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A Novel Combined Fuzzy MCDM Approach Based on IMF-SWARA and F-CODAS for Consulting Firm Selection

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ABSTRACT

In today's challenging industry conditions, where being good is not enough to be successful, companies trying to be the best need consultancy in different fields. Consulting firms provide consultancy services to businesses, and they need to determine the most appropriate one for them. Fuzzy MCDM (Multi Criteria Decision Making) methods are appropriate to solve consulting firm selection problem. In this study, consulting firm selection problem of a textile company operating in Istanbul, Turkey is introduced by using a novel combined fuzzy MCDM method based on IMF-SWARA (Improved Fuzzy Stepwise Weight Assessment Ratio Analysis) and F-CODAS (Fuzzy COmbinative Distance-based Assessment) methods. The importance weights of the criteria are calculated with IMF-SWARA method. Findings indicate that the top three important criteria are experience, references, and reliability, respectively. Then, F-CODAS method is used to rank the consulting firms and the best one is presented to the Human Resources (HR) department of the textile company. This study contributes to the existing literature in various aspects. It suggests a novel combined fuzzy MCDM method to solve consulting firm selection and a new Fuzzy CODAS based on Triangular Fuzzy Numbers (TFNs) is proposed. Moreover, HR managers can use the findings of this study to evaluate consulting firms.

Keywords: Fuzzy Multi Criteria Decision Making, IMF-SWARA, F-CODAS, Consulting Firm Selection.

JEL Classification Codes: C44, M10, O15

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INTRODUCTION

A consulting firm can be described as a professional service firm providing advice to an organization for a specified fee. A consulting firm consists of consultants who are experts in various fields (El-Santawy & El-Dean, 2012: 126). There are numerous reasons companies really need consulting firms. Companies generally focus on their day-to-day operations and their core activity. Moreover, it is inevitable that companies can face problems and they demand guidance in various area. At this point, consulting firms offer great solutions to businesses. After a company decides to hire a consulting firm according to the needs of the organization, it focuses an evaluation and selection problem among various consulting firms and this problem can be solved using MCDM tools (Tuş Işık & Aytaç Adalı, 2016: 56). Until today, many MCDM tools were used for the selection of the consulting firm in the literature. Tsai et al. (2007) used AHP to solve ERP consultant selection problem. Saremi et al. (2009) solved external consultant selection problem using F-TOPSIS. El-Santawy & El-Dean (2012) applied the SDV and MOORA approach to selection of a consulting firm. Tuş Işık and Aytaç Adalı (2016) applied UTA method to consulting firm selection problem. Razi et al. (2020) have handled consultant selection problem with the AHP method. Avikal et al. (2022) have solved the problem of consultant selection in ERP projects using hybrid method based on F-AHP and COPRAS-G. Nomir and Hammad (2023) used qualifications-based selection and fuzzy TOPSIS to select engineering consultants.

This study aims to integrate theory with practice and select the best consulting firm for the textile company which is operated in İstanbul, Turkey. For this purpose, a novel combined IMF-SWARA and F-CODAS approach has been used. Selection of consulting firm problem can be affected by uncertain and imprecise data, and it should be noted that not only quantitative objectives, but also qualitative objectives are considered in this problem (Kabir and Sumi, 2014: 381). As stated by Sporrong (2011), it is generally difficult to evaluate qualitative criteria related to consultant firms. According to Razi et al. (2020), selecting the best consultant firm is a very complex problem and generally includes qualitative criteria. Therefore, fuzzy set based MCDM method is used in this study.

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A study introduced by Peker and Görener (2023), in which they applied improved fuzzy SWARA and fuzzy CODAS methods to determine the new facility location of a company. Differently from the other papers in the literature, this study applied a combination of IMF-SWARA and F-CODAS method to select consulting firm. The contributions of this study are threefold. Firstly, this study aims to implement a novel combined fuzzy MCDM method based on IMF-SWARA and F-CODAS to consulting firm selection problem. The second contribution is to use IMF-SWARA which is proposed by Vrtagić et al. (2021) to avoid the use of inadequate linguistic scale of original fuzzy SWARA. Third one is the application of F-CODAS method with triangular fuzzy numbers (TFNs) demonstrated in this study. Additionally, the real-life application about consulting firm selection based on fuzzy MCDM can be a new reference for practitioners and researchers.

The content of the study is given as follows: First, research methods including fuzzy set theory, IMF-SWARA and F-CODAS are presented. Then, the real-life application is given. At the end, conclusion and recommendation for further studies are presented.

RESEARCH METHODS

The fuzzy set theory, IMF-SWARA method, and F-CODAS method are introduced in this part.

Fuzzy Set Theory

In daily life, some expressions such as "probably so", "very likely", "not very clear" can be heard. These expressions have a common point in that they include uncertainty (Tsaur et al., 2002: 109). Fuzzy set theory was proposed by Zadeh (1965) to overcome imprecision of human thought. Moreover, Bellman & Zadeh (1970) introduced decision making in fuzzy environment. Fuzzy decision-making theory is covered in this MCDM study.

Triangular Fuzzy Numbers (TFNs)

TFN can be defined as (l,m,u), where $l \le m \le u$. TFN $\tilde{M}$ is demonstrated in Figure 1 (Kahraman et al., 2004: 174).

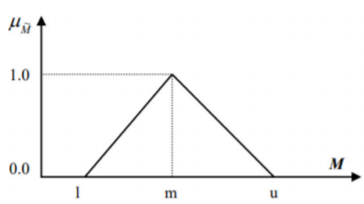

Figure 1. Geometric space of TFN

The membership function of a triangular fuzzy number $\tilde{M} = (l, m, u)$ is given as in equation 1 (Guo & Zhao, 2017: 24):

$$\mu_{\tilde{M}}(x) = \begin{cases} 0, & x < l \\ \frac{(x-l)}{(m-l)}, & l \le x < m \\ \frac{(u-x)}{(u-m)}, & m \le x \le u \\ 0, & x > u \end{cases} \quad (1)$$

Basic algebraic operations of the two positive TFN $\tilde{X} = (l_1, m_1, u_1)$ and $\tilde{Y} = (l_2, m_2, u_2)$ are shown in equations 2 - 10 (Ecer, 2015: 6):

$$\tilde{X} \oplus \tilde{Y} = (l_1 + l_2,\ m_1 + m_2,\ u_1 + u_2) \quad (2)$$

$$\tilde{X} \ominus \tilde{Y} = (l_1 - u_2,\ m_1 - m_2,\ u_1 - l_2) \quad (3)$$

$$\tilde{X} \otimes \tilde{Y} = (l_1.l_2,\ m_1.m_2,\ u_1.u_2) \quad (4)$$

$$\tilde{X} \otimes k = (l_1, m_1, u_1) \otimes k = (l_1.k,\ m_1.k, u_1.k) \quad (5)$$

