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A Hybrid Hesitant Fuzzy Model for Healthcare Systems Ranking of European Countries

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Abstract: Ranking several countries on a specific area may require the consideration of various factors simultaneously. To obtain a ranking of countries, the development of analytical approaches, which can aggregate opinions of a group of people on various criteria, is essential. The main aim of this study was to propose such a ranking approach for European countries in terms of healthcare services. To this end, a hybrid group decision-making model based on Hesitant Fuzzy Linguistic Terms Set (HFLTS) and Hesitant Fuzzy Technique of Order Preference by Similarity to Ideal Solution (HF-TOPSIS) is presented in this study. Importance degree of indicators were determined by the HFLTS-based group decision-making approach, and then HF-TOPSIS was used to obtain the rank of countries. According to the results obtained by the proposed model, Austria, Sweden and Finland are the best European countries in terms of healthcare services. Moreover, two comparative analyses, one for the utilization of different hesitant fuzzy distance measures in HF-TOPSIS and one for the ranking of countries obtained by utilizing TOPSIS, return some variations in country rankings. While Austria remained the best country for all distance measures in the hesitant fuzzy environment, Luxemburg was found to be the best for the deterministic case of TOPSIS.

Keywords: hesitant fuzzy sets; group decision making; HFLTS; TOPSIS; healthcare systems

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1. Introduction

Nowadays, some institutions and companies share different types of information. This information is collected and shared by worldwide organizations related to the subject of information. Such data help analysts to understand their position against other organizations in the same sector. In terms of countries, there are many indicators to show their status against other countries. The values for these indicators are calculated by organizations in each country and these organizations share data for their activities in specific periods. Data from different countries' organizations are collected by worldwide organizations to share with people all around the world.

The most known information resource for countries to compare them with other countries is the World Development Indicators database of the World Bank [1]. There are values of many development indicators related to all countries for each year in this database. These data give people the opportunity to see a country's position in terms of different indicators. Furthermore, these variables are categorized in this database for different subjects such as education, economy, security, healthcare, etc.

Among all the different types of indicators, indicators related to healthcare services should be considered separately. Because of their importance for human life, healthcare services' quality is the most important among the other services [2]. Nevertheless, the existence of a number of indicators requires the aggregation of different indicators to understand a country's status against other countries. At this point, using multiple criteria decision making seems to be an efficient way to aggregate different indicators. Multiple criteria decision-making methods are utilized in different applications such as aircraft selection [3], productivity evaluation [4], third-party reverse logistics service provider selection [5], and medical device selection [6].

Studies on MCDM applications in healthcare systems are common in the literature. The procurement of healthcare technology processes was analyzed by Nobre et al. [7]. An assessment of waste treatment alternatives in healthcare systems was made by MCDM approaches [8]. The fuzzy extension of the Analytic Hierarchy Process (AHP) method was used to find the best location for a hospital [9]. Fuzzy AHP and TOPSIS methods were combined to evaluate web-based service quality levels of 13 hospitals in Turkey [10]. Hung et al. [11] considered the fee schedule setting problem in orthopedic procedures in Taiwan by using both fuzzy and non-fuzzy MCDM methods. The priority of health interventions was set in Tromp and Baltussen's study [12] by utilizing MCDM methods. The service quality of public hospitals in Turkey was evaluated by using an AHP and Fuzzy Information Axiom-based hybrid model [13]. The perceived value of the healthcare services of patients was evaluated by using the DEMATEL method in Efe and Efe's study [14]. Ghouschchi et al. [15] evaluated alternative locations for medical waste landfills by using a spherical fuzzy set-based SWARA-WASPAS method. Al Awadh [16] utilized a SERVQUAL-based AHP method to evaluate the quality of hospitals in Saudi Arabia. A PROMETHEE-based MCDM method was used by Pereira et al. [17] to evaluate the feasibility of implementing a hospital information system for a military public institution. Wang et al. [18] analyzed the efficiency of intervention strategies in response to the COVID-19 pandemic by using a group decision-making approach based on BWM.

In the literature, there are some studies on service quality evaluation in healthcare systems [4,7,16]. However, there are no studies comparing countries in terms of healthcare services. To fill this gap in the literature, the main aim in this study was to develop an analytic approach to rank 28 European Union member countries in terms of healthcare indicators. To consider different healthcare indicators in an aggregated manner, a multiple criteria decision-making approach based on Hesitant Fuzzy Linguistic Terms Set (HFLTS) and Hesitant Fuzzy Technique of Order Preference by Similarity to Ideal Solution (HF-TOPSIS) is proposed. HFLTS is used to determine the importance degree of each healthcare indicator of healthcare service quality, and HF-TOPSIS is used to rank countries. The existence of uncertainty and hesitancy in ranking the criteria score of countries was taken into account by using hesitant fuzzy elements. The reason hesitant fuzzy sets are used in the study is the necessity to model uncertainty and hesitancy that decision makers face in the evaluation of healthcare indicators and country performances. Hesitant fuzzy elements have been proven to be useful in several studies such as [19,20] to model uncertainty. Moreover, the analysis of rankings obtained by using different hesitant fuzzy distance measures in HF-TOPSIS and rankings obtained by the deterministic TOPSIS method were also presented as comparative analyses of the proposed model. The main contributions of the study can be summarized as follows:

- Healthcare services in European countries compared by using a MCDM model.
- HFLTS-based group decision making is used to calculate the criteria weights.
- HF-TOPSIS is applied to determine the ranking of countries.
- A comparison of rankings for the utilization of different hesitant fuzzy distance measures is made.
- A comparison of HF-TOPSIS and deterministic TOPSIS is presented.

The rest of the paper is organized as follows. Section 2 consists of a brief explanation of the methodology of the proposed approach. Healthcare indicators considered for the evaluation of healthcare services and data for countries are explained in Section 3. Section 4 consists of the application steps with the analysis of rankings obtained by using different distance measures. The paper concludes in Section 5 with suggestions for further studies.

