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Research Article

Determination of the Most Appropriate Ultrasound Device in Healthcare Institutions with the Critic-GRA Hybrid Method

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Abstract

Aim: Medical devices used in health institutions are quite costly and many criteria such as the selection process, efficiency and ease of use of these devices should be taken into account. Careful selection of these devices is in the class of difficult problems as it involves the evaluation of various criteria. This study is to determine the selection process of the same type of medical devices and the most appropriate device of the relevant health institution, especially when alternatives are available.

Material and Methods: The solution of the problem is modeled by using the Critic and Gray Relational Analysis (GRA) methods in an integrated structure. The basis of the study is the applicability of Multi criteria decision making (MCDM) methods. The criteria and alternatives of the created decision making model were determined by using the opinions of physicians working in the field and the literature. A case study was conducted on a decision problem of determining the most suitable ultrasound device for a healthcare institution in Düzce.

Results: According to the analysis results obtained, it was determined that the most suitable device was A3 (GE) and the most inappropriate ultrasound device was A4 (MN). In addition, the most effective criterion was K1 (Price), while the least effect was K5 (Durability).

Conclusion: It has been determined that the findings obtained are consistent with the literature. In addition, the results of the study were shared with the relevant physicians and managers.

Keywords: MCDM methods, critic method, gray relational analysis method, medical devices, health sector

INTRODUCTION

In the last century, the global economy, shaped by innovations and advances in technology, has shown remarkable growth in the medical device industry, resulting in high competition between companies and manufacturers. Different brands, different quality levels and prices of the products make it difficult for the relevant health institutions to purchase a suitable product. When multiple alternatives are available, it becomes very complex to determine the most suitable alternative, as there are many criteria to consider to make the most appropriate choice. The complexity of this type of decision problem comes from conflicting and conflicting goals. After the decision taken, the necessity of a systematic analysis that guarantees minimizing regret becomes evident. Therefore, Multi criteria decision making (MCDM) methods have emerged to support the decisions taken and increase the reliability of the chosen solution (1).

In the application of MCDM methods, which alternative should not be easily selected as a priority, especially when

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comparing the alternatives according to the criteria. This indicates that the decision problem contains a difficult solution. That means the criteria are contradicting and conflicting. Otherwise, the relevant decision problem can be solved at a glance without the need for any analysis.

In the healthcare industry, systems that take into account minimum cost have always been of great interest in terms of research and development. This interest can be attributed to the high spending of this industry and the lack of savings performance compared to other leading industries such as retail and manufacturing (2) focused on health expenditures and the reasons why doctors prefer medical equipment (3). Multi-purpose decision making methods for the products preferred by doctors based on value modeling principles were used and the hierarchical structure of the created model was applied on MCDM methods.

One of the decision problems faced by health sector enterprises is the determination of optimum medical devices. The decision maker, individually or as a group, has to decide which device to purchase. The availability of different models of equipment with the same function offered by manufacturers makes it difficult for decision makers to choose the most suitable device. This problem arises when many criteria need to be considered in a decision making process and there are elements of conflict between the criteria. The emergence of this problem is important for two reasons; first, choosing products with a structured method can reduce costs. Second, the right decision can increase the rate of good treatment of patients depending on the determination of the most appropriate device. For this reason, it is essential for health sector businesses to make correct and appropriate decisions, otherwise the cost of regret after the decisions taken is very heavy.

MCDM methods help healthcare organizations determine the best benefit in the device purchasing process. These methods do not limit the cost of a device to just the purchase price; it also takes into account factors such as device energy consumption, maintenance requirements and lifetime. Thus, healthcare organizations can manage their budgets correctly and save money in the long run by choosing the optimum devices.

Another important reason for health institutions to use MCDM methods to provide optimum devices is to increase quality. High-quality devices ensure accurate diagnoses and effective treatments. This ensures that the treatment processes of patients are more successful and efficient. At the same time, devices with up-to-date and advanced technology increase the working efficiency of healthcare personnel and reduce errors.

Therefore, in the study, the selection of the most suitable medical device among many alternatives was accepted as a decision problem and its solution was handled with MCDM methods. In solving this problem, it is aimed to choose the most suitable ultrasound device alternative among many similar options. In this study, both Critic and Gray Relational Analysis (GRA) methods were used in a hybrid structure.