In equation 5, $k \ge 0$

$$\tilde{X} \otimes k = (l_1, m_1, u_1) \otimes k = (u_1.k,\ m_1.k,\ l_1.k) \quad (6)$$

In equation 6, $k < 0$

$$\tilde{X} \oslash \tilde{Y} = (l_1/u_2,\ m_1/m_2,\ u_1/l_2) \quad (7)$$

$$\tilde{X} \oslash k = (l_1, m_1, u_1) \oslash k = (l_1/k,\ m_1/k, u_1/k) \quad (8)$$

In equation 8, $k > 0$

$$\tilde{X} \oslash k = (l_1, m_1, u_1) \oslash k = (u_1/k,\ m_1/k, l_1/k) \quad (9)$$

In equation 9, $k < 0$

$$\tilde{X}^{-1} = (1/u_1,\ 1/m_1,\ 1/l_1) \quad (10)$$

TFN $\tilde{A}$ is defuzzified by using equation 11 (Perçin, 2019: 535):

$$d(\tilde{X}) = \frac{l_1 + m_1 + u_1}{3} \quad (11)$$

IMPROVED FUZZY SWARA

SWARA method has been proposed by Kersuliene et al. in 2010 to assess criteria weights. Incomplete, inaccessible, or uncertain types of information make it difficult to be certain in the decision-making process. Hence, fuzzy MCDM methods were developed to effectively address the problems associated with such imprecise information. Mavi et al. (2017) extended SWARA method to F-SWARA. As seen in previous studies in the literature, it is thought that there is a complexity regarding the use of linguistic scales for the F-SWARA method. In order to fill this gap and prevent misuse of linguistic scales, Vrtagić et al. (2021) has proposed improved fuzzy SWARA (IMF-SWARA). The current literature shows that researchers

Table 1. Fuzzy linguistic scale

Linguistic variable	Abbreviation	TFNs
Equally important	(EI)	(1, 1, 1)
Moderately less important	(MOLI)	(2/3, 1, 3/2)
Less important	(LI)	(2/5, 1/2, 2/3)
Very less important	(VLI)	(2/7, 1/3, 2/5)
Much less important	(MULI)	(2/9, 1/4, 2/7)

Source: Chang (1996)

Table 2. New fuzzy linguistic scale of IMF-SWARA

Linguistic variable	Abbreviation	Response Scale
Equally significant	(ES)	(0, 0, 0)
Weakly less significant	(WLS)	(2/9, 1/4, 2/7)
Moderately less significant	(MDLS)	(1/4, 2/7, 1/3)
Less significant	(LS)	(2/7, 1/3, 2/5)
Really less significant	(RLS)	(1/3, 2/5, 1/2)
Much less significant	(MLS)	(2/5, 1/2, 2/3)
Dominantly less significant	(DLS)	(1/2, 2/3, 1)
Absolutely less significant	(ALS)	(1, 1, 1)

Source: Vrtagić et al. (2021)

used IMF-SWARA method to analyze different topics. Vrtagić et al. (2021) applied the IMF-SWARA method to evaluate the safety degree of the observed road sections. Zolfani et al. (2021) used IMF-SWARA and fuzzy MABAC methods to evaluate logistics villages in Turkey. Stević et al. (2022) applied IMF-SWARA and EDAS model based on the Bonferroni operator for the ranking of road infrastructure sections considering buses. Puška et al. (2023) determined the weights of criteria in selecting suppliers using IMF-SWARA. Moslem et al. (2023) applied IMF- SWARA and Fuzzy Bonferroni operator to determine significance of the supply quality elements of urban bus transport services.

The difference between SWARA and the IMF-SWARA relates to TFN scale. Vrtagić et al. (2021) have stated that the initial F-SWARA method has not been well conceived and have proved that with two examples. Accordingly, in evaluation process of criteria, although it is indicated that two criteria have equal importance by decision makers (DMs), fuzzy SWARA method results do not support this evaluation. On the other hand, the new fuzzy linguistic scale of IMF-SWARA method has overcome this shortcoming (Vrtagić et al., 2021). For this reason, the IMF-SWARA method proposed by Vrtagić et al. (2021) has been used in this study. The distinction between F-SWARA and IMF-SWARA is based on linguistic scale and other steps are similar. For more details relating to IMF-SWARA, readers can refer to Vrtagić et al. (2021). The IMF-SWARA method has five steps as below (Mavi et al., 2017: 2405-2407; Vrtagić et al., 2021: 6-7):

Step 1: Firstly, criteria have been selected, and according to the significance level all criteria are ranked.

Step 2: Considering the previously determined rank, each decision-maker determines the relative significance of the criterion (*j*) based on the earlier one (*j*-1). Then, the process is repeated. This ratio is expressed with S_j and indicates the comparative significance of the average value. Table 1 indicates the linguistic scale developed by Chang (1996) which is used in many previous studies about F-SWARA in the literature and Table 2 shows new linguistic scale which is developed for IMF-SWARA.

$\tilde{s}_j$ is known as the comparative importance and denotes the evaluation of decision maker for the criterion *j*.

$$\tilde{s}_j = \left(s_j^l, s_j^m, s_j^u\right) \tag{12}$$

In the literature values are calculated by aggregating the evaluations. However, usually it is quite difficult to quite difficult to obtain a common ranking. On the other hand, researchers can face a problem that the rank of importance is quite different and complex in the questionnaire results. Hence, in this study an aggregated evaluation is performed, and average fuzzy weights are obtained using the arithmetic mean.

Step 3. The fuzzy coefficients are determined by using equation 13.

$$\tilde{k}_j = \begin{cases} \tilde{1}, & j = 1 \\ \tilde{s}_j + \tilde{1}, & j > 1 \end{cases} \quad (13)$$

where triangular fuzzy number $\tilde{1} = (1,1,1)$.

Step 4. Fuzzy weights are calculated with the help of equation 14.

$$\tilde{q}_j = \begin{cases} \tilde{1}, & j = 1 \\ \frac{\tilde{q}_{j-1}}{\tilde{k}_j}, & j > 1 \end{cases} \quad (14)$$

Step 5. Final weights of criteria are calculated by equation 15.

$$\tilde{w}_j = \frac{\tilde{q}_j}{\sum_{k=1}^{n} \tilde{q}_k} \quad (15)$$

where $\tilde{w}_j = (\tilde{w}_j^l, \tilde{w}_j^m, \tilde{w}_j^u)$ is the final fuzzy weight of the criterion j.

