00	0.43	0.00	Total Sum	
Sum	4.34	3.57	4.48	1.21	5.04	3.14	3.28	25.06	
$\bar{C} = 0.5966$		**(=Total Sum of all indexes/# of Values in Matrix)**							

Table 11. Discordance matrix (indexes D_{pq})

Highlighted cells pointed out the outranking set based on discordance ($D_{pq} < \bar{D}$)

	A1	A2	A3	A4	A5	A6	A7		
A1	0.0000	1.0000	1.0000	1.0000	0.5856	1.0000	1.0000	Number of Values in matrix = (7*7)—7 = 49−7 = 42 **Zeroes are not counted**	Values = Abs (minimum value among negatives)/ Maximum (of abs values)
A2	0.7421	0.0000	0.3711	1.0000	0.4392	1.0000	0.6588		
A3	0.7895	1.0000	0.0000	1.0000	0.8785	0.9238	1.0000		
A4	0.0371	0.5113	0.0626	0.0000	0.0000	0.2309	0.0490		
A5	1.0000	1.0000	1.0000	1.0000	0.0000	1.0000	1.0000		
A6	0.4273	0.9623	1.0000	1.0000	0.7217	0.0000	1.0000		
A7	0.6928	1.0000	0.5692	1.0000	0.0000	0.6928	0.0000	Total Sum	
Sum	3.6888	5.4735	4.0029	6.0000	2.6250	4.8475	4.7079	31.3456	
$\bar{D} = 0.7463$			**(=Total Sum of all indexes/# of Values in Matrix)**						

Table 12. Outranking relationships

Alternatives Relationships	**A1**	**A2**	**A3**	**A4**	**A5**	**A6**	**A7**
A1		FALSE	FALSE	FALSE	TRUE	FALSE	FALSE
A2	TRUE		TRUE	FALSE	TRUE	FALSE	TRUE
A3	FALSE	FALSE		FALSE	FALSE	FALSE	FALSE
A4	TRUE	TRUE	TRUE		TRUE	TRUE	TRUE
A5	FALSE	FALSE	FALSE	FALSE		FALSE	FALSE
A6	TRUE	FALSE	FALSE	FALSE	TRUE		FALSE
A7	FALSE	FALSE	TRUE	FALSE	TRUE	FALSE	

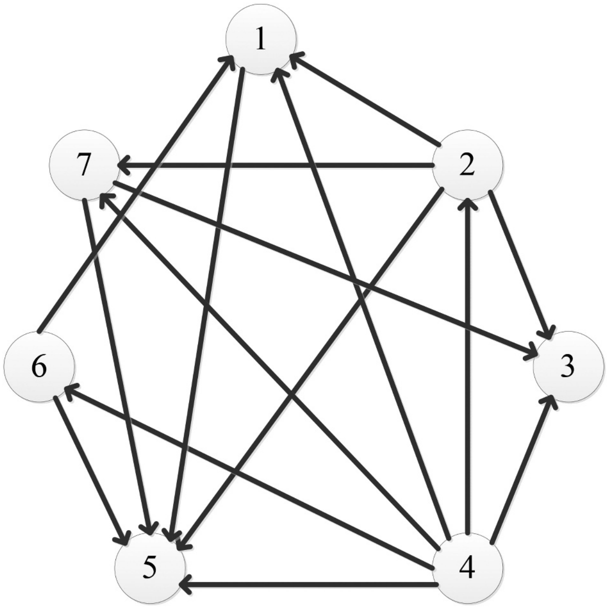


Figure 2. Outranking diagram.

Table 13. Net-concordance and net-discordance

Rank	Alternative	Net Concordance (Sorted in descending order)	Alternative	Net Discordance (Sorted in ascending order)
1	A4	4.32	A4	−5.11
2	A6	0.77	A2	−1.262
3	A7	0.55	A7	−0.753
4	A2	0.35	A6	0.264
5	A3	−1.31	A3	1.589
6	A1	−1.61	A1	1.897
7	A5	−3.07	A5	3.375

5. Discussion

Healthcare providers always face the hurdle of selecting a medical device that fulfills their expectations on several conflicting constraints. Still, making decisions based on just subjective evaluations may lead to a non-optimal choice. The net result summarized in Table 13 shows that alternative 4 is the dominating one since it outranks every other alternative in terms of concordance and discordance. The ranking is based on concordance and discordance, as can be seen, that 1st, 3rd, 5th, 6th, and seventh ranks agreed upon by concordance and discordance. This result gives the decision-maker confidence when selecting the best alternative and leaving the worst selection.