2. Methodology

In this study, a hybrid hesitant fuzzy group decision-making algorithm based on HFLTS and TOPSIS was proposed. Currently, the only study integrating these approaches was by Aktas and Kabak [21], who used them to evaluate potential sites for solar energy plants. Using hesitant fuzzy sets provides the ability to handle the hesitancy of decision makers among possible linguistic terms used in the evaluation. After the definition of the decision problem, Yavuz et al.'s HFLTS-based group decision-making algorithm [22] was used to determine criteria weights. The hierarchical structure modeling of the decision problem and using hesitant fuzzy linguistic representations for expressions make it possible for this algorithm to handle complex MCDM problems. Then, Xu and Zhang's HF-TOPSIS method [23] was used to evaluate alternatives. The construction of a hesitant fuzzy decision matrix makes it possible to handle different evaluation scores expressed by decision makers and enables us to obtain a decision combining different opinions. The flowchart for the proposed decision-making algorithm is given in Figure 1.

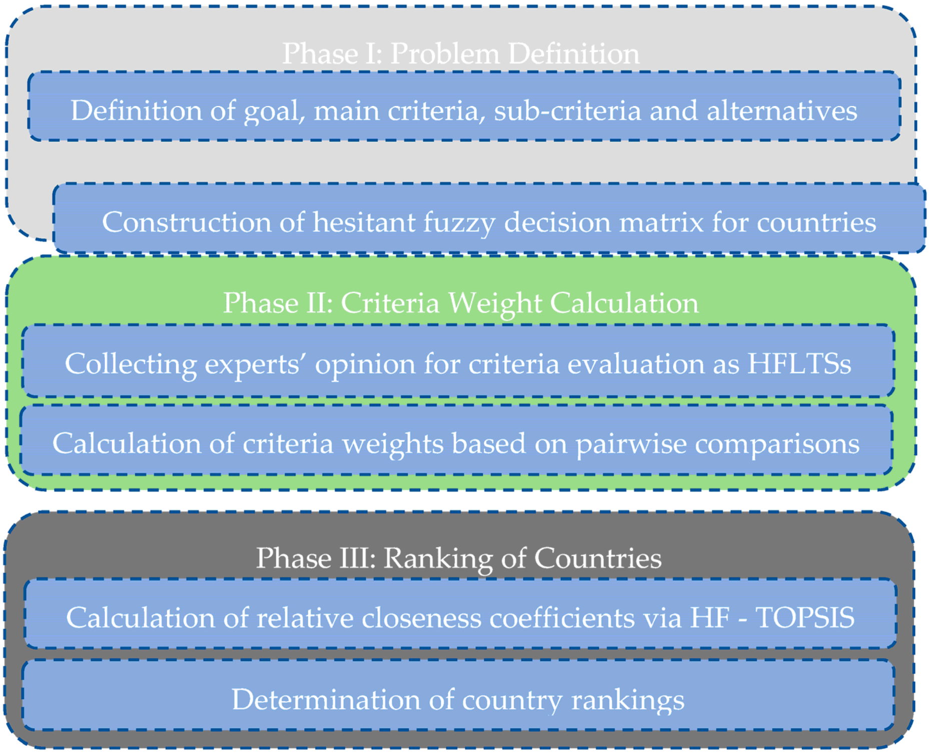

Figure 1. Steps of the algorithm.

The first phase of the proposed algorithm gives a definition of the problem. In this phase, the goal of the problem, decision criteria, and alternatives to be evaluated are defined. Then, a hesitant fuzzy decision matrix, which consists of experts' opinions in terms of decision criteria for each alternative, is constructed.

The calculation of criteria weights is the second phase of this algorithm. Pairwise comparison matrices constructed using HFLTS which represent the opinions of experts on criteria are used to calculate the importance degree values of decision criteria.

The last phase of the algorithm is the ranking of countries. In this phase, alternatives are evaluated by using the hesitant fuzzy decision matrix and the criteria importance degree values calculated in phase 2. The relative closeness coefficient for each country is calculated by the HF-TOPSIS method, and the ranking of countries is determined.

The proposed model was developed in order to handle uncertainty in criteria evaluation by HFLTS and the vagueness of alternative evaluations by different experts via the HF-TOPSIS method. By using the model, the linguistic evaluation of experts on criteria can be expressed by more than one linguistic term, since the method uses a context-free grammar structure. Moreover, different thoughts of experts on alternative scores with respect to each criterion may have different membership values, which can be handled by hesitant fuzzy elements in the TOPSIS method.

TOPSIS is a well-known MCDM method. It can be used to obtain the ranking of alternatives, where the furthest alternative from the least desired solution is in the first order. Its ease of application and common utilization in a variety of decision-making applications are the main reasons for choosing the method.

3. Ranking of European Countries by Using the Proposed Approach

3.1. Hierarchical Structure of the Problem

In this phase, definitions of the goal, main criteria, and sub–criteria for site selection were determined, and the hierarchical structure of site selection procedure was constructed. The structure is given in Figure 2.

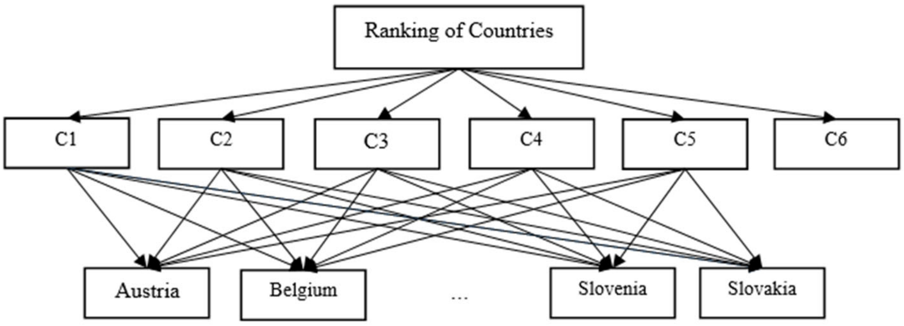

Figure 2. Hierarchical structure.

The goal of the problem is ranking European countries in terms of healthcare development indicators. In this study, the rank of countries is determined by considering six regularly collected indicators related to healthcare services from the World Bank's World Development Indicators database [1]. These six indicators are health expenditure per capita (C_1), hospital beds per 1000 people (C_2), life expectancy at birth (C_3), number of under-five deaths (C_4), survival to age 65 for females (C_5), and survival to age 65 for males (C_6). Readers may have a look at the database for descriptions of criteria and other related criteria.

The decision matrix of the problem shows each alternative's value based on available decision-making criteria. This matrix is constructed by asking three experts about their opinion on each alternative's suitability as decision-making criteria in the interval [0, 1]. It means that for an expert, an alternative is suitable in terms of decision-making criteria when the expert's opinion for that alternative is closer to 1, and the alternative is not suitable in terms of that criteria when the expert's opinion is closer to 0. Since repeat times of values are not considered to be significant, if two or more experts have the same opinion for an alternative under the same criterion, this opinion is shown only once in the decision matrix. The decision matrix of the problem is given in Table 1.