F-CODAS

Keshavarz Ghorabaee et al. (2016) proposed CODAS method and later fuzzy CODAS method was proposed by Keshavarz Ghorabaee et al. (2017). Assessment scores of alternatives are determined using Euclidean and Taxicab distances in CODAS method. The Euclidean and Taxicab distances cannot be used in fuzzy environment. Hence, in F-CODAS method fuzzy weighted Euclidean and Hamming distances are used (Keshavarz Ghorabaee et al., 2017: 7).

Various fuzzy numbers are used according to different subjects, and TFNs and trapezoidal fuzzy numbers (TrFNs) are the commonly used in fuzzy MCDM applications (Musani and Jemain, 2013: 1007). Hadi-Vencheh and Mokhtarian (2011) stated that TFNs are particular cases of TrFNs and the general statement is that if the middle two fuzzy numbers are the same, TrFNs transform to TFNs. The original F-CODAS method used TrFNs. However, for the sake of ease of operation and simplicity, differently from the original F-CODAS, TFNs are used in this study.

The scholars used F-CODAS for solving different problems in literature. Keshavarz Ghorabaee et al. (2017) proposed F-CODAS for market segments evaluation and selection. Personnel selection problem has been introduced with Atanassov intuitionistic F-CODAS method by Yeni and Özçelik (2019). For the same purpose, Yalçın and Yapıcı Pehlivan (2019) used the F-CODAS. Katrancı and Kundakcı (2020) applied the F-CODAS method to assess ten cryptocurrency alternatives. Ulutaş (2021) handled supplier selection problem using F-CODAS. Peker and Görener (2023) applied improved fuzzy SWARA and fuzzy CODAS methods to determine the new facility location of a company.

The steps of the F-CODAS method are summarized below (Keshavarz Ghorabaee et al., 2017: 7-9):

Step 1: Alternatives are determined, and DMs express their assessments by the linguistic terms in Table 3. Later, the average fuzzy decision matrix is constructed as seen in equation 16 using equation 17.

$$\tilde{X} = [\tilde{x}_{ij}]_{mxn} = \begin{bmatrix} \tilde{x}_{11} & \tilde{x}_{12} & \cdots & \tilde{x}_{1n} \\ \tilde{x}_{21} & \tilde{x}_{22} & \cdots & \tilde{x}_{2n} \\ \vdots & \vdots & \cdots & \vdots \\ \tilde{x}_{m1} & \tilde{x}_{m2} & \cdots & \tilde{x}_{mn} \end{bmatrix} \quad (16)$$

$$\tilde{x}_{ij} = (x_{ij}^l, x_{ij}^m, x_{ij}^u) = \left(\frac{\sum_{k=1}^{K} x_{ijk}^l}{K}, \frac{\sum_{k=1}^{K} x_{ijk}^m}{K}, \frac{\sum_{k=1}^{K} x_{ijk}^u}{K} \right) \quad (17)$$

In which $\tilde{x}_{ij}$ indicates the average fuzzy performance value of i^{th} alternative for j^{th} criterion and k is the number of DMs.

Table 3. Linguistic terms and TFNs

Linguistic Variables	Abbreviation	TFNs
Very Poor	(VP)	(0, 0, 1)
Poor	(P)	(0, 1, 3)
Medium Poor	(MP)	(1, 3, 5)
Fair	(F)	(3, 5, 7)
Medium Good	(MG)	(5, 7, 9)
Good	(G)	(7, 9, 10)
Very Good	(VG)	(9, 10, 10)

Source: Chen (2000)

Step 2: Fuzzy normalized decision matrix $\tilde{N}$ is obtained as expressed between equations 18-20:

$$\tilde{N} = [\tilde{n}_{ij}]_{mxn} \tag{18}$$

$$\tilde{n}_{ij} \begin{cases} \frac{\tilde{x}_{ij}}{\max(\tilde{x}_{ij})} & \text{if } j \in \text{Benefit} \quad (19) \\ 1 - \left(\frac{\tilde{x}_{ij}}{\max(\tilde{x}_{ij})}\right) & \text{if } j \in \text{Cost} \quad (20) \end{cases}$$

Step 3: Fuzzy weighted normalized decision matrix $\tilde{R}$ is obtained. The fuzzy weighted normalized performance values $\tilde{r}_{ij}$ are calculated by using equations 21 and 22:

$$\tilde{R}[\tilde{r}_{ij}]_{mxn} \tag{21}$$

$$\tilde{r}_{ij} = (\tilde{w}_j \otimes \tilde{n}_{ij}) \tag{22}$$

Step 4: Fuzzy negative ideal solution is obtained using the equations 23 and 24:

$$\widetilde{NS} = [\widetilde{ns}_j]_{1xn} \tag{23}$$

$$\widetilde{ns}_j = \min_i \tilde{r}_{ij} \tag{24}$$

Step 5: Fuzzy weighted Euclidean (ED_i) and fuzzy weighted Hamming (HD_i) distances are calculated. Let two triangular fuzzy numbers be $\tilde{A}_1 = (l_1, m_1, u_1)$ and $\tilde{B} = (l_2, m_2, u_2)$. The fuzzy weighted Euclidean (ED_i) distance is calculated by using equations 25 and 26 (Roszkowska & Wachowicz, 2015: 6):

$$d_E(\tilde{A}, \tilde{B}) = \sqrt{\frac{(l_1-l_2)^2+2(m_1-m_2)^2+(u_1-u_2)^2}{4}} \tag{25}$$

$$ED_i = \sum_{j=1}^{n} d_E(\tilde{r}_{ij}, \widetilde{ns}_j) \tag{26}$$

where d_E denotes weighted Euclidean distance.

HD_i is calculated as seen in equation 27 and 28 (Roszkowska & Wachowicz, 2015: 6):

$$d_H(\tilde{A}, \tilde{B}) = \frac{|l_1-l_2|+2|m_1-m_2|+|u_1-u_2|}{4} \tag{27}$$

$$HD_i = \sum_{j=1}^{n} d_H(\tilde{r}_{ij}, \widetilde{ns}_j) \tag{28}$$

where d_H denotes weighted Hamming distance.

Step 6: Relative assessment matrix (RA) is established by using equations 29 and 30.

$$RA = [p_{ik}]_{mxm} \tag{29}$$

$$p_{ik} = (ED_i - ED_k) + (t(x).(HD_i - HD_k)) \tag{30}$$

Where, $k \in \{1,2, \ldots, m\}$ *and* t is a threshold function. It is calculated by equation 31:

$$t(x) = \begin{cases} 1, \text{if } |ED_i - ED_k| \geq \theta \\ 0, \text{if } |ED_i - ED_k| < \theta \end{cases} \tag{31}$$

The threshold parameter (θ) is in the range of 0.01 - 0,05 and determined by DMs (Keshavarz Ghorabaee et al., 2017: 9). Based on the literature, we utilize θ= 0.02 in this study.