The resulting ranking shows that physicians, based on their criteria selection, used A7 instead of A4. Implementing structured multi-criteria techniques helped in the manipulation of the criteria confliction. The result was discussed with physicians; they showed interest and appreciation for the framework and agreed upon it. We consider this as a validation of the model.

6. Comparison study

In order to establish the effectiveness of this hybrid framework compared with AHP, a comparison study is essential to justify the superiority of the hybrid framework compared with AHP. This study also helps in validating the performance of the provided solution of the hybrid framework. Table 14 presents the comparison study results highlighting the effectiveness of each used method individually and combined.

Table 14. Comparison between AHP, ELECTRE, and the hybrid framework

	AHP	AHP-ELECTRE (The Hybrid Framework)	
Rank		Net Concordance (Sorted in descending order)	Net Discordance (Sorted in ascending order)
1	A4	A4	A4
2	A6	A6	A2
3	A2	A7	A7
4	A7	A2	A6
5	A3	A3	A3
6	A1	A1	A1
7	A5	A5	A5

The results show that the best alternative is A4 based on AHP and the hybrid framework method. The two methods also agreed on the last three alternatives. This outcome validates the hybrid framework outputs in terms of the ranking of the alternatives. However, the hybrid framework provided a more detailed ranking on the 2nd, 3rd, and 4th positions, and hence, the alternatives ranking was different both methods. This shows the strength of the hybrid framework in guiding more informed decisions represented by the achieved alternatives ranking. The provided alternatives were discussed with the related physicians who participated in this study. They adviced the alternatives provided by the Hybrid approach are more applicable in the selection process of medical devices.

7. Conclusion and future work

In this research, a decision framework for medical device selection was illustrated through a specific example on Ultrasound machines. Professional physicians participated in this study to build the model and provide input. Two MCDM techniques were employed in one framework to provide a final ranking of the seven alternatives based on ten criteria accurately determined for Ultrasound machines. The full ranking of the candidate alternatives enables buyers (Physicians or healthcare organizations) to induce a better objective decision. The physicians who took part in this study were asked which device they already have and why; three of them said they have the alternative 7 (A7) in the original list (Unranked). This device had the third rank agreed upon by the concordance as well as discordance sets. Physicians' justification for this choice is that they decided based on their subject evaluations as another kind of decision.

This research was vital for two core reasons; first, it put already presented MCDM techniques in the healthcare context and implements them to the medical devices' selection theme. Second, this research could be used as a reference tutorial on applying a detailed explanation to other similar problems.

However, the limitation of this method is that it needs a large amount of data to identify the best consistent weights and subsequently reduce the error in estimation and hence the after decision-making regrets. In addition, the applicability and usability of this method need to involve a proper sample size and type of physicians that should be identified using statistical sampling techniques to obtain consistent opinions about the achieved alternatives and their best weights values. The proposed framework is applicable only for deterministic environments, making this the main drawback if a vague environment is encountered in terms of medical device selection.

Future work requires involving a representative sample of physicians to reflect fair opinions regarding the criteria used in medical device selection. Other ELECTRE methods (II, III) could be applied for other alternative selection comparison purposes from the technique perspective. The researchers suggest expanding current research on medical device selection by adopting fuzziness in the proposed framework to capture the uncertainty that might be inherited in some of the medical selection problem features. As well, different weights estimation methods could be employed.

Funding
The authors received no direct funding for this research.