Table 1. Decision matrix of the problem.

	C_1	C_2	C_3	C_4	C_5	C_6
AUT	{1.0, 0.8, 0.5}	{1.0, 0.9, 0.8}	{0.9, 0.7, 0.5}	{0.3}	{0.9, 0.7, 0.6}	{0.8, 0.7, 0.6}
BEL	{0.9, 0.7, 0.4}	{0.7, 0.6, 0.3}	{0.9, 0.7, 0.5}	{0.4, 0.3}	{0.7, 0.6, 0.5}	{0.8, 0.7, 0.6}
BGR	{0.2, 0.1}	{1.0, 0.7, 0.5}	{0.2, 0.1, 0.0}	{0.6, 0.5, 0.4}	{0.2, 0.1, 0.0}	{0.2, 0.1}
CZE	{0.4, 0.2}	{0.9, 0.8, 0.7}	{0.7, 0.4, 0.1}	{0.4, 0.3}	{0.7, 0.5, 0.2}	{0.6, 0.4, 0.2}
DNK	{1.0, 0.8, 0.6}	{0.2, 0.1}	{0.9, 0.6, 0.3}	{0.3}	{0.7, 0.4, 0.1}	{0.8, 0.7, 0.5}
EST	{0.3, 0.2, 0.1}	{0.8, 0.5, 0.3}	{0.5, 0.2, 0.0}	{0.2}	{0.6, 0.2, 0.0}	{0.3, 0.1, 0.0}
FIN	{0.9, 0.7, 0.4}	{0.9, 0.7, 0.4}	{0.9, 0.7, 0.4}	{0.3, 0.2}	{0.9, 0.7, 0.6}	{0.8, 0.6, 0.5}

Table 1. *Cont.*

	C_1	C_2	C_3	C_4	C_5	C_6
FRA	{0.9, 0.8, 0.5}	{0.9, 0.8, 0.6}	{0.9, 0.8, 0.6}	{1.0, 0.9}	{0.8, 0.7, 0.6}	{0.8, 0.7, 0.5}
DEU	{1.0, 0.8, 0.5}	{1.0, 0.9}	{0.9, 0.7, 0.5}	{1.0, 0.9, 0.8}	{0.8, 0.7, 0.5}	{0.8, 0.7, 0.6}
HRV	{0.3, 0.2, 0.1}	{0.5, 0.4}	{0.5, 0.3, 0.1}	{0.3, 0.2}	{0.7, 0.5, 0.3}	{0.6, 0.4, 0.3}
NLD	{1.0, 0.8, 0.4}	{0.3, 0.2}	{0.9, 0.7, 0.5}	{0.5, 0.4}	{0.8, 0.6, 0.5}	{0.9, 0.8, 0.7}
GRC	{0.7, 0.4, 0.2}	{0.3, 0.2}	{0.9, 0.7, 0.6}	{0.5, 0.4, 0.3}	{0.9, 0.8}	{0.8, 0.7}
GBR	{0.8, 0.6, 0.4}	{0.2, 0.1, 0.0}	{0.9, 0.7, 0.5}	{1.0, 0.9}	{0.8, 0.6, 0.4}	{0.9, 0.8, 0.7}
IRL	{1.0, 0.7, 0.3}	{0.4, 0.2, 0.0}	{0.9, 0.7, 0.3}	{0.3}	{0.9, 0.6, 0.4}	{0.9, 0.8, 0.6}
ESP	{0.7, 0.5, 0.3}	{0.1, 0.0}	{1.0, 0.8, 0.6}	{0.9, 0.8, 0.6}	{0.9, 0.8}	{0.9, 0.8, 0.6}
SWE	{1.0, 0.8, 0.5}	{0.3, 0.1, 0.0	{0.9, 0.8, 0.7}	{0.3}	{0.9, 0.8, 0.7}	{0.9, 0.8}
ITA	{0.8, 0.6, 0.4}	{0.5, 0.2, 0.1	{1.0, 0.8, 0.7}	{1.0, 0.8, 0.7}	{0.9, 0.7}	{0.9, 0.8, 0.7}
CYP	{0.5, 0.3, 0.2}	{0.2, 0.1}	{0.8, 0.7, 0.5}	{0.2}	{0.9, 0.8, 0.7}	{0.9, 0.8, 0.7}
LVA	{0.3, 0.2, 0.1}	{1.0, 0.8, 0.3}	{0.2, 0.1, 0.0}	{0.3, 0.2}	{0.2, 0.1, 0.0}	{0.1, 0.0}
LTU	{0.3, 0.2, 0.1}	{1.0, 0.9, 0.7}	{0.2, 0.1, 0.0}	{0.3, 0.2}	{0.2, 0.1, 0.0}	{0.1, 0.0}
LUX	{1.0, 0.9, 0.6}	{0.7, 0.5, 0.4}	{0.9, 0.7, 0.4}	{0.2}	{0.8, 0.6, 0.4}	{0.8, 0.7, 0.5}
HUN	{0.3, 0.2, 0.1}	{0.9, 0.8, 0.7}	{0.3, 0.1, 0.0}	{0.5, 0.4, 0.3}	{0.2, 0.1, 0.0}	{0.2, 0.1, 0.0}
MLT	{0.6, 0.3, 0.2}	{0.8, 0.4, 0.2}	{0.9, 0.7, 0.5}	{0.2}	{0.8, 0.7, 0.5}	{0.9, 0.8, 0.7}
POL	{0.2, 0.1}	{0.6, 0.4, 0.3}	{0.6, 0.3, 0.1}	{1.0, 0.9, 0.7}	{0.5, 0.3, 0.1}	{0.4, 0.2, 0.1}
PRT	{0.6, 0.4, 0.2}	{0.1}	{0.9, 0.6, 0.3}	{0.5, 0.3}	{0.9, 0.7, 0.5}	{0.8, 0.6, 0.4}
ROU	{0.2, 0.1}	{0.8, 0.7, 0.5}	{0.2, 0.1, 0.0}	{1.0, 0.9, 0.7}	{0.2, 0.1, 0.0}	{0.2, 0.1, 0.0}
SVN	{0.5, 0.4, 0.2}	{0.4, 0.3, 0.2}	{0.9, 0.5, 0.2}	{0.2}	{0.8, 0.6, 0.3}	{0.8, 0.5, 0.3}
SVK	{0.3, 0.2, 0.1}	{0.9, 0.7, 0.5}	{0.5, 0.2, 0.1}	{0.4, 0.3}	{0.5, 0.3, 0.1}	{0.4, 0.2, 0.1}

3.2. HFLTS for Criteria Weights Calculation

The hesitant fuzzy set concept was introduced by Torra [24] to model hesitant situations on several values of an element. Rodriguez et al. [25] extended the concept into Hesitant Fuzzy Linguistic Terms Set (HFLTS) to model the hesitant situations where the decision elements can be expressed by using various linguistic variables at the same time.