Step 7: Assessment score (AS_i) of each alternative is calculated as seen in equation 32.

$$AS_i = \sum_{k=1}^{m} p_{ik} \tag{32}$$

Step 8: Finally, alternatives are ranked in descending order of AS_i. The highest AS_i shows the best alternative.

APPLICATION

The consulting firm selection problem of a textile company which is operated in İstanbul is introduced with a novel combined fuzzy MCDM approach in this study. This approach is based on the IMF-SWARA and F-CODAS method. The flowchart of the combined fuzzy MCDM method is given in Figure 2.

The Human Resources department of the textile company wants to select the best consulting firm to train its employees in the field of personal development. For this purpose, a decision committee is formed to define the criteria and then they evaluate the alternative consulting firms. This decision committee consists of 5 DMs. Table 4 shows the background information of DMs.

Table 4. Demographic characteristics of DMs

	Age	Gender	Education level	Position	Working duration
DM_1	34	Female	Bachelor	HR specialist	8 years
DM_2	39	Male	Bachelor	HR specialist	15 years
DM_3	45	Female	Master	HR manager	20 years
DM_4	35	Female	Bachelor	HR specialist	7 years
DM_5	40	Male	Master	HR specialist	14 years

After preliminary screening, three alternative consulting firms are determined. Table 5 shows the information about alternative consulting firms.

Table 5. Background information of alternatives

	Experience in the sector	Firm size
A_1	24 years	103 employees
A_2	12 years	56 employees
A_3	15 years	35 employees

Criteria determination have been made by circulating questions and answers of the DMs and researchers. Later, ten criteria have been identified with group decision. These criteria are seen in Table 6.

Table 6. Decision Criteria

C_1	Experience
C_2	Reputation
C_3	Reliability
C_4	References
C_5	Professional knowledge
C_6	Technical skills / certificates
C_7	Managerial skills
C_8	Communication skills
C_9	Consulting Fee
C_{10}	Team quality

Decision committee evaluated all criteria individually. To obtain the weights of the evaluation criteria steps of the IMF-SWARA method are followed. Criteria are ranked according to their significance and each DMs express the relative significance of the criterion j according to the previous criterion j-1 with fuzzy linguistic scale as in Table 2. Evaluation outcomes of the 5 DMs are given between Table 7 and 11. For each decision maker, $\tilde{s}_j$ values are obtained as seen in equation 12, then $\tilde{k}_j$ values are obtained by equation 13. Later, fuzzy weights $\tilde{q}_j$ are determined by using equation 14. At the end, the final weights of all the criteria are calculated via equation 15.

Table 7. Evaluation results of DM_1

	$\tilde{s}_j$			$\tilde{k}_j$			$\tilde{q}_j$			$\tilde{w}_j$		
	l	***m***	***u***	***l***	***m***	***u***	***l***	***m***	***u***	***l***	***m***	***u***
C_1				1.000	1.000	1.000	1.000	1.000	1.000	0.147	0.153	0.160
C_3	0.000	0.000	0.000	1.000	1.000	1.000	1.000	1.000	1.000	0.147	0.153	0.160
C_4	0.000	0.000	0.000	1.000	1.000	1.000	1.000	1.000	1.000	0.147	0.153	0.160
C_9	0.000	0.000	0.000	1.000	1.000	1.000	1.000	1.000	1.000	0.147	0.153	0.160
C_5	0.286	0.333	0.400	1.286	1.333	1.400	0.714	0.750	0.778	0.105	0.115	0.125
C_{10}	0.222	0.250	0.286	1.222	1.250	1.286	0.556	0.600	0.636	0.082	0.092	0.102
C_6	0.286	0.333	0.400	1.286	1.333	1.400	0.397	0.450	0.495	0.058	0.069	0.079
C_8	0.333	0.400	0.500	1.333	1.400	1.500	0.265	0.321	0.371	0.039	0.049	0.059
C_7	0.286	0.333	0.400	1.286	1.333	1.400	0.189	0.241	0.289	0.028	0.037	0.046
C_2	0.333	0.400	0.500	1.333	1.400	1.500	0.126	0.172	0.217	0.019	0.026	0.035
$\Sigma\tilde{q}_j$							6.246	6.535	6.786			

Table 8. Evaluation results of DM_2

	$\tilde{s}_j$			$\tilde{k}_j$			$\tilde{q}_j$			$\tilde{w}_j$		
	l	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*
C_4				1.000	1.000	1.000	1.000	1.000	1.000	0.174	0.185	0.202
C_1	0.000	0.000	0.000	1.000	1.000	1.000	1.000	1.000	1.000	0.174	0.185	0.202
C_9	0.333	0.400	0.500	1.333	1.400	1.500	0.667	0.714	0.750	0.116	0.132	0.152
C_2	0.000	0.000	0.000	1.000	1.000	1.000	0.667	0.714	0.750	0.116	0.132	0.152
C_3	0.000	0.000	0.000	1.000	1.000	1.000	0.667	0.714	0.750	0.116	0.132	0.152
C_5	0.500	0.667	1.000	1.500	1.667	2.000	0.333	0.429	0.500	0.058	0.079	0.101
C_7	0.222	0.250	0.286	1.222	1.250	1.286	0.259	0.343	0.409	0.045	0.063	0.083
C_6	0.286	0.333	0.400	1.286	1.333	1.400	0.185	0.257	0.318	0.032	0.048	0.064
C_{10}	1.000	1.000	1.000	2.000	2.000	2.000	0.093	0.129	0.159	0.016	0.024	0.032
C_8	0.250	0.286	0.333	1.250	1.286	1.333	0.069	0.100	0.127	0.012	0.019	0.026
$\Sigma\tilde{q}_j$							4.940	5.400	5.764			