Author details
Mohammad A. Shbool[1]
E-mail: m.shbool@ju.edu.jo
ORCID ID: http://orcid.org/0000-0002-9413-7985
Omar S. Arabeyyat[2]
Ammar Al-Bazi[3]
Wafa' H. AlAlaween[1]
[1] Industrial Engineering Department, School of Engineering, the University of Jordan, Amman 11942, Jordan.
[2] Computer Engineering Department, Al-Balqa Applied University, Salt 19117, Jordan.
[3] School of Mechanical, Aerospace and Automotive Engineering, Coventry University, Coventry CV1 5FB, UK.

Citation information
Cite this article as: An integrated multi-criteria decision-making framework for a medical device selection in the healthcare industry, Mohammad A. Shbool, Omar S. Arabeyyat, Ammar Al-Bazi & Wafa' H. AlAlaween, *Cogent Engineering* (2021), 8: 1968741.

References

Abbas, A., Al-Bazi, A., & Palade, V. (2018). A constrained fuzzy knowledge-based system for the management of container yard operations. *International Journal of Fuzzy Systems*, *20*(4), 1205–1223. https://doi.org/10.1007/s40815-018-0448-9

Abdel Aleem, S. H., Zobaa, A. F., & Abdel Mageed, H. M. (2015). Assessment of energy credits for the enhancement of the Egyptian green pyramid rating system. *Energy Policy*, *87* (1), 407–416. https://doi.org/10.1016/j.enpol.2015.09.033

Abdel-Basset, M., Manogaran, G., Gamal, A., & Smarandache, F. (2019). A group decision making framework based on neutrosophic TOPSIS approach for smart medical device selection. *Journal of Medical Systems*, *43*(2), 38. https://doi.org/10.1007/s10916-019-1156-1

Abdolazimi, A., Momeni, M., & Montazeri, M. (2015). Comparing ELECTRE and linear assignment methods in zoning shahroud-bastam watershed for artificial recharge of groundwater with GIS technique. *Modern Applied Science*, *9*(1), 68–82. https://doi.org/10.5539/mas.v9n1p68

Afshari, A. R., Mojahed, M., Yusuff, R. M., Hong, T. S., & Ismail, M. Y. (2010). Personnel selection using ELECTRE. *Journal of Applied Sciences*, *10*(23), 3068–3075. https://doi.org/10.3923/jas.2010.3068.3075

Akcan, S., & Güldeş, M. (2019). Integrated multicriteria decision-making methods to solve supplier selection problem: A case study in a hospital. *Journal of Healthcare Engineering*, *2019*, 1–10. https://doi.org/10.1155/2019/5614892

Bari, F., & Leung, V. (2007). Application of ELECTRE to network selection in a hetereogeneous wireless network environment. In *IEEE wireless communications and networking conference*, 3813–3818. https://doi.org/10.1109/WCNC.2007.697

Barrios, M. A., Felice, F. D., Negrete, K. P., Romero, B. A., Arenas, A. Y., & Petrillo, A. (2016). An AHP-topsis integrated model for selecting the most appropriate tomography equipment. *International Journal of Information Technology & Decision Making*, *15*(4), 861–885. https://doi.org/10.1142/S021962201640006X

Budak, A., Ustundag, A., Oztaysi, B., & Cevikcan, E. (2016). A multi-criteria intuitionistic fuzzy group decision making model for real time location system integration: An application from healthcare system. *Uncertainty Modelling in Knowledge Engineering and Decision Making: Proceedings of the 12th International FLINS Conference*, 580–587, Roubaix, France. World Scientific.

Buyukozkan, G., & Gocer, F. (2019). Smart medical device selection based on intuitionistic fuzzy Choquet integral. *Soft Computing*, *23*(20), 10085–10103. https://doi.org/10.1007/s00500-018-3563-5

Carnero, M. C., & Gomez, A. (2019). Optimization of decision making in the supply of medicinal gases used in health care. *Sustainability*, *11*(10), 2952. https://doi.org/10.3390/su11102952

Cho, K., & Kim, S. (2003). Selecting medical devices and materials for development in Korea: The analytic hierarchy process approach. *The International Journal of Health Planning and Management*, *18*(2), 161–174. https://doi.org/10.1002/hpm.703