Within the proposed decision-making model, the determination of priority values for development indicators were determined by using the HFLTS-based group decision-making approach, which was proposed by Yavuz et al. [22]. HFLTS is used in this study, because it is aimed at handling the hesitancy of decision makers in expressing their opinions on healthcare service quality indicators. The steps of the algorithm are given as follows:

Step 1: Definition of linguistic terms and context-free grammar.

Linguistic terms for importance degrees used in the study are presented in Table 2. Linguistic terms are connected to the others by using an appropriate relation term from the set of "at most", "at least", "greater than", "lower than", "is", and "between". Readers may refer to Rodriguez et al. [13] for a detailed description of the context-free grammar structure.

Table 2. Importance degrees and related linguistic terms.

Importance Degree	Linguistic Term
0	No importance (n)
1	Very low importance (vl)
2	Low importance (l)
3	Medium importance (m)
4	High importance (h)
5	Very high importance (vh)
6	Absolute importance (a)

Step 2: Collecting preferences of experts for criteria.

Experts' preferences are given in Tables 3–5. An expert group of three people was formed to determine and evaluate indicators. The expert group consists of an expert from the Ministry of Health, an academician working on healthcare services quality, and the quality manager of a state hospital in Turkey.

Table 3. Preferences of Expert 1 for criteria.

	C_1	C_2	C_3	C_4	C_5	C_6
C_1	-	between vl and l	is vl	at most vl	is vl	is vl
C_2	between h and vh	-	between vl and l	at most vl	between vl and l	between vl and l
C_3	is vh	between h and vh	-	is m	between h and vh	between h and vh
C_4	at least vh	at least vh	is m	-	is m	is m
C_5	is vh	between h and vh	between vl and l	is m	-	between h and vh
C_6	is vh	between h and vh	between vl and l	is m	between vl and l	-

Table 4. Preferences of Expert 2 for criteria.

	C1	C2	C3	C4	C5	C6
C_1	-	at most m	at most l	at most vl	between vl and l	between vl and l
C_2	at least m	-	between vl and m	at most m	is m	is m
C_3	at least h	between m and vh	-	between vl and m	between m and h	between m and h
C_4	at least vh	at least m	between m and vh	-	is m	is m
C_5	between h and vh	is m	between l and m	is m	-	is m
C_6	between h and vh	is m	between l and m	is m	is m	-

Table 5. Preferences of Expert 3 for criteria.

	C_1	C_2	C_3	C_4	C_5	C_6
C_1	-	lower than m	lower than l	at most l	at most m	lower than h
C_2	greater than m	-	between l and m	at most m	is l	is l
C_3	greater than h	between m and h	-	at most m	is m	is m
C_4	at least h	at least m	at least m	-	at least m	at least m
C_5	at least m	is h	is m	at most m	-	between m and h
C_6	greater than l	is h	is m	at most m	between l and m	-

Step 3: Converting the expert preferences to HFLTS.

According to the context-free grammar rules proposed by Rodriguez et al. [25], linguistic expressions that represent the expert preferences are converted to HFLTS. HFLTS equivalents of linguistic expressions that can be used by experts are presented in Table 6 with their HFLTS equivalents. In this table, x and y represent the linguistic terms corresponding to the preferences of experts. $x - 1$ and $x + 1$ show the linguistic term with the lower importance degree and higher importance degree than x, respectively.

Step 4: Obtaining optimistic and pessimistic collective preferences by using a selected linguistic aggregation operator.

Optimistic and pessimistic collective preferences are determined by the arithmetic mean of importance degrees of linguistic terms in HFLTS. Optimistic and pessimistic collective preferences for criteria are given in Tables 7 and 8, respectively.

Table 6. HFLTS equivalents of grammar rules.

Experts' Preference	HFLTS Equivalent
at most x	[n, x]
at least x	[x, a]
lower than x	[n, x − 1]
greater than x	[x + 1, a]
is x	[x, x]
between x and y	[x, y]

Table 7. Optimistic collective preferences for criteria.

	C_1	C_2	C_3	C_4	C_5	C_6
C_1	-	2.333	1.333	1.333	2.000	2.000
C_2	5.667	-	2.667	2.333	2.333	2.333
C_3	5.667	4.667	-	3.000	4.000	4.000
C_4	6.000	6.000	4.667	-	4.000	4.000
C_5	5.333	4.000	2.667	3.000	-	4.000
C_6	5.333	4.000	2.667	3.000	2.667	-

Table 8. Pessimistic collective preferences for criteria.

	C_1	C_2	C_3	C_4	C_5	C_6
C_1	-	0.333	0.333	0.000	0.667	0.667
C_2	3.667	-	1.333	0.000	2.000	2.000
C_3	4.667	3.333	-	1.333	3.333	3.333
C_4	4.667	3.667	3.000	-	3.000	3.000
C_5	4.000	3.667	2.000	2.000	-	3.333
C_6	4.000	3.667	2.000	2.000	2.000	-

Step 5: Building the vector of intervals for collective preferences.

The vector of intervals is built by the arithmetic mean of rows in pessimistic and optimistic aggregate preference matrices.

Step 6: Obtaining priority values by normalization of interval values.

Interval midpoints are calculated, and normalized interval midpoints show priority values. Calculations in Steps 5 and 6 gave the priority values of criteria in Table 9.

Table 9. Calculations for criteria weights.

	Interval Utilities		Midpoints	Weights
C_1	0.400	1.800	1.100	0.061
C_2	1.800	3.067	2.433	0.135
C_3	3.200	4.267	3.733	0.207
C_4	3.467	4.933	4.200	0.233
C_5	3.000	3.800	3.400	0.189
C_6	2.733	3.533	3.133	0.174

It can be seen that according to the expert group's aggregated opinions, the most important indicator for healthcare services of a country is the number of under-five deaths.