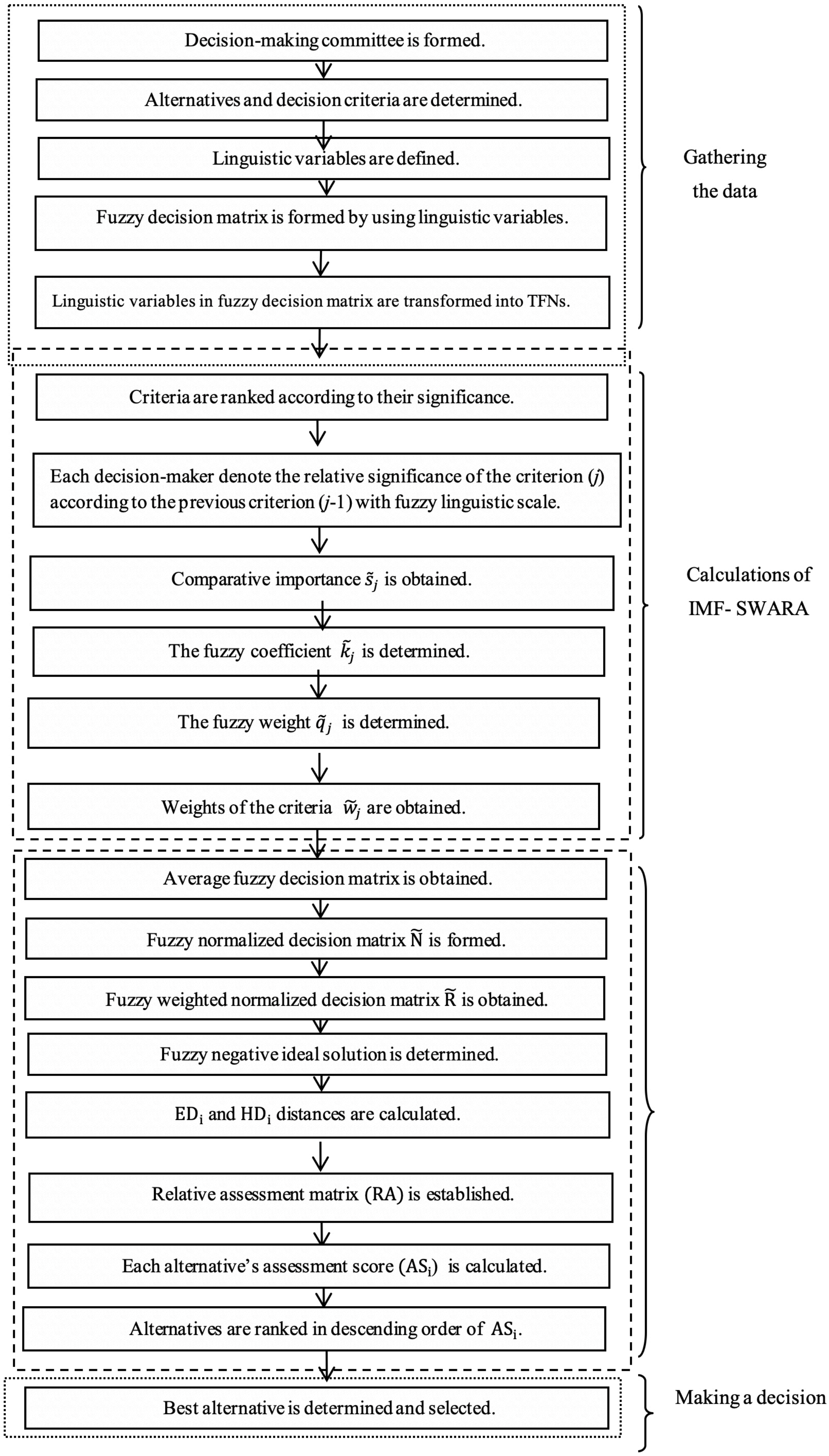

Figure 2. Flowchart of the combined fuzzy MCDM method

Table 9. Evaluation results of DM_3

	$\tilde{s}_j$			$\tilde{k}_j$			$\tilde{q}_j$			$\tilde{w}_j$		
	l	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*
C_1				1.000	1.000	1.000	1.000	1.000	1.000	0.212	0.220	0.231
C_4	0.000	0.000	0.000	1.000	1.000	1.000	1.000	1.000	1.000	0.212	0.220	0.231
C_5	0.222	0.250	0.286	1.222	1.250	1.286	0.778	0.800	0.818	0.165	0.176	0.189
C_8	0.286	0.333	0.400	1.286	1.333	1.400	0.556	0.600	0.636	0.118	0.132	0.147
C_2	1.000	1.000	1.000	2.000	2.000	2.000	0.278	0.300	0.318	0.059	0.066	0.073
C_3	0.000	0.000	0.000	1.000	1.000	1.000	0.278	0.300	0.318	0.059	0.066	0.073
C_6	0.222	0.250	0.286	1.222	1.250	1.286	0.216	0.240	0.260	0.046	0.053	0.060
C_7	0.400	0.500	0.667	1.400	1.500	1.667	0.130	0.160	0.186	0.027	0.035	0.043
C_9	0.500	0.667	1.000	1.500	1.667	2.000	0.065	0.096	0.124	0.014	0.021	0.029
C_{10}	1.000	1.000	1.000	2.000	2.000	2.000	0.032	0.048	0.062	0.007	0.011	0.014
$\Sigma\tilde{q}_j$							4.332	4.544	4.723			

Table 10. Evaluation results of DM_4

	$\tilde{s}_j$			$\tilde{k}_j$			$\tilde{q}_j$			$\tilde{w}_j$		
	l	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*
C_4				1.000	1.000	1.000	1.000	1.000	1.000	0.179	0.191	0.206
C_9	0.222	0.250	0.286	1.222	1.250	1.286	0.778	0.800	0.818	0.139	0.153	0.169
C_{10}	0.222	0.250	0.286	1.222	1.250	1.286	0.605	0.640	0.669	0.108	0.122	0.138
C_3	0.250	0.286	0.333	1.250	1.286	1.333	0.454	0.498	0.536	0.081	0.095	0.111
C_1	0.000	0.000	0.000	1.000	1.000	1.000	0.454	0.498	0.536	0.081	0.095	0.111
C_7	0.000	0.000	0.000	1.000	1.000	1.000	0.454	0.498	0.536	0.081	0.095	0.111
C_6	0.000	0.000	0.000	1.000	1.000	1.000	0.454	0.498	0.536	0.081	0.095	0.111
C_5	0.400	0.500	0.667	1.400	1.500	1.667	0.272	0.332	0.383	0.049	0.063	0.079
C_8	0.222	0.250	0.286	1.222	1.250	1.286	0.212	0.265	0.313	0.038	0.051	0.065
C_2	0.222	0.250	0.286	1.222	1.250	1.286	0.165	0.212	0.256	0.030	0.041	0.053
$\Sigma\tilde{q}_j$							4.846	5.241	5.581			

