

Extended EDAS Method for Fuzzy Multi-criteria Decision-making: An Application to Supplier Selection

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Abstract:

In the real-world problems, we are likely confronted with some alternatives that need to be evaluated with respect to multiple conflicting criteria. Multi-criteria decision-making (MCDM) refers to making decisions in such a situation. There are many methods and techniques available for solving MCDM problems. The evaluation based on distance from average solution (EDAS) method is an efficient multi-criteria decision-making method. Because the uncertainty is usually an inevitable part of the MCDM problems, fuzzy MCDM methods can be very useful for dealing with the real-world decision-making problems. In this study, we extend the EDAS method to handle the MCDM problems in the fuzzy environment. A case study of supplier selection is used to show the procedure of the proposed method and applicability of it. Also, we perform a sensitivity analysis by using simulated weights for criteria to examine the stability and validity of the results of the proposed method. The results of this study show that the extended fuzzy EDAS method is efficient and has good stability for solving MCDM problems.

Keywords: Multi-criteria decision-making, Fuzzy sets, Fuzzy MCDM, EDAS method, Fuzzy EDAS, Supplier selection.

1 Introduction

Usually, the real-world decision-making problems are very complex and could not be considered as single-criterion problems. In other words, using only one dimension for the decision-making process could lead to an unrealistic decision [7], [9], [10], [33], [34]. To obtain more

comprehensive models for these problems, we need to involve multiple factors or criteria. Multi-criteria decision-making (MCDM) comprises efficient methods and techniques to deal with problems that include more than one criterion in the decision-making process [4], [13] [19], [25], [35].

The information about the real-world problems is usually not known accurately. This uncertainty makes the decision-making process complex and challenging. Fuzzy set theory was proposed by Zadeh [31] to deal with this kind of subjective and imprecise information. This theory is a very efficient modeling tool for the MCDM problems in an uncertain environment. Linguistic terms defined by fuzzy sets are usually used to represent uncertain information in the fuzzy decision-making process [18].

Many researchers have applied and extended fuzzy MCDM methods in real-world problems [5], [26], [27]. Nieto-Morote and Ruz-Vila [20] proposed an MCDM approach based on the fuzzy AHP and linguistic terms to evaluate combined cooling, heat, and power production systems. Cagri Tolga et al. [6] developed a fuzzy MCDM approach based on the analytic network process for retail location selection problem. Sedaghat [23] presented a fuzzy MCDM approach based on AHP, TOPSIS, VIKOR and SAW methods for evaluation of productivity improvement of private banks. Wan and Dong [28] developed a new method for solving the multi-criteria group decision-making problems with the trapezoidal intuitionistic fuzzy number and incomplete criteria weight information, and used it for stock selection problem. Stanujkic [24] developed an extended version of ARAS method with interval-valued triangular fuzzy numbers and utilized it for evaluating the performance of websites. Baležentis et al. [3] extended the MULTIMOORA method with intuitionistic fuzzy numbers and applied it for personnel selection problem. Keshavarz Ghorabae [14] proposed an extended VIKOR method with interval type-2 fuzzy sets and applied it to a problem of evaluation and selection of the industrial robots.

Due to involvement of many factors in evaluation and selection of the suppliers, this problem is usually considered as an MCDM problem [12]. Like many other MCDM problems, supplier selection problem is usually handled in an uncertain environment. Therefore, fuzzy MCDM methods and techniques are very useful to deal with this problem. Many researchers have studied supplier selection problem using fuzzy set theory. Yücenur et al. [30] developed a model for selecting the global supplier using the fuzzy analytic hierarchy process and analytic network process. Baležentis and Baležentis [2] developed an innovative MCDM approach based on MULTIMOORA method and 2-tuple linguistics for supplier evaluation and selection. Pitchipoo et al. [22] proposed a structured and integrated decision-making approach for evaluating suppliers by combining the fuzzy analytic hierarchy process and grey relational analysis (GRA). Keshavarz Ghorabae et al. [15] extended a multi-criteria group decision-making based on the COPRAS method with type-2 fuzzy sets, and applied it to supplier selection process. Kar [16] developed a hybrid group decision support system for supplier selection using analytic hierarchy process, fuzzy set theory and neural network.