Elbasuony, G. S., Abdel Aleem, S. H., Ibrahim, A. M., & Sharaf, A. M. (2018). A unified index for power quality evaluation in distributed generation systems. *Energy*, *149*(1), 607–622. https://doi.org/10.1016/j.energy.2018.02.088

Emec, S., Turanoglu, B., Oztas, S., & Akkaya, G. (2019). An integarted MCDM for a medical company selection in health sector. *International Journal of Scientific and Technological Research*, *5*(4), 77–89. https://doi.org/10.7176/JSTR/5-4-09

Figueira, J., Mousseau, V., & Roy, B. (2005). ELECTRE methods. In S. Greco (Ed.), *Multiple criteria decision analysis: State of the art surveys* (Vol. 78, pp. 133–162). Springer-Verlag.

Frazão, T. D. C., Camilo, D. G. G., Cabral, E. L. S., & Souza, R. P. (2018). Multicriteria decision analysis (MCDA) in health care: A systematic review of the main characteristics and methodological steps. *BMC Medical Informatics and Decision Making*, *18*(1), 90. https://doi.org/10.1186/s12911-018-0663-1

Glaize, A., Duenas, A., Martinelly, C. D., & Fagnot, I. (2019). Healthcare decision-making applications using multicriteria decision analysis: A scoping review. *Journal of Multi-Criteria Decision Analysis*, *26*(1–2), 62–83. https://doi.org/10.1002/mcda.1659

Goh, M., Zhong, S., & De Souza, R. (2018). Operational framework for healthcare supplier selection under a fuzzy multi-criteria environment. *Proceedings of the 23rd International Symposium on Logistics (ISL 2018)*, Bali, Indonesia. https://doi.org/10.17863/CAM.54027

Gorener, A. (2012). Comparing AHP and ANP: An application of strategic decisions making in a manufacturing company. *International Journal of Business and Social Science*, *3*(11), 194–208. https://ijbssnet.com/journals/Vol_3_No_11_June_2012/22.pdf

Govindan, K., & Jepsen, M. B. (2016). ELECTRE: A comprehensive literature review on methodologies and applications. *European Journal of Operational Research*, *250*(1), 1–29. https://doi.org/10.1016/j.ejor.2015.07.019

Hodgett, R. E. (2016). Comparison of multi-criteria decision-making methods for equipment selection. *The International Journal of Advanced Manufacturing Technology*, *85*(5), 1145–1157. https://doi.org/10.1007/s00170-015-7993-2

Improta, G., Converso, G., Murino, T., Gallo, M., Perrone, A., & Romano, M. (2019). Analytic hierarchy process (AHP) in dynamic configuration as a tool for health technology assessment (HTA): The case of biosensing optoelectronics in oncology. *International Journal of Information Technology & Decision Making*, *18*(5), 1533–1550. https://doi.org/10.1142/S0219622019500263

Ishizaka, A., & Labib, A. (2011). Review of the main development in the analytic hierarchy process. *Expert Systems with Applications*, *38*(11), 14336–14345. https://doi.org/10.1016/j.eswa.2011.04.143

Ishizaka, A., & Nemery, P. (2013). *Multi-criteria decision analysis: Methods and software*. John Wiley & Sons, Ltd.

Ivlev, I., Jablonsky, J., & Kneppo, P. (2016). Multiple-criteria comparative analysis of magnetic resonance imaging systems. *International Journal of Medical Engineering and Informatics*, *8*(2), 124–141. https://doi.org/10.1504/IJMEI.2016.075757

IVLEV, I., KNEPPO, P., & BARTAK, M. (2014). Multicriteria decision analysis: A multifaceted approach to medical equipment management. *Technological and Economic Development of Economy*, *20*(3), 576–589. https://doi.org/10.3846/20294913.2014.943333

Ivlev, I., Vacek, J., & Kneppo, P. (2015). Multi-criteria decision analysis for supporting the selection of medical devices under uncertainty. *European Journal of Operational Research*, *247*(1), 216–228. https://doi.org/10.1016/j.ejor.2015.05.075