Table 11. Evaluation results of DM_5

	$\tilde{s}_j$			$\tilde{k}_j$			$\tilde{q}_j$			$\tilde{w}_j$		
	l	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*
C_3				1.000	1.000	1.000	1.000	1.000	1.000	0.228	0.235	0.245
C_1	0.000	0.000	0.000	1.000	1.000	1.000	1.000	1.000	1.000	0.228	0.235	0.245
C_4	1.000	1.000	1.000	2.000	2.000	2.000	0.500	0.500	0.500	0.114	0.118	0.122
C_{10}	0.286	0.333	0.400	1.286	1.333	1.400	0.357	0.375	0.389	0.081	0.088	0.095
C_2	0.000	0.000	0.000	1.000	1.000	1.000	0.357	0.375	0.389	0.081	0.088	0.095
C_8	0.222	0.250	0.286	1.222	1.250	1.286	0.278	0.300	0.318	0.063	0.071	0.078
C_5	0.250	0.286	0.333	1.250	1.286	1.333	0.208	0.233	0.255	0.048	0.055	0.062
C_7	0.333	0.400	0.500	1.333	1.400	1.500	0.139	0.167	0.191	0.032	0.039	0.047
C_9	0.000	0.000	0.000	1.000	1.000	1.000	0.139	0.167	0.191	0.032	0.039	0.047
C_6	0.250	0.286	0.333	1.250	1.286	1.333	0.104	0.130	0.153	0.024	0.031	0.037
$\Sigma\tilde{q}_j$							4.082	4.246	4.385			

Table 12. Average fuzzy weights of the criteria

		l	*m*	*u*	Defuzzified Weights
C_1	Experience	0.168	0.178	0.190	0.179
C_2	Reputation	0.061	0.071	0.082	0.071
C_3	Reliability	0.126	0.136	0.148	0.137
C_4	References	0.165	0.173	0.184	0.174
C_5	Professional knowledge	0.085	0.098	0.111	0.098
C_6	Technical skills / certificates	0.048	0.059	0.070	0.059
C_7	Managerial skills	0.043	0.054	0.066	0.054
C_8	Communication skills	0.054	0.064	0.075	0.064
C_9	Consulting Fee	0.090	0.100	0.111	0.100
C_{10}	Team quality	0.059	0.067	0.076	0.067

The arithmetic means of the evaluation results of the 5 DMs are calculated to obtain the average fuzzy weight values for all criteria. The obtained average fuzzy weights are given on Table 12 and defuzzified weights are calculated using equation 11.

According to the outcomes of the study, C_1: Experience (0.179) and C_4: References (0.174) are the most significant criteria and C_7: Managerial Skills (0.054) is the least significant criterion. According to this, C_7: Managerial Skills criterion may be ignored in future studies on this subject.

There are some studies in literature that solved the same problem with MCDM. El-Santawy & El-Dean (2012) have revealed that Expected Growth and Current Cost are the most important criteria while Company Size is the least important criterion. A similar study of Kabir and Sumi (2014) demonstrate that Work Experience in Related Field is the most important criterion while Communication and Interpersonal Skills is least important criteria. Razi et al. (2020) selected the best consultant. The study findings show that Past Experience is one of the most important criteria and this result coheres with this study. However, differently from this study References is relatively less important criterion than other criteria. Avikal et al. (2022) have solved the problem of consultant selection in ERP projects. The findings show that the top two important criteria are Reputation and ERP Project Experience. The findings are consistent as compared to this study findings.

To calculate the ranking of alternatives, steps of F-CODAS method are followed, and the best consulting firm is determined. The alternatives have been evaluated separately by the decision committee under each criterion with the linguistic variables that are given in Table 3. Five decision maker's evaluation results are summarized in Table 13. As C_9 Consulting Fee is a quantitative criterion there is no need to use linguistic variables and it is given in terms of Euro.

Table 13. Evaluation results of five DMs

	DM_1			DM_2			DM_3			DM_4			DM_5		
	A_1	A_2	A_3	A_1	A_2	A_3	A_1	A_2	A_3	A_1	A_2	A_3	A_1	A_2	A_3
C_1	VG	MG	G	G	G	VG	VG	G	G	G	MG	MG	VG	G	G
C_2	G	G	VG	VG	MG	G	MG	G	VG	VG	G	G	G	MG	VG
C_3	G	MG	G	MG	G	G	G	VG	MG	G	MG	G	VG	MG	G
C_4	VG	G	MG	VG	G	MG	G	MG	G	G	G	VG	G	G	VG
C_5	MG	VG	G	G	VG	G	VG	G	MG	VG	G	G	VG	G	G
C_6	G	G	VG	G	VG	VG	G	VG	G	G	MG	VG	G	VG	MG
C_7	G	VG	G	MG	G	G	MG	G	VG	G	MG	VG	MG	G	G
C_8	VG	G	MG	VG	MG	G	VG	G	MG	MG	VG	G	VG	G	MG
C_9	3750	3200	2700	3750	3200	2700	3750	3200	2700	3750	3200	2700	3750	3200	2700
C_{10}	G	VG	MG	G	MG	VG	G	VG	G	VG	G	MG	G	MG	G

These evaluations which are given as linguistic variables are expressed with TFNs. Crisp numbers are crisp data that presents the value of the involved criteria. As C_9 criterion is quantitative it is given as a crisp number. Then, the average fuzzy decision matrix is obtained with the help of equation 17 and can be seen on Table 14.

Table 14. The average fuzzy decision matrix

	A_1			A_2			A_3		
	l	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*
C_1	8.2	9.6	10.0	6.2	8.2	9.6	7.0	8.8	9.8
C_2	7.4	9.0	9.8	6.2	8.2	9.6	8.2	9.6	10.0
C_3	7.0	8.8	9.8	6.2	8.0	9.4	6.6	8.6	9.8
C_4	7.8	9.4	10.0	6.6	8.6	9.8	7.0	8.6	9.6
C_5	7.8	9.2	9.8	7.8	9.4	10.0	6.6	8.6	9.8
C_6	7.0	9.0	10.0	7.8	9.2	9.8	7.8	9.2	9.8
C_7	5.8	7.8	9.4	7.0	8.8	9.8	7.8	9.4	10.0
C_8	8.2	9.4	9.8	7.0	8.8	9.8	5.8	7.8	9.4
C_9	3750	3750	3750	3200	3200	3200	2700	2700	2700
C_{10}	7.4	9.2	10.0	7.0	8.6	9.6	6.6	8.4	9.6

Later, normalized fuzzy decision matrix is obtained via equations between 18 – 20 as seen on Table 15.