The evaluation based on distance from average solution (EDAS) method was introduced by Keshavarz Ghorabae et al. [17] for inventory ABC classification. It was presented that the EDAS method has good efficiency and needs fewer computations in comparison with other ABC classification methods. Moreover, the efficiency of the EDAS method as an MCDM method was demonstrated by comparing it with some commonly used methods. The evaluation of alternatives in this method is based on distances of each alternative from the average solution with respect to each criterion. In this study, the EDAS method is extended to deal with the fuzzy MCDM problems. In this paper, these linguistic terms are defined by trapezoidal fuzzy numbers to extend the EDAS method in fuzzy environment. A case study of supplier selection is employed to describe the process and demonstrate the effectiveness of the proposed extended method. We also perform a sensitivity analysis with different sets of simulated criteria weights to represent the validity and stability of the ranking results when the weights of criteria are changed. The

results of sensitivity analysis show that the proposed fuzzy method is stable in different weights of criteria and has a good efficiency in a fuzzy environment.

The rest of this paper is organized as follows. In Section 2, we summarize some basic concepts and definitions about the fuzzy set theory and arithmetic operation of fuzzy numbers. In Section 3, an extended EDAS method is presented to deal with MCDM problems under fuzzy environment. In Section 4, we use a case study of supplier selection to illustrate the procedure and application of the extended EDAS method. In Section 5, a sensitivity analysis is performed to show the validity and stability of the results of the proposed method. The conclusions are discussed in Section 6.

2 Basic Concepts and Definitions

Fuzzy set theory was developed by Zadeh [31] for handling problems in which information is imprecise, vague, and uncertain. The term “fuzzy” is related to the situation that we have not well-defined boundaries of the set of activities or observations. Some of the definitions related to fuzzy sets and fuzzy numbers, which are used in this research to extend the EDAS method, are stated as follows:

Definition 1. A fuzzy subset $\tilde{A}$ of a universal set X can be defined by its membership function $\mu_{\tilde{A}}(x)$ as [36]:

$$\tilde{A} = (x, \mu_{\tilde{A}}(x)) | x \in X \quad (1)$$

where $x \in X$ denotes the elements belonging to the universal set, and $\mu_{\tilde{A}}(x) : X \mapsto [0, 1]$.

Definition 2. A fuzzy number is a special case of a convex, normalized fuzzy subset ($\sup \mu_{\tilde{A}}(x) = 1$) of the real line $\mathbb{R}(\mu_{\tilde{A}}(x) : \mathbb{R} \mapsto [0, 1])$ [29].

Definition 3. A fuzzy number $\tilde{A}$ is a trapezoidal fuzzy number (TFN) if its membership function is [21]:

$$\mu_{\tilde{A}}(x) = \begin{cases} (x - a_1)/(a_2 - a_1) & a_1 \leq x \leq a_2 \\ 1 & a_2 \leq x \leq a_3 \\ (a_4 - x)/(a_4 - a_3) & a_3 \leq x \leq a_4 \\ 0 & \text{otherwise} \end{cases} \quad (2)$$

This fuzzy number can also be defined by a quadruplet $\tilde{A} = (a_1, a_2, a_3, a_4)$. An example of this type of fuzzy numbers is shown in Figure 1.

Definition 4. A crisp number k can be represented by a trapezoidal fuzzy number $\tilde{k} = (k, k, k, k)$.

Definition 5. Suppose that $\tilde{A} = (a_1, a_2, a_3, a_4)$ and $\tilde{B} = (b_1, b_2, b_3, b_4)$ be two positive trapezoidal fuzzy numbers ($a_1 \geq 0$ and $b_1 > 0$) and k is a crisp number. The arithmetic operations with these fuzzy numbers are defined as follows [8]:

- Addition:

$$\tilde{A} \oplus \tilde{B} = (a_1 + b_1, a_2 + b_2, a_3 + b_3, a_4 + b_4) \quad (3)$$

$$\tilde{A} + k = (a_1 + k, a_2 + k, a_3 + k, a_4 + k) \quad (4)$$

- Subtraction:

$$\tilde{A} \ominus \tilde{B} = (a_1 - b_4, a_2 - b_3, a_3 - b_2, a_4 - b_1) \quad (5)$$