In the following sections of the study; literature review, methodology of the study, findings and evaluation of the results are included.

Literature Review

In the process of examining the domestic and foreign literature, studies on methods such as MCDM methods and their hybrid applications in different health fields, especially in the selection of medical devices, were presented. In addition, these studies were categorized according to their subjects and the nature of the decision making method.

Glaize and friends provide a practical perspective on how Multi criteria decision making methods are applied in different health institutions (4). They proposed a model of how MCDM methods are applied in different health areas, including medical device selection (5), and presented a new MCDM method model for the most appropriate medical device selection under uncertainty conditions. Frazao et al. determined the most suitable Magnetic Resonance Imaging (MR) system for regional hospitals in the Czech Republic (6). Comparing different MCDM methods such as AHP, TOPSIS, PROMETHEE II and Simple Additive Weighting (SAW) methods, they proposed the most appropriate MCDM model for medical equipment selection.

MCDM methods in uncertainty environments, for example (7), have presented a new approach to evaluate the smart medical device selection process under uncertainty conditions. The intuitionistic fuzzy Choquet integral (IFCI) approach was used in their work to address uncertainty and ambiguity. Carnero and Gomez proposed the fuzzy MCDM approach to evaluate a single medical device supplier in their study (8). Tadic et al. evaluate a new approach including Neutrosophic TOPSIS method to optimize the selection process of smart medical devices in a fuzzy decision environment (9). Basset et al. stated the dominance of AHP and other methods of fuzzy logic in the literature in their studies (10).

They used the AHP approach to select important medical equipment in resource-constrained environments (11). Ivlev et al. used both MACBETH (Measuring Attractiveness by a Categorical Based Evaluation Technique) and FAHP (Fuzzy AHP) methods separately in their studies for the optimal selection of medical gas supply devices (12). Both AHP and fuzzy VIKOR (Vlekriterijumsko Kompromisno Rangiranje) methods have been used by (13) to select the most suitable protein isolation device in a scientific research laboratory. Emec et al. used fuzzy VIKOR-based fuzzy MCDM method in the problem of evaluating available alternatives for medical waste disposal in their study (14).

A hybrid fuzzy MCDM approach (15) consisting of fuzzy AHP method and fuzzy TOPSIS method was used to select the most suitable medical device manufacturer. A Multi criteria decision making approach (16) based on fuzzy AHP and fuzzy TOPSIS has been used in a fuzzy Multi criteria decision making environment to improve the supplier selection process in the healthcare industry.

Hybrid MCDM methods have been applied to select the most appropriate medical device in different decision environments. Goh et al. proposed an effective and efficient MCDM model that includes three different methods of AHP, Multi-Feature Range Evaluation (MARE) and ELECTRE III to solve healthcare equipment selection problems (17). Hodgett proposed a model that integrates TOPSIS (intuitionistic fuzzy set) approaches to select the most appropriate real-time location system technology in a hospital-based Multi criteria structure (18). Budak et al. developed a hybrid model combining Analytical Hierarchy Process (AHP) and TOPSIS methods for the most appropriate medical equipment selection (19). Willeme and Dumont developed the HMCDM (Hybrid MCDM) method, which mixes AHP, TOPSIS, ELECTRE, GRA and SAW methods to select the most suitable supplier in the healthcare industry (20).

No study has been found in the literature, which has contradicting and conflicting criteria, analyzed with the Critic and GRA methods, for the determination of the most appropriate medical device in the health sector. For this reason, in this study, it is aimed to present a hybrid model by using the Critic and GRA methods together on the most appropriate medical device selection for the relevant health institutions. In the research, the Critic method was used to find the criteria weights, and the most suitable alternative was determined in line with the weighted criteria with the GRA method.

MATERIAL AND METHOD

Thanks to the technological medical devices produced in recent years, diagnosis has become easier in the medical world, so the life expectancy of people has become longer (21). Since the excessive increase in health expenditures complicates health problems, scientific methods, especially MCDM methods, are needed in solving the decision problems encountered.