Table 15. Normalized fuzzy matrix

	A_1			A_2			A_3		
	l	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*
C_1	0.82	0.96	1.00	0.62	0.82	0.96	0.70	0.88	0.98
C_2	0.74	0.90	0.98	0.62	0.82	0.96	0.82	0.96	1.00
C_3	0.71	0.90	1.00	0.63	0.82	0.96	0.67	0.88	1.00
C_4	0.78	0.94	1.00	0.66	0.86	0.98	0.70	0.86	0.96
C_5	0.78	0.92	0.98	0.78	0.94	1.00	0.66	0.86	0.98
C_6	0.70	0.90	1.00	0.78	0.92	0.98	0.78	0.92	0.98
C_7	0.58	0.78	0.94	0.70	0.88	0.98	0.78	0.94	1.00
C_8	0.84	0.96	1.00	0.71	0.90	1.00	0.59	0.80	0.96
C_9	0.00	0.00	0.00	0.15	0.15	0.15	0.28	0.28	0.28
C_{10}	0.74	0.92	1.00	0.70	0.86	0.96	0.66	0.84	0.96

Weighted normalized fuzzy decision matrix is constructed via equations 21–22 as seen on Table 16.

Table 16. Weighted normalized fuzzy matrix

	A_1			A_2			A_3		
	l	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*
C_1	0.14	0.17	0.19	0.10	0.15	0.18	0.12	0.16	0.19
C_2	0.04	0.06	0.08	0.04	0.06	0.08	0.05	0.07	0.08
C_3	0.09	0.12	0.15	0.08	0.11	0.14	0.09	0.12	0.15
C_4	0.13	0.16	0.18	0.11	0.15	0.18	0.12	0.15	0.18
C_5	0.07	0.09	0.11	0.07	0.09	0.11	0.06	0.08	0.11
C_6	0.03	0.05	0.07	0.04	0.05	0.07	0.04	0.05	0.07
C_7	0.02	0.04	0.06	0.03	0.05	0.06	0.03	0.05	0.07
C_8	0.05	0.06	0.07	0.04	0.06	0.07	0.03	0.05	0.07
C_9	0.00	0.00	0.00	0.01	0.01	0.02	0.03	0.03	0.03
C_{10}	0.04	0.06	0.08	0.04	0.06	0.07	0.04	0.06	0.07

Fuzzy negative-ideal solutions are obtained by the equations 23-24 and given on Table 17.

Table 17. Fuzzy negative-ideal solutions

	l	*m*	*u*
C_1	0.10	0.15	0.18
C_2	0.04	0.06	0.08
C_3	0.08	0.11	0.14
C_4	0.11	0.15	0.18
C_5	0.06	0.08	0.11
C_6	0.03	0.05	0.07
C_7	0.02	0.04	0.06
C_8	0.03	0.05	0.07
C_9	0.00	0.00	0.00
C_{10}	0.04	0.06	0.07

Fuzzy weighted Euclidean distances are obtained by the equations 25-26 and fuzzy weighted Hamming distances are calculated via equations 27-28 and summarized on Table 18.

Table 18. Fuzzy weighted Euclidean and Hamming distances

	A_1	A_2	A_3
ED	0.076	0.038	0.068
HD	0.071	0.036	0.064

Relative assessment matrix is obtained via equations 29-31 and given on Table 19.

Table 19. Relative assessment matrix

	A_1	A_2	A_3
A_1	0.000	0.073	0.008
A_2	-0.073	0.000	-0.058
A_3	-0.008	0.058	0.000

Finally, assessment scores are obtained via equation 32 as seen in Table 20.

Table 20. Assessment scores of alternatives

	AS_i
A_1	0.082
A_2	-0.131
A_3	0.049

Assessment scores of alternatives show that $A_1 > A_3 > A_2$. Then, it is suggested to the textile company hire A_1 consulting firm. The textile company have found the result appropriate and decided to hire A_1 consulting firm.

CONCLUSION AND DISCUSSION

Consulting firms have been buzzword among businesses with the numerous benefits they provide to companies. After the company decides to hire a consulting firm, it evaluates firms in terms of many criteria which are qualitative or quantitative. For the effective evaluation of consultancy firms, it is significant to determine the weights of the criteria correctly. Consulting firm selection problem have been introduced in this study. Ten criteria have been determined for the selection of the best consulting firm. Since all the criteria except "C_9 Consulting Fee" in this study are qualitative, it is thought that fuzzy MCDM is an appropriate tool to solve consultant selection problem.

Based on our findings, the top three important criteria for consulting firm selection problem are C_1: Experience, C_4: References and C_3: Reliability. In addition to this, the best consulting firm has been determined with the help of the F-CODAS method. According to the results obtained from the F-CODAS method, A_1 consulting firm is found as the best alternative.

This study contributes to literature as follows. This study presents the application of a novel combined IMF-SWARA and F-CODAS method to consulting firm selection. The IMF-SWARA and F-CODAS model can be used as a beneficial reference in the field of fuzzy MCDM. The original F-CODAS method includes trapezoidal fuzzy numbers. However, for the sake of ease of operation and simplicity, differently from the original F-CODAS, TFNs are used in this study. The use of F-CODAS method with TFNs will be a new reference for researchers. The findings of this study can be used by HR managers to identify and select the best consulting firm.

The limitation of this study is that the obtained results depend on a single case study. For future research, the criteria, and alternatives handled for consulting firm selection problem can be extended and different fuzzy MCDM methods or the combined method can be applied. Also, the assessments can be taken by different group decision making methods and the findings can be compared.

REFERENCES

Avikal, S., Nigam, M., & Ram, M. (2022). A hybrid multi criteria decision making approach for consultant selection problem in ERP project. *International Journal of System Assurance Engineering and Management*, 1-10.

Bellman, R. E., & Zadeh, L.A. (1970). Decision making in a fuzzy environment. *Management Sciences*, *17*, 141-164.

Chang, D. Y. (1996). Applications of the extent analysis method on fuzzy AHP. *European Journal of Operational Research*, *95*, 649-655.

Chen, C. T. (2000). Extensions of the TOPSIS for group decision-making under fuzzy environment. *Fuzzy Sets and Systems*, *114*(1), 1-9.

Ecer, F. (2015). Performance evaluation of internet banking branches via a hybrid MCDM model under fuzzy environment. *Economic Computation & Economic Cybernetics Studies & Research*, *49*(2), 211-230.

El-Santawy, M. F., & El-Dean, R. A. Z. (2012). Selection of a consulting firm by using SDV-MOORA. *Life Science Journal*, *9*(1s), 171-173.

Guo, S., & Zhao, H. (2017). Fuzzy Best-Worst multi-criteria decision-making method and its applications. *Knowledge-Based Systems*, *121*, 23-31.