This is followed by life expectancy at birth, survival to age 65 for females and males, hospital beds per 1000 people, and health expenditure per capita.

3.3. HF-TOPSIS for Ranking of Countries

TOPSIS method was first proposed by Hwang and Yoon [26] to find solutions in MCDM problems. It aims to find the shortest alternative to the positive ideal solution and the furthest alternative to the negative ideal solution. In this study, the Hesitant fuzzy extension of the TOPSIS method proposed by Xu and Zhang [25] was used. Hesitant fuzzy sets are used to cope with inherent hesitancy and uncertainty.

Since the decision matrix for this application given in Table 1 contains hesitant fuzzy elements with different numbers of experts' opinion values, it needed to be extended until all elements had the same length. The extension of hesitant fuzzy elements was made by adding the minimal value of element. The extension with minimal values added is the pessimistic case. The new decision matrix is given in Table 10.

Table 10. Extended decision matrix of the problem.

	C_1	C_2	C_3	C_4	C_5	C_6
AUT	{1.0, 0.8, 0.5}	{1.0, 0.9, 0.8}	{0.9, 0.7, 0.5}	{0.3, 0.3, 0.3}	{0.9, 0.7, 0.6}	{0.8, 0.7, 0.6}
BEL	{0.9, 0.7, 0.4}	{0.7, 0.6, 0.3}	{0.9, 0.7, 0.5}	{0.4, 0.3, 0.3}	{0.7, 0.6, 0.5}	{0.8, 0.7, 0.6}
BGR	{0.2, 0.1, 0.1}	{1.0, 0.7, 0.5}	{0.2, 0.1, 0.0}	{0.6, 0.5, 0.4}	{0.2, 0.1, 0.0}	{0.2, 0.1, 0.1}
CZE	{0.4, 0.2, 0.2}	{0.9, 0.8, 0.7}	{0.7, 0.4, 0.1}	{0.4, 0.3, 0.3}	{0.7, 0.5, 0.2}	{0.6, 0.4, 0.2}
DNK	{1.0, 0.8, 0.6}	{0.2, 0.1, 0.1}	{0.9, 0.6, 0.3}	{0.3, 0.3, 0.3}	{0.7, 0.4, 0.1}	{0.8, 0.7, 0.5}
EST	{0.3, 0.2, 0.1}	{0.8, 0.5, 0.3}	{0.5, 0.2, 0.0}	{0.2, 0.2, 0.2}	{0.6, 0.2, 0.0}	{0.3, 0.1, 0.0}
FIN	{0.9, 0.7, 0.4}	{0.9, 0.7, 0.4}	{0.9, 0.7, 0.4}	{0.3, 0.2, 0.2}	{0.9, 0.7, 0.6}	{0.8, 0.6, 0.5}
FRA	{0.9, 0.8, 0.5}	{0.9, 0.8, 0.6}	{0.9, 0.8, 0.6}	{1.0, 0.9, 0.9}	{0.8, 0.7, 0.6}	{0.8, 0.7, 0.5}
DEU	{1.0, 0.8, 0.5}	{1.0, 0.9, 0.9}	{0.9, 0.7, 0.5}	{1.0, 0.9, 0.8}	{0.8, 0.7, 0.5}	{0.8, 0.7, 0.6}
HRV	{0.3, 0.2, 0.1}	{0.5, 0.4, 0.4}	{0.5, 0.3, 0.1}	{0.3, 0.2, 0.2}	{0.7, 0.5, 0.3}	{0.6, 0.4, 0.3}
NLD	{1.0, 0.8, 0.4}	{0.3, 0.2, 0.2}	{0.9, 0.7, 0.5}	{0.5, 0.4, 0.4}	{0.8, 0.6, 0.5}	{0.9, 0.8, 0.7}
GRC	{0.7, 0.4, 0.2}	{0.3, 0.2, 0.2}	{0.9, 0.7, 0.6}	{0.5, 0.4, 0.3}	{0.9, 0.8, 0.8}	{0.8, 0.7, 0.7}
GBR	{0.8, 0.6, 0.4}	{0.2, 0.1, 0.0}	{0.9, 0.7, 0.5}	{1.0, 0.9, 0.9}	{0.8, 0.6, 0.4}	{0.9, 0.8, 0.7}
IRL	{1.0, 0.7, 0.3}	{0.4, 0.2, 0.0}	{0.9, 0.7, 0.3}	{0.3, 0.3, 0.3}	{0.9, 0.6, 0.4}	{0.9, 0.8, 0.6}
ESP	{0.7, 0.5, 0.3}	{0.1, 0.0, 0.0}	{1.0, 0.8, 0.6}	{0.9, 0.8, 0.6}	{0.9, 0.8, 0.8}	{0.9, 0.8, 0.6}
SWE	{1.0, 0.8, 0.5}	{0.3, 0.1, 0.0}	{0.9, 0.8, 0.7}	{0.3, 0.3, 0.3}	{0.9, 0.8, 0.7}	{0.9, 0.8, 0.8}
ITA	{0.8, 0.6, 0.4}	{0.5, 0.2, 0.1}	{1.0, 0.8, 0.7}	{1.0, 0.8, 0.7}	{0.9, 0.7, 0.7}	{0.9, 0.8, 0.7}
CYP	{0.5, 0.3, 0.2}	{0.2, 0.1, 0.1}	{0.8, 0.7, 0.5}	{0.2, 0.2, 0.2}	{0.9, 0.8, 0.7}	{0.9, 0.8, 0.7}
LVA	{0.3, 0.2, 0.1}	{1.0, 0.8, 0.3}	{0.2, 0.1, 0.0}	{0.3, 0.2, 0.2}	{0.2, 0.1, 0.0}	{0.1, 0.0, 0.0}
LTU	{0.3, 0.2, 0.1}	{1.0, 0.9, 0.7}	{0.2, 0.1, 0.0}	{0.3, 0.2, 0.2}	{0.2, 0.1, 0.0}	{0.1, 0.0, 0.0}
LUX	{1.0, 0.9, 0.6}	{0.7, 0.5, 0.4}	{0.9, 0.7, 0.4}	{0.2, 0.2, 0.2}	{0.8, 0.6, 0.4}	{0.8, 0.7, 0.5}
HUN	{0.3, 0.2, 0.1}	{0.9, 0.8, 0.7}	{0.3, 0.1, 0.0}	{0.5, 0.4, 0.3}	{0.2, 0.1, 0.0}	{0.2, 0.1, 0.0}
MLT	{0.6, 0.3, 0.2}	{0.8, 0.4, 0.2}	{0.9, 0.7, 0.5}	{0.2, 0.2, 0.2}	{0.8, 0.7, 0.5}	{0.9, 0.8, 0.7}
POL	{0.2, 0.1, 0.1}	{0.6, 0.4, 0.3}	{0.6, 0.3, 0.1}	{1.0, 0.9, 0.7}	{0.5, 0.3, 0.1}	{0.4, 0.2, 0.1}
PRT	{0.6, 0.4, 0.2}	{0.1, 0.1, 0.1}	{0.9, 0.6, 0.3}	{0.5, 0.3, 0.3}	{0.9, 0.7, 0.5}	{0.8, 0.6, 0.4}
ROU	{0.2, 0.1, 0.1}	{0.8, 0.7, 0.5}	{0.2, 0.1, 0.0}	{1.0, 0.9, 0.7}	{0.2, 0.1, 0.0}	{0.2, 0.1, 0.0}
SVN	{0.5, 0.4, 0.2}	{0.4, 0.3, 0.2}	{0.9, 0.5, 0.2}	{0.2, 0.2, 0.2}	{0.8, 0.6, 0.3}	{0.8, 0.5, 0.3}
SVK	{0.3, 0.2, 0.1}	{0.9, 0.7, 0.5}	{0.5, 0.2, 0.1}	{0.4, 0.3, 0.3}	{0.5, 0.3, 0.1}	{0.4, 0.2, 0.1}