The main purpose of this study is the problem of determining the most appropriate medical device in health institutions, which is considered as a decision making problem. The modeling of the problem, the determination of the criteria and alternatives were created entirely by the opinions of active physicians in the sector and by examining the literature. The weights of the criteria were determined by the Critic method and the priority order of the alternatives was determined by the GRA method. Analyzes were carried out in accordance with the hierarchical solution model of the study and the solution stages of the relevant MCDM methods. The aggregated results of the analysis performed are explained in detail in the interpretation of the findings.

While determining the criteria used to identify the most suitable ultrasound device, similar studies in the literature were primarily used. Then, the opinions of doctors and technical staff working in the sector were taken. In addition, the performance values within the framework of the criteria of each alternative were obtained from the official authorities of the companies selling the devices.

Moreover, the reasons for choosing the Critic method in determining the weights of the criteria in the study are explained in detail below;

a. Its calculations include simple steps,
b. Decision makers can take action without having to make a judgment about the criteria,

c. Taking into account the trend that exists on other criteria such as standard deviation and correlation,

d. It is considered more objective than other weighting methods in the literature.

The MCDM methods used in the study and the process steps are explained in detail in the titles that follow respectively.

Critic Method

The Critic Method emerged in the first study by Diakoulaki et al. in 1995. This study aimed to evaluate the financial performance data of eight pharmaceutical companies. In the analysis phase, the Critic Method, which can be used in cases where there is no definite information about the decision makers, and which allows objective weighting to the criteria, was used.

The "Critic Method" or "Critic Approach", which is among the Multi criteria decision making methods, is a method that enables the evaluation and weighting of more than one criterion in the decision making process.

The Critic Method is an effective method used in complex decision making processes. The determination and weighting of the criteria may vary depending on the preferences and goals of the decision maker. In addition, different results can be obtained by using the evaluations of different experts or objective data.

The solution steps of the Critic Method can be listed as follows (21);

1. Normalizing the decision matrix of the decision problem: Normalizing the data in the decision matrix is done to ensure that they can be evaluated on the same scale.
2. Determining the degree of relationship between the criteria: According to the decision matrix, the degree of relationship between the criteria is determined. This refers to the importance levels of the criteria with each other.
3. Expressing the criterion weights depending on the relation degrees: The criterion weights are calculated by using the determined relation degrees. These weights are used to determine the order of importance of criteria in the decision making process.

Gray Relational Analysis (GRA) Method

The general purpose of Multi criteria decision making methods is to determine the most suitable one among the alternatives based on different criteria. Recently, GRA has become a frequently used approach. The basis of this approach was developed by Julong Deng in the early 1980s. The GRA method is based on the Gray number theory. This method, in MCDM problems, allows for the elimination of numerical uncertainties easily and makes it possible to make an evaluation based on the basic data set (22).

GRA method stands out as an approach used in MCDM problems. In this method, decision making process is performed based on Gray number theory. In GRA method, performance data is converted into Gray numbers and analyzed. Gray numbers have three components to express a particular value: upper class, middle class and lower class. These components are used to express performance values according to the level of uncertainty.

The method evaluates the relations of the alternatives with each other and determines the priority order of these relations. Thus, weights and evaluations are obtained that will be used in the decision making process to determine the most suitable alternatives.

Gray number theory-based (GRA) method can be easily used when certainty cannot be established in decision problems and there is not enough information about alternatives (23).

The GRA Method consists of six stages and these stages can be listed as follows (24);

1. Building the reference matrix based on the basic data set: In the first step, the reference matrix is created based on the basic data set. The reference matrix contains values that reflect the performance of alternatives in terms of criteria.

2. Normalizing the base data matrix: The values in the data matrix are normalized, that is, they are standardized so that they can be evaluated on the same scale.

3. Creating the Absolute Value Matrix: Absolute value matrix is created by using the normalized basic data matrix. This matrix is used to determine the relationships between criteria.

4. Determination of Gray Relational Coefficient Matrix: Based on the absolute value matrix, the gray relational coefficient matrix is determined. This matrix expresses the relationship of the alternatives with each other and the level of importance according to the criteria.

5. Determination of the weighted average values of the alternatives: The weighted average values of the alternatives are determined by using the gray relational coefficient matrix. These values are used to determine the order of importance of the alternatives.