$$\tilde{A} - k = (a_1 - k, a_2 - k, a_3 - k, a_4 - k) \quad (6)$$

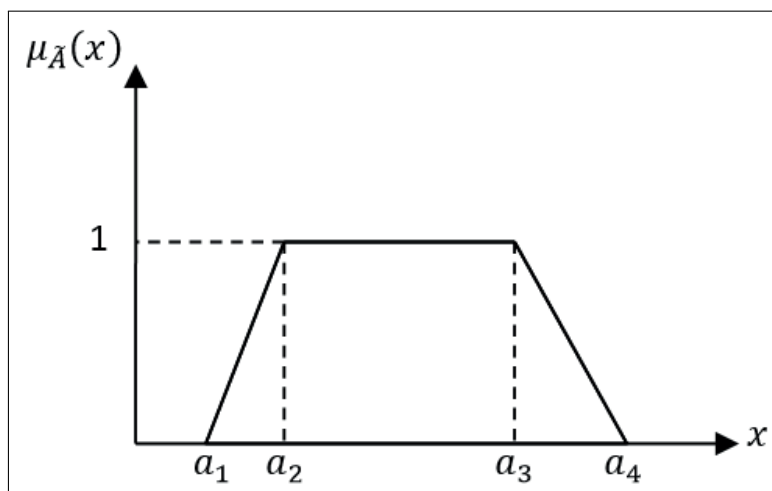


Figure 1: A trapezoidal fuzzy number

- Multiplication:

$$\tilde{A} \otimes \tilde{B} = (a_1 \times b_1, a_2 \times b_2, a_3 \times b_3, a_4 \times b_4) \quad (7)$$

$$\tilde{A} \times k = \begin{cases} (a_1 \times k, a_2 \times k, a_3 \times k, a_4 \times k) & \text{if } k \geq 0 \\ (a_4 \times k, a_3 \times k, a_2 \times k, a_1 \times k) & \text{if } k < 0 \end{cases} \quad (8)$$

- Division:

$$\tilde{A} \oslash \tilde{B} = (a_1/b_4, a_2/b_3, a_3/b_2, a_4/b_1) \quad (9)$$

$$\tilde{A}/k = \begin{cases} (a_1/k, a_2/k, a_3/k, a_4/k) & \text{if } k > 0 \\ (a_4/k, a_3/k, a_2/k, a_1/k) & \text{if } k < 0 \end{cases} \quad (10)$$

Definition 6. Let $\tilde{A} = (a_1, a_2, a_3, a_4)$ be a trapezoidal fuzzy number. Then, the defuzzified (crisp) value of this fuzzy number can be defined as follows [15]:

$$\kappa(\tilde{A}) = \frac{1}{3} \left(a_1 + a_2 + a_3 + a_4 - \frac{a_3 a_4 - a_1 a_2}{(a_3 + a_4) - (a_1 + a_2)} \right) \quad (11)$$

Definition 7. Suppose that $\tilde{A} = (a_1, a_2, a_3, a_4)$ be a trapezoidal fuzzy number. A function, called psi (ψ), is defined in the following to find the maximum between a trapezoidal fuzzy number and zero.

$$\psi(\tilde{A}) = \begin{cases} \tilde{A} & \text{if } \kappa(\tilde{A}) > 0 \\ \tilde{0} & \text{if } \kappa(\tilde{A}) \leq 0 \end{cases} \quad (12)$$

where $\tilde{0} = (0, 0, 0, 0)$.

3 An Extended EDAS Method

As previously stated, the EDAS method was developed by Keshavarz Ghorabae et al. [17] for multi-criteria inventory classification. It was also demonstrated that the EDAS method is an efficient method to handle MCDM problems. In this section, an extended version of the EDAS

method is proposed to deal with multi-criteria group decision-making problems in the fuzzy environment. In this study, the decision-makers express the weights of criteria and the rating of alternatives with respect to each criterion by linguistic terms. These linguistic terms are quantified by positive trapezoidal fuzzy numbers. Therefore, the concepts and arithmetic operations of the trapezoidal fuzzy numbers are utilized for extending the EDAS method. Suppose that we have a set of n alternatives ($A = \{A_1, A_2, \dots, A_n\}$), a set of m criteria ($C = \{c_1, c_2, \dots, c_m\}$) and k decision-makers ($D = \{D_1, D_2, \dots, D_k\}$). The steps of the extended fuzzy EDAS method are presented as follows:

Step 1: Construct the average decision matrix (X), shown as follows:

$$X = [\tilde{x}_{ij}]_{n \times m} \quad (13)$$

$$\tilde{x}_{ij} = \frac{1}{k} \bigoplus_{p=1}^k \tilde{x}_{ij}^p \quad (14)$$

where $\tilde{x}_{ij}^p$ denotes the performance value of alternative A_i ($1 \leq i \leq n$) with respect to criterion c_j ($1 \leq j \leq m$) assigned by the p th decision-maker ($1 \leq p \leq k$).