The positive ideal solution (A^+) and the negative ideal solution (A^-) for benefit-type criteria in Hesitant F-TOPSIS are defined by Xu and Zhang [22] and given as follows:

$$\begin{aligned} A^+ &= \left\{ x_j, \max_i \left\langle h_{ij}^{\sigma(\lambda)} \right\rangle \middle| j = 1, 2, \ldots, n \right\} \\ A^- &= \left\{ x_j, \min_i \left\langle h_{ij}^{\sigma(\lambda)} \right\rangle \middle| j = 1, 2, \ldots, n \right\} \end{aligned} \tag{1}$$

For cost-type criteria, positive and negative ideal solutions are defined as follows:

$$\begin{aligned} A^+ &= \left\{ x_j, \min_i \left\langle h_{ij}^{\sigma(\lambda)} \right\rangle \middle| j = 1, 2, \ldots, n \right\} \\ A^- &= \left\{ x_j, \max_i \left\langle h_{ij}^{\sigma(\lambda)} \right\rangle \middle| j = 1, 2, \ldots, n \right\} \end{aligned} \tag{2}$$

Types of decision-making criteria are defined as benefit (B) and cost (C), and positive and negative ideal solutions are given in Table 11.

Table 11. Positive and negative ideal solutions of the problem.

	C_1 (B)	C_2 (B)	C_3 (B)	C_4 (C)	C_5 (B)	C_6 (B)
A^+	{1.0, 0.9, 0.6}	{1.0, 0.9, 0.9}	{1.0, 0.8, 0.7}	{0.2, 0.2, 0.2}	{0.9, 0.8, 0.8}	{0.9, 0.8, 0.8}
A^-	{0.2, 0.1, 0.1}	{0.1, 0.0, 0.0}	{0.2, 0.1, 0.0}	{1.0, 0.9, 0.9}	{0.2, 0.1, 0.0}	{0.1, 0.0, 0.0}

Hwang and Yoon [14] proposed to use the Euclidian distance measure in TOPSIS. The Euclidian distance measure for the hesitant fuzzy environment was proposed by Xu and Xia [27]. In HF-TOPSIS, the distances of the ith alternative from the positive ideal solution (PIS) (d_i^+) and from the negative ideal solution (NIS) (d_i^-) are presented in the following form:

$$d_i^+ = \sum_{j=1}^{n} d\left(h_{ij}, h_j^+\right) w_j = \sum_{j=1}^{n} w_j \sqrt{\frac{1}{l} \sum_{\lambda=1}^{l} \left| h_{ij}^{\sigma(\lambda)} - \left(h_j^{\sigma(\lambda)}\right)^+ \right|^2} \tag{3}$$

$$d_i^- = \sum_{j=1}^{n} d\left(h_{ij}, h_j^-\right) w_j = \sum_{j=1}^{n} w_j \sqrt{\frac{1}{l} \sum_{\lambda=1}^{l} \left| h_{ij}^{\sigma(\lambda)} - \left(h_j^{\sigma(\lambda)}\right)^- \right|^2} \tag{4}$$

After calculating distances of alternatives from positive and negative ideal solutions, the ranking of alternatives is executed by using relative closeness coefficients. The relative closeness coefficient is calculated by using the following formula:

$$C_i = \frac{d_i^-}{d_i^+ + d_i^-} \tag{5}$$

By using this given formula, the distance of alternatives to positive and negative ideal solutions and relative closeness coefficients are calculated. Values of d_i^+, d_i^-, and C_i are given in Table 12.

Since the best country is the furthest from the negative ideal solution, the higher value of the relative closeness coefficient positions a country in the best rank. Therefore, the first country in Europe in terms of healthcare indicators is Austria. Austria is followed by Sweden and Finland.

Table 12. Distance of alternatives to PIS and NIS and relative closeness coefficients.

	d_i^+	d_i^-	C_i	Ranking
AUT	0.434	0.550	0.8536	1
BEL	0.991	1.097	0.7440	7
BGR	2.960	2.952	0.2771	26
CZE	2.086	2.181	0.5800	18
DNK	1.939	1.969	0.6087	16
EST	2.559	2.554	0.4343	22
FIN	0.579	0.733	0.7895	3
FRA	1.502	1.774	0.6411	13
DEU	1.323	1.558	0.6690	11
HRV	2.193	2.265	0.5292	19
NLD	1.197	1.310	0.6951	9
GRC	1.054	1.240	0.7309	8
GBR	2.258	2.451	0.5047	20
IRL	1.314	1.407	0.6863	10
ESP	1.723	1.977	0.6088	15
SWE	0.506	0.649	0.7956	2
ITA	1.436	1.670	0.6427	12
CYP	0.898	1.030	0.7481	6
LVA	2.799	2.723	0.3333	24
LTU	2.699	2.621	0.3610	23
LUX	0.809	0.900	0.7742	5
HUN	2.875	2.843	0.3330	25
MLT	0.722	0.812	0.7810	4
POL	2.978	3.125	0.2694	27
PRT	1.959	2.122	0.6034	17
ROU	3.154	3.220	0.1623	28
SVN	1.688	1.801	0.6241	14
SVK	2.417	2.451	0.4494	21

4. Comparative Analyses

4.1. Analysis of Using Different Distance Measures on HF-TOPSIS

Due to the type of problem data, measuring the distance to the ideal solution may require a different distance measure from Euclidian distance. In this section, this situation is analyzed. In addition to Euclidian distance, five other distance measures are introduced. These new measures are used for calculating the distance to the ideal solution of our application, and the obtained rankings of countries are compared. Readers who are interested in the details for these distance measures can refer to Liao et al.'s study [28]. We only give formulations for these measures and the results for our application.