Lee, Y.-C., Chung, P.-H., & Shyu, J. Z. (2017). Performance evaluation of medical device manufacturers using a hybrid fuzzy MCDM. *Journal of Scientific and Industrial Research*, *76*(1), 28–31. http://nopr.niscair.res.in/bitstream/123456789/39298/1/JSIR%2076%281%29%2028-31.pdf

Liu, H.-C., Wu, J., & Li, P. (2013). Assessment of health-care waste disposal methods using a VIKOR-based fuzzy multi-criteria decision making method. *Waste Management*, *33*(12), 2744–2751. https://doi.org/10.1016/j.wasman.2013.08.006

Marsh, K., Goetghebeur, M., Thokala, P., & Baltussen, R. (Eds.). (2017). *Multi-criteria decision analysis to support healthcare decisions*. Springer International Publishing.

Park, J., Kim, E., & Shin, K. (2019). Developing an evaluation framework for selecting optimal medical devices. *Journal of Open Innovation: Technology, Market, and Complexity*, *5* (3), 64. https://doi.org/10.3390/joitmc5030064

Parnell, G., Bresnick, T., Tani, S., & Johnson, E. (2013). *Handbook of decision analysis*. John Wiley & Sons.

Rawa, M., Abusorrah, A., Bassi, H., Mekhilef, S., Ali, Z. M., Abdel Aleem, S. H., Hasanien, H. M., & Omar, A. I. (2021). Economical-technical-environmental operation of power networks with wind-solar-hydropower generation using analytic hierarchy process and improved grey wolf algorithm. *Ain Shams Engineering Journal*. https://doi.org/10.1016/j.asej.2021.02.004

Roy, B. (1968). Classement et choix en pr´esence de points de vue multiples (la m´ethode ELECTRE). *Revue d'Informatique et de Recherche Op´erationnelle*, *2*(8), 57–75. http://www.numdam.org/article/RO_1968__2_1_57_0.pdf

Saaty, T. L. (1980). *The analytic hierarchy process: Planning, priority setting, resource allocation*. McGraw-Hill.

Saaty, T. L., & Tran, L. T. (2007). On the invalidity of fuzzifying numerical judgments in the Analytic Hierarchy Process. *Mathematical and Computer Modelling*, *46*(7–8), 962–975. https://doi.org/10.1016/j.mcm.2007.03.022

Shbool, M. A. (2016). *Essays in physicians preference items and inventory management within the healthcare supply chain* [Theses and Dissertations]. ScholarWorks@UARK. https://scholarworks.uark.edu/etd/1566

Shbool, M. A., & Rossetti, M. D. (2017). Physician preference items–a decision making framework. *In IIE Annual Conference. Proceedings*, Pittsburgh, PA.

Shbool, M. A., & Rossetti, M. D. (2020, August). Decision-making framework for evaluating physicians' preference items using multi-objective decision analysis principles. *Sustainability*, *12*(16), 6415. https://doi.org/10.3390/su12166415

Supraja, S., & Kousalya, P. (2016). ELECTRE method for the selection of best computer system. *Indian Journal of Science and Technology*, *9*(39), 1–5. https://doi.org/10.17485/ijst/2016/v9i39/100787

Tadic, D., Stefanovic, M., & Aleksic, A. (2014). The evaluation and ranking of medical device suppliers by using fuzzy topsis methodology. *Journal of Intelligent & Fuzzy Systems*, *27*(4), 2091–2101. https://doi.org/10.3233/IFS-141174

Willemé, P., & Dumont, M. (2015). Machines that go 'Ping': Medical technology and health expenditures in OECD countries. *Health Economics*, *24*(8), 1027–1041. https://doi.org/10.1002/hec.3089

Yücel, M. G., & Görener, A. (2016). Decision making for company acquisition by ELECTRE method. *International Journal of Supply Chain Management*, *5* (1), 75–83. https://ojs.excelingtech.co.uk/index.php/IJSCM/article/view/1166

***Cogent Engineering* (ISSN: 2331-1916) is published by Cogent OA, part of Taylor & Francis Group.**