Step 2: Construct the matrix of criteria weights, shown as follows:

$$W = [\tilde{w}_j]_{1 \times m} \quad (15)$$

$$\tilde{w}_j = \frac{1}{k} \bigoplus_{p=1}^k \tilde{w}_j^p \quad (16)$$

where $\tilde{w}_j^p$ denotes the weight of criterion c_j ($1 \leq j \leq m$) assigned by the p th decision-maker ($1 \leq p \leq k$).

Step 3: Construct the matrix of criteria weights, shown as follows:

$$AV = [\widetilde{av}_j]_{1 \times m} \quad (17)$$

$$\widetilde{av}_j = \frac{1}{n} \bigoplus_{i=1}^n \tilde{x}_{ij} \quad (18)$$

The elements of this matrix $\widetilde{av}_j$ represents the average solutions with respect to each criterion. Therefore, the dimension of the matrix is equal to the dimension of criteria weights matrix.

Step 4: Suppose that B is the set of beneficial criteria and N is the set of non-beneficial criteria. In this step the matrices of positive distance from average (PDA) and negative distance from average (NDA) are calculated according to the type of criteria (beneficial and non-beneficial), shown as follows:

$$PDA = [\widetilde{pda}_{ij}]_{n \times m} \quad (19)$$

$$NDA = [\widetilde{nda}_{ij}]_{n \times m} \quad (20)$$

$$\widetilde{pda}_{ij} = \begin{cases} \frac{\psi(\tilde{x}_{ij} \ominus \widetilde{av}_j)}{\kappa(\widetilde{av}_j)} & \text{if } j \in B \\ \frac{\psi(\widetilde{av}_j \ominus \tilde{x}_{ij})}{\kappa(\widetilde{av}_j)} & \text{if } j \in N \end{cases} \quad (21)$$

$$\widetilde{nda}_{ij} = \begin{cases} \frac{\psi(\widetilde{av}_j \ominus \tilde{x}_{ij})}{\kappa(\widetilde{av}_j)} & \text{if } j \in B \\ \frac{\psi(\tilde{x}_{ij} \ominus \widetilde{av}_j)}{\kappa(\widetilde{av}_j)} & \text{if } j \in N \end{cases} \quad (22)$$

where $\widetilde{pda}_{ij}$ and $\widetilde{nda}_{ij}$ denote the positive and negative distance of performance value of i th alternative from the average solution in terms of j th criterion, respectively.

Step 5: Calculate the weighted sum of positive and negative distances for all alternatives, shown as follows:

$$\widetilde{sp}_i = \bigoplus_{j=1}^m (\widetilde{w}_j \otimes \widetilde{pda}_{ij}) \quad (23)$$

$$\widetilde{sn}_i = \bigoplus_{j=1}^m (\widetilde{w}_j \otimes \widetilde{nda}_{ij}) \quad (24)$$

Step 6: The normalize values of $\widetilde{sp}_i$ and $\widetilde{sn}_i$ for all alternatives are calculated as follows:

$$\widetilde{ns}_i = \frac{\widetilde{sp}_i}{\max_i(\kappa(\widetilde{sp}_i))} \quad (25)$$

$$\widetilde{nsn}_i = 1 - \frac{\widetilde{sn}_i}{\max_i(\kappa(\widetilde{sn}_i))} \quad (26)$$

Step 7: Calculate the appraisal score ($\widetilde{as}_i$) for all alternatives, shown as follows:

$$\widetilde{as}_i = \frac{1}{2}(\widetilde{ns}_i \oplus \widetilde{nsn}_i) \quad (27)$$

Step 8: Rank the alternatives according to the decreasing values of appraisal scores ($\widetilde{as}_i$). In other words, the alternative with the highest appraisal score is the best choice among the candidate alternatives.