6. Expression of gray associative degrees: In the last step, gray associative degrees are expressed. These degrees are the values that explain the relationship of the alternatives with each other and the order of importance according to the criteria.

Application: Determination of the Most Appropriate Ultrasound Device with MCDM Methods

The decision problem analyzed within the study is aimed at determining the most appropriate medical device in health institutions. The goal is to identify the device that outweighs all alternatives within the framework of the determined criteria. In this analysis process, the solution steps of the relevant MCDM methods were fully adhered to. The study was carried out in a health institution operating in Düzce and criteria and alternatives were created in line with the opinions of five physicians in the relevant health institution. According to the data obtained as a result of the physicians' evaluation of the criteria in order of importance, the first eight criteria were accepted for the analysis.

Four alternative ultrasound devices were evaluated in this study. The names of these devices are expressed with short codes on the basis of data confidentiality. The codes of these devices are AL, SA, GE and MN. In addition, in the later parts of the study, the Criteria are expressed with only their codes as K1, K2... in order to fit the tables on the pages. For example, K1 is the "Price" criterion.

Determining the Weights of the Criteria with the Critic Method

In order to apply the analysis stages of the Critic method, the basic data matrix must first be expressed. The basic data matrix is expressed in Table 1.

Table 2 shows the normalized version of the correlation matrix.

Table 1. Basic data matrix

	K1: Price ($) Min	K2: Viewing Quality (out of 10 points) Max.	K 3: Size (Size) m3 Min.	K 4: Ease of Use (out of 10 points) Max.	K5: Durability (out of 10 points) Max.	K 6: Number of Probes Max.	K 7: Warranty Period Max.	K 8: Service Time Max.
A1	35000	5	0.9	6	6	3	2	1
A2	40000	7	1.2	8	7	5	3	2
A3	44000	8	1.3	7	8	4	4	4
A4	37000	6	1.1	5	5	3	2	1

Tablo 2. Normalized correlation matrix								
	K1	K2	K3	K4	K5	K6	K7	K8
K1	0.0000	1.9891	0.0530	1.5934	1.8572	1.6224	1.9780	1.9631
K2	1.9891	0.0000	1.9827	0.4000	0.2000	0.3258	0.0561	0.0871
K3	0.0530	1.9827	0.0000	1.5292	1.6803	1.6625	1.8664	1.8281
K4	1.5934	0.4000	1.5292	0.0000	0.2000	0.0561	0.3258	0.4523
K5	1.8572	0.2000	1.6803	0.2000	0.0000	0.3258	0.0561	0.0871
K6	1.6224	0.3258	1.6625	0.0561	0.3258	0.0000	0.3636	0.5076
K7	1.9780	0.0561	1.8664	0.3258	0.0561	0.3636	0.0000	0.0153
K8	1.9631	0.0871	1.8281	0.4523	0.0871	0.5076	0.0153	0.0000

The matrix containing the Cj and standard deviation values used while calculating the final weights of the criteria in the last step of the Critic method is clearly expressed in Table 3. Standard deviation values were calculated for each criterion one by one by considering all alternatives. When calculating the final Cj values, the standard deviation value for each criterion is multiplied by the row total value and divided by the total Cj value. These obtained values are also an expression of the weight of each criterion.

As it is clearly stated in Table 3; K1: The price criterion has a value of 0.216 and has priority in the first degree. The second priority is K3: Size criterion with a value of 0.203. The most important factor in obtaining the results in this way is the economic conditions of the market and the importance of functional use for physicians.

Table 3. Final weights of criteria					
	STD Deviation Value	Row Totals	STD* Row Totals	Cj/Total Cj	Weights
K1	0.4351	11.0561	4.8104	0.2162	**0.2162**
K2	0.4303	5.0408	2.1692	0.0975	**0.0975**
K3	0.4270	10.6022	4.5267	0.2034	**0.2034**
K4	0.4303	4.5568	1.9609	0.0881	**0.0881**
K5	0.4303	4.4066	1.8963	0.0852	**0.0852**
K6	0.4787	4.8639	2.3284	0.1046	**0.1046**
K7	0.4787	4.6614	2.2315	0.1003	**0.1003**
K8	0.4714	4.9406	2.3290	0.1047	**0.1047**

Determining the Priority of the Most Appropriate Ultrasound Device Alternatives for the GRA Method

In order to apply the GRA method, reference values based on the basic data matrix must first be found. For this reason, Table 4 contains the reference matrix expressing the reference values.