Hadi-Vencheh, A., & Mokhtarian, M. N. (2011). A new fuzzy MCDM approach based on centroid of fuzzy numbers. *Expert Systems with Applications*, *38*(5), 5226-5230.

Kabir, G., & Sumi, R. S. (2014). Integrating fuzzy analytic hierarchy process with PROMETHEE method for total quality management consultant selection. *Production & Manufacturing Research*, *2*(1), 380-399.

Kahraman, C., Cebeci, U., & Ruan, D. (2004). Multi-attribute comparison of catering service companies using fuzzy AHP: The case of Turkey. *International Journal of Production Economics*, *87*, 171–184.

Katrancı, A., & Kundakcı, N. (2020). Evaluation of cryptocurrency investment alternatives with fuzzy CODAS Method. *Afyon Kocatepe University Journal of Social Science*, *22*(4), 958-973.

Kersuliene, V., Zavadskas, E.K., & Turskis, Z. (2010). Selection of rational dispute resolution method by applying new step- wise weight assessment ratio analysis (SWARA). *Journal of Business Economics and Management*, *11*(2), 243-258.

Keshavarz Ghorabaee, M., Amiri, M., Zavadskas, E. K., Hooshmand, R., & Antucheviciene, J. (2017). Fuzzy extension of the CODAS method for multi-criteria market segment evaluation. *Journal of Business Economics and Management, 18*(1), *1-19*.

Keshavarz Ghorabaee, M., Zavadskas, E. K., Turskis, Z., & Antucheviciene, J. (2016). A new combinative distance-based assessment (CODAS) method for multi-criteria decision-making. *Economic Computation & Economic Cybernetics Studies & Research*, *50*(3), 25-44.

Mavi, R. K., Goh, M., & Zarbakhshnia, N. (2017). Sustainable third-party reverse logistic provider selection with fuzzy SWARA and fuzzy MOORA in plastic industry. *International Journal of Advanced Manufacturing Technology*, *91*, 2401–2418.

Moslem, S., Stević, Ž., Tanackov, I., & Pilla, F. (2023). Sustainable development solutions of public transportation: An integrated IMF SWARA and Fuzzy Bonferroni operator. *Sustainable Cities and Society*, *93*, 104530.

Musani, S., & Jemain, A. A. (2013, November). A fuzzy MCDM approach for evaluating school performance based on linguistic information. In *AIP Conference Proceedings* (Vol. 1571, No. 1, pp. 1006-1012). American Institute of Physics.

Nomir, M., & Hammad, A. (2023). Decision support system for selecting engineering consultants using Qualifications-Based Selection (QBS) and fuzzy TOPSIS. Canadian Journal of Civil Engineering. e-First https://doi.org/10.1139/cjce-2022-0076

Peker, B. N., & Görener, A. (2023). Facility location selection with improved fuzzy SWARA and fuzzy CODAS methods: An application in the manufacturing industry. *Journal of Turkish Operations Management*, *7*(1), 1493-1512.

Perçin, S. (2019). An integrated fuzzy SWARA and fuzzy AD approach for outsourcing provider selection. *Journal of Manufacturing Technology Management*, *30*(2), 531-552.

Puška, A., Nedeljković, M., Stojanović, I., & Božanić, D. (2023). Application of fuzzy TRUST CRADIS method for selection of sustainable suppliers in agribusiness. *Sustainability*, *15*(3), 2578.

Razi, P. Z., Ramli, N. I., Ali, M. I., & Ramadhansyah, P. J. (2020). Selection of best consultant by using Analytical Hierarchy Process (AHP). *IOP Conference Series: Materials Science and Engineering* (712(1), pp. 012016). IOP Publishing.

Roszkowska, E., & Wachowicz, T. (2015). Application of fuzzy TOPSIS to scoring the negotiation offers in ill-structured negotiation problems. *European Journal of Operational Research, 242*(3), 920-932.

Saremi, M., Mousavi, S. F., & Sanayei, A. (2009). TQM consultant selection in SMEs with TOPSIS under fuzzy environment. *Expert Systems with Applications*, *36*(2), 2742-2749.

Sporrong, J. (2011). Criteria in consultant selection: public procurement of architectural and engineering services. *Australasian Journal of Construction Economics and Building*, *11*(4), 59-76.

Stević, Ž., Subotić, M., Softić, E., & Božić, B. (2022). Multi-criteria decision-making model for evaluating safety of road sections. *J. Intell. Manag. Decis*, *1*(2), 78-87.

Terzioğlu (Eds.), *Advances in Econometrics, Operational Research, Data Science and Actuarial Studies. Contributions to Economics.* (pp. 389-404) Springer, Cham. https://doi.org/10.1007/978-3-030-85254-2_24.

Tsai, W. H., Lin, T. W., Chen, S. P., & Hung, S. J. (2007). Users' service quality satisfaction and performance improvement of ERP consultant selections. *International Journal of Business and Systems Research*, *1*(3), 280-301.

Tsaur, S. H., Chang, T. Y., & Yen, C. H. (2002). The evaluation of airline service quality by fuzzy MCDM. *Tourism management*, *23*(2), 107-115.

Tuş Işık, A., & Aytaç Adalı, E. (2016). UTA method for the consulting firm selection problem. *Journal of Engineering Science & Technology Review*, *9*(1), 56-60.

Ulutaş, A. (2021). *Supplier Evaluation with BWM and Fuzzy CODAS Methods*. Handbook of Research on Recent Perspectives on Management, International Trade, and Logistics (pp. 335-351). IGI Global.

Vrtagić, S., Softić, E., Subotić, M., Stević, Ž., Dordevic, M., & Ponjavic, M. (2021). Ranking road sections based on MCDM model: new improved fuzzy SWARA (IMF SWARA). *Axioms*, *10*(2), 92.

Yalçın, N., & Yapıcı Pehlivan, N. (2019). Application of the fuzzy CODAS method based on fuzzy envelopes for hesitant fuzzy linguistic term sets: A case study on a personnel selection problem. *Symmetry*, *11*(4), 493.

Yeni, F. B., & Özçelik, G. (2019). Interval-valued Atanassov intuitionistic fuzzy CODAS method for multi criteria group decision making problems. *Group Decision and Negotiation*, *28*(2), 433-452.

Zadeh, L. A. (1965). Fuzzy sets. *Information and Control*, *8*, 338-353.

Zolfani, S. H., Görçün, Ö. F., & Küçükönder, H. (2021). Evaluating logistics villages in Turkey using hybrid improved fuzzy SWARA (IMF SWARA) and fuzzy MABAC techniques. *Technological and Economic Development of Economy*, *27*(6), 1582-1612.