4 Case Study of Supplier Selection

In this section, we use the proposed fuzzy MCDM method for a real supplier selection case study. The case study is related to a detergent manufacturer. The main product of this company is washing powder. In general, washing powder contains water softeners, bleach, enzymes, surfactants, fragrances, brighteners and many other agents. The company needs to supply the chemical materials of these components from an appropriate supplier for the future of its production. For this aim, the chief executive officer of the company formed a group of five experts from the company's employees. We consider the members of this group as the decision-makers (DM_1 to DM_5). After a basic assessment performed by this group, five candidates (Supplier 1 to Supplier 5) are remained for further evaluation. These candidates are considered as the alternatives of the MCDM problem (A_1 to A_5). Six criteria with some sub-criteria are selected by decision-makers for evaluation of suppliers. Figure 2 shows the criteria, sub-criteria and the hierarchical structure of the case study problem.

In this structure, "Total cost" and "Distance" are non-beneficial sub-criteria, and the other sub-criteria are beneficial. The linguistic terms are utilized by decision-makers for evaluation of criteria importance and rating the alternatives on each criterion. These linguistic terms and their corresponding trapezoidal fuzzy numbers are represented in Table 1.

The importance weights of the criteria determined by five decision-makers are shown in Table 2 and the ratings of the alternatives (suppliers) given by these decision-makers under the various criteria are presented in Table 3. The process of using the proposed fuzzy method for this problem is summarized as follows:

Step 1: Based on Tables 1 and 3 and Eqs. (13) and (14), the average decision matrix is constructed. The elements of this matrix can be found in Table 4.

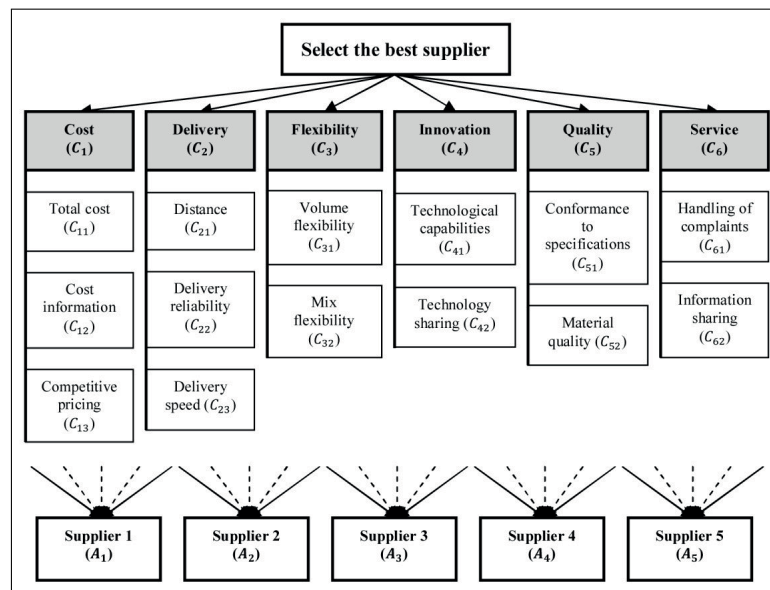


Figure 2: The criteria, sub-criteria and the hierarchical structure of the case study

Table 1: Linguistic terms and their corresponding trapezoidal fuzzy number.

Terms	TFN for weighting criteria	TFN for rating alternatives
Very low (VL)	(0, 0, 0.1, 0.2)	(0, 0, 1, 2)
Low (L)	(0.1, 0.2, 0.2, 0.3)	(1, 2, 2, 3)
Medium low (ML)	(0.2, 0.3, 0.4, 0.5)	(2, 3, 4, 5)
Medium (M)	(0.4, 0.5, 0.5, 0.6)	(4, 5, 5, 6)
Medium high (MH)	(0.5, 0.6, 0.7, 0.8)	(5, 6, 7, 8)
High (H)	(0.7, 0.8, 0.8, 0.9)	(7, 8, 8, 9)
Very high (VH)	(0.8, 0.9, 1, 1)	(8, 9, 10, 10)

Steps 2 and 3: Based on Tables 1 and 2 and Eqs. (15) and (16), the average weight of each criterion is calculated (the last column of Table 2), and by using the results of Step 1 and Eqs. (17) and (18) the average solution matrix can be calculated (the last column of Table 4).