After calculating the Reference Matrix, the basic data matrix was normalized. The obtained values are clearly expressed in Table 5.

After the data are normalized, the absolute value matrix should be created in accordance with the stages of the GRA method. Accordingly, after the absolute value matrix of the data was created, the gray relational coefficient matrix was formed. While calculating the data for this stage, ς=0.5 was accepted as the gray relational coefficient value, which is frequently used in the literature. The results obtained are clearly expressed in Table 6.

After finding the gray relational coefficient matrix values, the gray relational degrees ($\Gamma 0i$) of each alternative were calculated. According to the data obtained, the priority order of each alternative has been determined. Gray relational degrees are shown in Table 7.

At the last stage of the GRA method, the alternatives are ranked according to their priorities, taking into account the gray relational degrees of each alternative. In fact, in order to evaluate the results in detail, the weights of the criteria were calculated separately depending on whether they were equal or not. This final ranking is expressed in Table 8.

Table 4. Reference matrix

	K1	K2	K3	K4	K5	K6	K7	K8
Reference values	**35000**	**8**	**0.9**	**8**	**8**	**5**	**4**	**4**
A1	35000	5	0.9	6	6	3	2	1
A2	40000	7	1.2	8	7	5	3	2
A3	44000	8	1.3	7	8	4	4	4
A4	37000	6	1.1	5	5	3	2	1

Table 5. Normalized matrix

	K1	K2	K3	K4	K5	K6	K7	K8
A1	1.0000	0.0000	1.0000	0.3333	0.3333	0.0000	0.0000	0.0000
A2	0.4444	0.6667	0.2500	1.0000	0.6667	1.0000	0.5000	0.3333
A3	0.0000	1.0000	0.0000	0.6667	1.0000	0.5000	1.0000	1.0000
A4	0.7778	0.3333	0.5000	0.0000	0.0000	0.0000	0.0000	0.0000

Table 6. Gray relational coefficient matrix

	K1	K2	K3	K4	K5	K6	K7	K8
A1	1.0000	0.3333	1.0000	0.4286	0.4286	0.3333	0.3333	0.3333
A2	0.4737	0.6000	0.4000	1.0000	0.6000	1.0000	0.5000	0.4286
A3	0.3333	1.0000	0.3333	0.6000	1.0000	0.5000	1.0000	1.0000
A4	0.6923	0.4286	0.5000	0.3333	0.3333	0.3333	0.3333	0.3333
Δmax	1.000							
Δmin	0.000							
ς	0.5							

Table 7. Gray relational grades of alternatives

	K1	K2	K3	K4	K5	K6	K7	K8	Γ0i
A1	1.0000	0.3333	1.0000	0.4286	0.4286	0.3333	0.3333	0.3333	**0.5238**
A2	0.4737	0.6000	0.4000	1.0000	0.6000	1.0000	0.5000	0.4286	**0.6253**
A3	0.3333	1.0000	0.3333	0.6000	1.0000	0.5000	1.0000	1.0000	**0.7208**
A4	0.6923	0.4286	0.5000	0.3333	0.3333	0.3333	0.3333	0.3333	**0.4109**

Table 8. Final ranking of alternatives

	If the Criteria Have Different Weights	If the criteria are of equal weight	Final Ranking
1.	A3	A3	**A3**
2.	A1	A2	**A1 or A2**
3.	A2	A1	**A1 or A2**
4.	A4	A4	**A4**

RESULTS

Health sector businesses may always be faced with the problem of choosing the most appropriate medical device with different contradicting and conflicting criteria, but making a decision based on personal experience alone does not guarantee that the optimum selection is made. According to the clear results summarized in Table 9, it was seen that Alternative A3 outperformed other alternatives when evaluated within the framework of the criteria. The ordering of the alternatives was done by completely adhering to the solution steps in both methods. This result increases the reliability of the analyzes when choosing the best alternative and determining the worst choice for the decision maker and the relevant businesses.