Hamming distance:

$$d_{hd}\left(H_s^1(x_i), H_s^2(x_i)\right) = \frac{1}{L}\sum_{l=1}^{L}\frac{\left|\delta_l^1 - \delta_l^2\right|}{2\tau + 1} \tag{6}$$

Hamming–Hausdorff distance:

$$d_{hd}\left(H_s^1(x_i), H_s^2(x_i)\right) = \max_{l=1,2,\ldots,L} \frac{\left|\delta_l^1 - \delta_l^2\right|}{2\tau + 1} \tag{7}$$

Euclidian–Hausdorff distance:

$$d_{hd}\left(H_s^1(x_i), H_s^2(x_i)\right) = \left(\max_{l=1,2,\ldots,L} \left(\frac{\left|\delta_l^1 - \delta_l^2\right|}{2\tau + 1}\right)^2\right)^{1/2} \tag{8}$$

Hybrid Hamming distance:

$$d_{hd}\left(H_s^1(x_i), H_s^2(x_i)\right) = \frac{1}{2}\left(\frac{1}{L}\sum_{l=1}^{L} \frac{\left|\delta_l^1 - \delta_l^2\right|}{2\tau + 1} + \max_{l=1,2,\ldots,L} \frac{\left|\delta_l^1 - \delta_l^2\right|}{2\tau + 1}\right) \tag{9}$$

Hybrid Euclidian distance:

$$d_{hd}\left(H_s^1(x_i), H_s^2(x_i)\right) = \left(\frac{1}{2}\left(\frac{1}{L}\sum_{l=1}^{L} \left(\frac{\left|\delta_l^1 - \delta_l^2\right|}{2\tau + 1}\right)^2 + \max_{l=1,2,\ldots,L} \left(\frac{\left|\delta_l^1 - \delta_l^2\right|}{2\tau + 1}\right)^2\right)\right)^{1/2} \tag{10}$$

The ranking of countries by using the distances for each measure is given in Table 13.

Table 13. Ranking of countries obtained by different distance measures.

Country	Euclidian	Hamming	Hamming–Hausdorff	Euclidian–Hausdorff	Hybrid Hamming	Hybrid Euclidian
AUT	1	1	1	1	1	1
BEL	7	7	8	8	8	8
BGR	26	26	27	27	26	27
CZE	18	18	18	18	18	18
DNK	16	17	16	16	16	16
EST	22	22	21	21	22	22
FIN	3	2	4	4	3	3
FRA	13	12	13	13	13	13
DEU	11	11	11	11	11	11
HRV	19	19	19	19	19	19
NLD	9	10	9	9	9	9
GRC	8	8	7	7	7	7
GBR	20	20	20	20	20	20
IRL	10	9	10	10	10	10
ESP	15	16	14	14	15	15
SWE	2	3	2	2	2	2
ITA	12	13	12	12	12	12
CYP	6	6	5	5	6	6
LVA	24	24	25	25	25	25
LTU	23	23	23	23	23	23
LUX	5	5	6	6	5	5

Table 13. *Cont.*

Country	Euclidian	Hamming	Hamming–Hausdorff	Euclidian–Hausdorff	Hybrid Hamming	Hybrid Euclidian
HUN	25	25	24	24	24	24
MLT	4	4	3	3	4	4
POL	27	27	26	26	27	26
PRT	17	15	17	17	17	17
ROU	28	28	28	28	28	28
SVN	14	14	15	15	14	14
SVK	21	21	22	22	21	21

There are some differences in rankings when different measures are used to calculate the distance to ideal solutions. The first country is not changed, but the results for some countries vary by using one measure over the other. Using different distance measures may lead to different results in HF-TOPSIS applications.

4.2. Comparison of Rankings Obtained by the Proposed Approach and Deterministic TOPSIS

The decision matrix for this application is constructed by 20-year-average values of countries' scores in terms of the six healthcare indicators. The decision matrix is presented in Table 14.

After the construction of the decision matrix, vector normalization was applied to obtain a normalized decision matrix. Weights obtained by the HFLTS method were applied to the normalized decision matrix to calculate the weighted normalized decision matrix. Positive and negative ideal solutions were determined, and the distances of alternatives to ideal solutions were calculated by the Euclidian distance formula. Distances to ideal solution values were used to compute the relative distance to the ideal solution value for alternatives. The resulting value of this step indicates the ranking of countries. Distance ideal solutions (d_i^+ and d_i^-) and relative distance to ideal solution (C_i) values are given in Table 15, along with the ranking of countries.

According to the TOPSIS method, Luxemburg seems to be the best country in terms of healthcare indicators in Europe. However, in the proposed methodology, Luxemburg's ranking is fifth or sixth based on the distance measure. Austria has the first rank in the proposed methodology, but in deterministic TOPSIS, Austria has the second rank. Sweden obtained second and third ranks in HF-TOPSIS, but in deterministic TOPSIS, they had the ninth rank. The results vary between the hesitant fuzzy uncertain environment and certainty.

The ranking changes between HF-TOPSIS and deterministic TOPSIS are due to the difference in decision matrices. The decision matrix for HF-TOPSIS is constructed based on the opinions of experts in healthcare services, while deterministic TOPSIS utilizes a decision matrix of numerical values obtained from public databases. Since numerical values may be insufficient or misleading to show the real performance of an alternative, expert opinions can be more useful. This is the main advantage of the HF-TOPSIS approach over deterministic TOPSIS. On the other hand, decision matrices constructed based on experts' opinions may have subjective contents. In case of selection of experts, who share subjective opinions may lead to wrong consequences and this is the main disadvantage of the method.