Steps 4 to 8: Based on the Table 4 and Eqs. (19) to (27), the positive and negative distances are determined and then we calculate the weighted sum of positive and negative distances ($\tilde{sp}_i$ and $\tilde{sn}_i$), the normalized values of them ($\tilde{ns\tilde{p}}_i$ and $\tilde{ns\tilde{n}}_i$) and the appraisal scores for all alternatives. Table 5 shows the selected results of these steps. The defuzzified values of appraisal scores are also represented in the last column of this table. According to Table 5, the ranking order of alternatives is $A_1 \succ A_5 \succ A_2 \succ A_4 \succ A_3$. Therefore, A_1 is the best supplier in our assessment.

5 Sensitivity Analysis

To show the stability of the results, the aforementioned example is solved using different sets of criteria (sub-criteria) weights. We simulate 14 sets of weights for the 14 sub-criteria of the example. Figure 3 shows the simulated weights in each set. As can be seen in this figure, one sub-criterion has the highest and one sub-criterion has the lowest weight in each set. Figure 4 shows the ranking of each alternative in each set of criteria (sub-criteria) weights. As can be seen in Figure 4, the ranks of all alternatives are relatively stable in different weights of sub-criteria

Table 2: The weight of criteria assigned by decision-makers and the matrix of criteria weights

Criteria		DM_1	DM_2	DM_3	DM_4	DM_5	W
C_1	C_{11}	VH	H	H	VH	VH	(0.76, 0.86, 0.92, 0.96)
	C_{12}	ML	M	ML	L	L	(0.2, 0.3, 0.34, 0.44)
	C_{13}	M	MH	H	M	M	(0.48, 0.58, 0.6, 0.7)
C_2	C_{21}	VH	VH	H	VH	MH	(0.72, 0.82, 0.9, 0.94)
	C_{22}	MH	H	MH	MH	M	(0.52, 0.62, 0.68, 0.78)
	C_{23}	H	H	H	MH	M	(0.6, 0.7, 0.72, 0.82)
C_3	C_{31}	ML	M	ML	M	M	(0.32, 0.42, 0.46, 0.56)
	C_{32}	L	VL	VL	L	ML	(0.08, 0.14, 0.2, 0.3)
C_4	C_{41}	VL	VL	L	L	VL	(0.04, 0.08, 0.14, 0.24)
	C_{42}	VL	VL	VL	VL	L	(0.02, 0.04, 0.12, 0.22)
C_5	C_{51}	H	MH	M	M	MH	(0.5, 0.6, 0.64, 0.74)
	C_{52}	VH	VH	H	VH	H	(0.76, 0.86, 0.92, 0.96)
C_6	C_{61}	ML	M	ML	L	ML	(0.22, 0.32, 0.38, 0.48)
	C_{62}	VL	L	ML	ML	L	(0.12, 0.2, 0.26, 0.36)

Table 3: The ratings of the alternatives with respect to each criterion and each decision-maker