According to the ranking obtained as a result, it is thought that it was determined as a result of seeing the A3 alternative as superior to the others, taking into account the criteria determined by the common opinion of the physicians. The use of the Critic method in determining the weights of the criteria has increased the reliability of the calculations in terms of the objectivity of the results. The data obtained as a result of the analyzes were shared with the relevant physicians and health institution managers. In addition, the consistency of the results obtained was confirmed by the relevant physicians. We consider this as validation of the model.

When the results obtained by both methods are examined, it is seen that the most suitable alternative is A3. The combination of the two methods yields more reliable results for hybrid structures than others. According to the data obtained, the rankings obtained by the hybrid method confirm their validity when compared with other studies in the literature. The results of the analyzes were examined in depth with the relevant physicians. Recommendations were made to those concerned that it would be possible to determine the most appropriate medical device through analyzes performed with hybrid MCDM methods.

DISCUSSION

In the study, the application of MCDM methods over the ultrasound devices to be selected for a decision problem for determining the most appropriate medical device in health institutions is shown. Physicians who are experts in their field; They were involved in the process of creating the model, determining the criteria and identifying alternatives. By using two MCDM methods in a hybrid structure, four alternatives were prioritized according to eight criteria.

As a result of these analyzes, physicians or organizations that want to supply medical devices were helped to make objective, correct and on-site decisions with MCDM methods. When the physicians participating in the study were asked how they obtained the medical devices they currently use, they said, "I do not know how and by what method the relevant management has taken it." It is an answer that leads to wrong in terms of the management of health institutions. Because of the supply of devices to be used by physicians, physicians must be included in the process and their opinions must be taken into account.

This study has two main aims; firstly, to be able to place the usability of existing MCDM methods in the health sector literature, and secondly, to guide future studies on this subject. However, some limitations were encountered while carrying out this study. These;

- The case of obtaining data from a health institution related to the subject in Düzce and therefore the limited number of the sample,
- Difficulties experienced in involving physicians in all aspects of the process in terms of work intensity,
- The medical device companies that make up the alternatives do not want to publicly declare their names in terms of data confidentiality,
- Limited number of alternatives,
- Inadequacy of software that can analyze Critic and GRA methods,
- The reluctance of health institutions to prefer scientific methods in this regard.

CONCLUSION

When the findings of the study are examined; First, the weights of the criteria were calculated. Accordingly, the most effective criterion was "Price" with a value of 0.216, followed by "Size" with a value of 0.203. In addition, A3 ranked first with a value of 0.1582 in the priority order of the alternatives calculated by the GRA method. In the last place is A4 with a value of 0.1135. These results are in line with similar studies in the literature (5,8).

The main contributions of this study to the literature can be summarized as follows;

- To propose a MCDM model that combines Critic and GRA methods in a hybrid structure for the problem of determining the most appropriate medical device with contradicting and conflicting criteria,
- To demonstrate the usability of MCDM methods in the selection process of medical devices to physicians and related researchers working in this field,
- Physicians' working with more suitable devices will speed up the treatment time and therefore reduce the patient density that causes confusion in health institutions.

MCDM methods also significantly affect the safety of patients. Healthcare organizations can keep patients' safety at the highest level by providing accurate and reliable devices. For example, the correct operation of surgical robotic systems used for sensitive surgeries is critical to ensuring the safety of patients. Devices selected with MCDM methods reduce the likelihood of technical problems and malfunctions, which contributes to patient safety.

In future studies, the inclusion of physicians as well as personnel who understand the technical structure of the devices, especially in the determination and comparison of the criteria, will provide more detailed and accurate results. It would be appropriate to use more up-to-date, hybrid, artificial intelligence-themed and fuzzy logic approaches in the analysis of the MCDM model. In addition, AHP, Entropy and Smart methods can be used in the process of weighting the criteria in future studies on similar subjects.