Table 14. Decision matrix of the problem for TOPSIS.

	C_1	C_2	C_3	C_4	C_5	C_6
AUT	4023.02	8.21	79.64	381.05	91.32	83.11
BEL	3405.36	6.49	79.23	609.42	90.26	82.73
BGR	321.19	7.08	72.78	1096.58	85.03	68.25
CZE	944.98	8.02	76.44	506.63	89.03	76.69
DNK	4726.86	3.99	78.19	301.21	88.73	82.58
EST	648.89	6.27	73.16	98.32	85.77	63.47
FIN	3171.27	6.90	79.10	207.68	91.32	81.15
FRA	3708.00	7.57	80.55	3675.47	91.41	81.71
DEU	3804.03	8.70	79.19	3360.53	90.84	82.76
HRV	766.39	5.77	75.29	297.42	89.17	75.55
NLD	3918.23	4.84	79.64	981.63	90.47	86.21
GRC	1870.84	4.77	79.53	647.53	92.46	83.42
GBR	2909.75	3.87	79.29	4303.84	90.06	84.58
IRL	3352.93	4.64	78.98	340.37	90.54	84.56
ESP	2070.18	3.64	80.74	2355.89	93.08	84.40
SWE	4125.18	3.50	80.75	356.68	91.93	87.43
ITA	2653.57	4.32	81.08	2462.32	92.69	86.33
CYP	1469.78	3.79	78.83	61.89	92.21	85.98
LVA	549.67	7.79	71.85	260.00	83.28	59.02
LTU	578.98	8.41	72.39	301.21	84.42	60.04
LUX	5970.25	6.11	79.51	19.53	90.53	82.85
HUN	771.67	7.66	73.19	806.21	84.06	65.71
MLT	1431.15	5.66	79.62	28.95	91.02	86.50
POL	575.61	5.70	75.25	2941.26	87.46	70.72
PRT	1727.47	3.62	78.29	548.11	91.25	80.66
ROU	295.20	6.87	72.38	4370.63	84.02	66.96
SVN	1567.86	4.95	77.88	81.11	90.41	78.78
SVK	816.35	7.18	74.49	542.32	87.46	70.79

Table 15. Distance to ideal solutions and ranking of countries obtained by TOPSIS.

	d_i^+	d_i^-	C_i	**Ranking**
AUT	0.012588	0.103039	0.891133	2
BEL	0.020624	0.095964	0.823102	7
BGR	0.037916	0.082901	0.686172	21
CZE	0.025367	0.098327	0.794921	11
DNK	0.021636	0.103573	0.827200	4
EST	0.027332	0.106956	0.796466	10
FIN	0.015128	0.105777	0.874878	3
FRA	0.091632	0.030279	0.248372	26

Table 15. *Cont.*

	d_i^+	d_i^-	C_i	**Ranking**
DEU	0.083676	0.037989	0.312242	25
HRV	0.026923	0.102083	0.791307	13
NLD	0.030132	0.086802	0.742317	19
GRC	0.028628	0.093745	0.766059	17
GBR	0.109268	0.016314	0.129908	27
IRL	0.021810	0.101907	0.823712	6
ESP	0.064021	0.052151	0.448914	22
SWE	0.024448	0.102061	0.806751	9
ITA	0.065000	0.050346	0.436476	23
CYP	0.028047	0.108044	0.793911	12
LVA	0.027653	0.103822	0.789672	15
LTU	0.027269	0.103291	0.791142	14
LUX	0.010988	0.112020	0.910675	1
HUN	0.031721	0.090421	0.740298	20
MLT	0.023148	0.109233	0.825139	5
POL	0.077673	0.037140	0.323486	24
PRT	0.030910	0.095849	0.756149	18
ROU	0.111677	0.014373	0.114023	28
SVN	0.024786	0.107440	0.812551	8
SVK	0.027530	0.096646	0.778298	16

5. Conclusions

In this study, a hybrid decision-making approach based on HFLTS and TOPSIS is proposed to rank 28 EU countries in terms of healthcare development indicators. Hesitant Fuzzy Linguistic Terms Set was used to cope with the hesitancy of decision makers. Within the proposed methodology, HFLTS-based group decision making is used to determine selection criteria weights, and HF-TOPSIS is used to rank the countries. An application of different distance measures in HF-TOPSIS and a comparison of rankings between HF-TOPSIS and original TOPSIS with the certainty assumption are also presented. This approach can be used in decision problems with conflicting decision-making criteria and non-dominating alternatives under a hesitant fuzzy environment.

Healthcare services are essential for the well-being of people in countries. Governments and international organizations devote substantial efforts to the improvement of healthcare services. Therefore, the comparison of healthcare services between countries should be considered an important issue. Since the main aim of the EU is to eliminate differences between their member states and improve the economic and living standards throughout the community, ranking healthcare services among EU members would help with policy making in the region. By the presented case study, a ranking model which provides an analytical basis for these processes is proposed.

There are some ranking differences between HF-TOPSIS and deterministic TOPSIS. The differences are due to the utilization of different decision matrices for these applications. HF-TOPSIS takes the existence of vagueness and uncertainty in life into account, which is an important consideration that must be included in decision-making processes. Deterministic TOPSIS uses an average score for each country based on 20 years of data. We conclude that the proposed model is superior to deterministic TOPSIS.

This is the first study to present a multi-criteria ranking model for countries in terms of healthcare services. Since the aim of the EU is to eliminate differences between their member states, improvement policies for healthcare systems in countries at lower rankings can be developed based on the results of the study. Moreover, this study may lead the way for researchers to focus on the comparison of countries by using MCDM models.

Criteria taken into consideration for MCDM analyses may vary from one study to another. Thus, different applications on the same problem may provide different results. Since the study takes only six indicators into account, further studies may focus on the consideration of different and more criteria in the analysis. Furthermore, in the aggregation procedure of experts' opinions on criteria, opinions of all the experts are assumed to be same. This assumption can be generalized by the application of weighting in the aggregation procedure. Moreover, since the criteria weights are effective in the ranking results, the changes in criteria weights can be analyzed as a sensitivity analysis. Finally, rankings obtained by different MCDM approaches such as MARCOS, MULTIMOORA, VIKOR, ELECTRE, and PROMETHEE can be compared with TOPSIS.

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