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REFERENCES

1. Marsh K, Goetghebeur M, Thokala P, Baltussen R. Multi-criteria decision analysis to support healthcare decisions. 1st edition. Springer Cham, 2017;1.
2. Shbool MA. Essays in physicians preference items and inventory management within the healthcare supply Chain. Graduate thesis and dissertations, University of Arkansas, Fayetteville, 2016.
3. Shbool MA, Rossetti MD. Physician preference items a decision making framework. In: IIE Annual Conference. Proceedings, Pittsburgh, PA. March 14, 2017.
4. Glaize A, Duenas A, Martinelly CD, Fagnot I. Healthcare decision making applications using multi criteria decision analysis: A scoping review. Journal of Multi criteria decision Analysis. 2019;26:62-83.
5. Ivlev I, Vacek J, Kneppo P. Multi criteria decision analysis for supporting the selection of medical devices under uncertainty. European Journal of Operational Research. 2015;247:216-28.
6. Frazão TDC, Camilo DGG, Cabral ELS, Souza RP. Multicriteria decision analysis (MCDA) in health care: a systematic review of the main characteristics and methodological steps. BMC Med Inform Decis Mak. 2018;18:90.
7. Büyüközkan G, Göçer F. Smart medical device selection based on intuitionistic fuzzy Choquet integral. Soft Computing. 2019:23:10085–103.
8. Carnero MC, Gomez A. Optimization of decision making in the supply of medicinal gases used in health care. Sustainability. 2019;11:2952.
9. Tadic D, Stefanovic M, Aleksic A. The evaluation and ranking of medical device suppliers by using fuzzy topsis methodology. Journal of Intelligent & Fuzzy Systems. 2014;27:2091–101.
10. Abdel-Basset M, Manogaran G, Gamal A, Smarandache F. A group decision making framework based on neutrosophic TOPSIS approach for smart medical device selection. J Med Syst. 2019;43:38.
11. Ivlev I, Jablonsky J, Kneppo P. Multiple criteria comparative analysis of magnetic resonance imaging systems. Int. J. Medical Engineering and Informatics. 2016;8:124–41.
12. Ivlev AV, Zhdanov SK, Khrapak SA, Morfill GE. Ion drag force in dusty plasmas Plasma Phys Control Fusion. 2004;46:B267.
13. Carnero MC, Gómez A. Optimization of decision making in the supply of medicinal gases used in health care. Sustainability. 2019;11:2952.
14. Emec S, Turanoglu B, Oztas S, Akkaya G. An integarted MCDM for a medical company selection in health sector. International Journal of Scientific and Technological Research. 2019;5:77–89.
15. Liu HC, Wu J, Li P. Assessment of health-care waste disposal methods using a VIKOR-based fuzzy multi-criteria decision making method. Waste Manag. 2013;33:2744-51.
16. Lee YC, Chung P-H, Shyu JZ. Performance evaluation of medical device manufacturers using a hybrid fuzzy MCDM. Journal of Scientific and Industrial Research. 2017;76,28-31.
17. Goh M, Zhong S, De Souza R. Operational framework for healthcare supplier selection under a fuzzy Multi criteria environment. 23rd International Symposium on Logistics (ISL 2018), 8 – 11 July 2018. Bali, Indonesia, 25.
18. Hodgett, R.E. Comparison of multi-criteria decision-making methods for equipment selection. Int J Adv Manuf Technol. 2016;85:1145–57.
19. Budak A, Ustundag A, Oztaysi B, Cevikcan E. A multi criteria intuitionistic fuzzy group decision making model for real time location system integration: An application from healthcare system. 12th International Conference on Uncertainty Modelling in Knowledge Engineering and Decision Making (FLINS), 24-26 August 2016, Roubaix, France, 580–7
20. Willemé P, Dumont M. Machines that go ‘Ping’: Medical technology and health expenditures in OECD countries. Health Economics. 2015;24:1027–41.
21. Barrios MA, Felice FD, Negrete KP, et al. An AHP-topsis integrated model for selecting the most appropriate tomography equipment. International Journal of Information Technology & Decision Making. 2016;15:861–85.
22. Akcan S, Güldeş M. Integrated multicriteria decision making methods to solve supplier selection problem: A case study in a hospital. Journal of Healthcare Engineering. 2019:1–10.
23. Arslan HM. Evaluation of the financial performance of the enterprises operating in technoparks with critic-topsis method. Duzce University Journal of Social Sciences. 2019;9:144-53.
24. Üstünışık NZ. Türkiye'deki iller ve bölgeler bazında sosyo-ekonomik gelişmişlik sıralaması araştırması: gri ilişkisel analiz yöntemi ve uygulaması. M.Sc. Thesis. Gazi Universitiy, Ankara. 2007.