		C_{11}	C_{12}	C_{13}	C_{21}	C_{22}	C_{23}	C_{31}	C_{32}	C_{41}	C_{42}	C_{51}	C_{52}	C_{61}	C_{62}
DM_1	A_1	VL	MH	H	M	H	MH	M	H	MH	ML	VH	H	H	MH
	A_2	ML	H	H	MH	M	MH	VH	MH	VH	M	L	H	L	MH
	A_3	H	M	L	M	L	M	H	MH	L	MH	L	L	M	L
	A_4	VH	ML	M	H	H	VH	M	L	L	H	MH	ML	L	H
	A_5	M	H	H	L	M	MH	VH	H	H	M	MH	H	L	MH
DM_2	A_1	L	MH	MH	M	MH	H	ML	MH	M	L	VH	H	H	H
	A_2	M	H	M	M	M	MH	VH	M	H	M	L	MH	VL	M
	A_3	H	M	ML	ML	L	M	H	MH	L	MH	L	ML	M	L
	A_4	VH	M	M	H	MH	VH	M	L	ML	VH	M	ML	L	H
	A_5	M	H	H	VL	M	MH	VH	H	H	M	MH	H	VL	MH
DM_3	A_1	L	M	H	ML	H	H	ML	MH	MH	ML	H	MH	MH	VH
	A_2	ML	MH	MH	M	MH	MH	H	MH	H	MH	VL	MH	L	M
	A_3	MH	ML	ML	M	ML	MH	VH	H	ML	H	VL	ML	MH	L
	A_4	H	L	MH	MH	MH	H	ML	VL	ML	VH	M	M	VL	MH
	A_5	ML	MH	H	L	ML	H	H	MH	MH	ML	M	VH	VL	M
DM_4	A_1	VL	MH	M	ML	H	H	M	H	M	ML	H	H	MH	VH
	A_2	ML	H	M	M	MH	H	H	MH	VH	M	VL	H	VL	MH
	A_3	H	ML	ML	ML	ML	MH	VH	H	VL	H	VL	L	M	VL
	A_4	H	L	MH	MH	MH	VH	ML	ML	ML	VH	M	ML	VL	H
	A_5	MH	MH	MH	ML	ML	H	H	MH	H	ML	MH	H	VL	M
DM_5	A_1	L	H	MH	M	MH	MH	ML	MH	M	L	VH	MH	H	MH
	A_2	M	H	M	MH	M	H	H	M	H	M	L	MH	L	MH
	A_3	MH	L	L	M	ML	MH	VH	M	VL	MH	VL	L	MH	L
	A_4	VH	L	M	MH	H	VH	ML	L	L	H	MH	ML	VL	MH
	A_5	M	H	H	L	M	MH	VH	MH	H	M	H	H	VL	MH

Table 4: The elements of the average decision-matrix and the average solution matrix

	A_1	A_2	A_3	A_4	A_5	AV
C_{11}	(0.06, 0.12, 0.16, 0.26)	(0.28, 0.38, 0.44, 0.54)	(0.62, 0.72, 0.76, 0.86)	(0.76, 0.86, 0.92, 0.96)	(0.38, 0.48, 0.52, 0.62)	(0.42, 0.51, 0.56, 0.65)
C_{12}	(0.52, 0.62, 0.68, 0.78)	(0.66, 0.76, 0.78, 0.88)	(0.26, 0.36, 0.4, 0.5)	(0.18, 0.28, 0.3, 0.4)	(0.62, 0.72, 0.76, 0.86)	(0.45, 0.55, 0.58, 0.68)
C_{13}	(0.56, 0.66, 0.7, 0.8)	(0.48, 0.58, 0.6, 0.7)	(0.16, 0.26, 0.32, 0.42)	(0.44, 0.54, 0.58, 0.68)	(0.66, 0.76, 0.78, 0.88)	(0.46, 0.56, 0.6, 0.7)
C_{21}	(0.32, 0.42, 0.46, 0.56)	(0.44, 0.54, 0.58, 0.68)	(0.32, 0.42, 0.46, 0.56)	(0.58, 0.68, 0.74, 0.84)	(0.66, 0.76, 0.78, 0.88)	(0.35, 0.45, 0.49, 0.59)
C_{22}	(0.62, 0.72, 0.76, 0.86)	(0.44, 0.54, 0.58, 0.68)	(0.16, 0.26, 0.32, 0.42)	(0.58, 0.68, 0.74, 0.84)	(0.32, 0.42, 0.46, 0.56)	(0.42, 0.52, 0.57, 0.67)
C_{23}	(0.62, 0.72, 0.76, 0.86)	(0.58, 0.68, 0.74, 0.84)	(0.46, 0.56, 0.62, 0.72)	(0.78, 0.88, 0.96, 0.98)	(0.58, 0.68, 0.74, 0.84)	(0.6, 0.7, 0.76, 0.85)
C_{31}	(0.28, 0.38, 0.44, 0.54)	(0.74, 0.84, 0.88, 0.94)	(0.76, 0.86, 0.92, 0.96)	(0.28, 0.38, 0.44, 0.54)	(0.76, 0.86, 0.92, 0.96)	(0.56, 0.66, 0.72, 0.79)
C_{32}	(0.58, 0.68, 0.74, 0.84)	(0.46, 0.56, 0.62, 0.72)	(0.56, 0.66, 0.7, 0.8)	(0.1, 0.18, 0.22, 0.32)	(0.58, 0.68, 0.74, 0.84)	(0.46, 0.55, 0.6, 0.7)
C_{41}	(0.44, 0.54, 0.58, 0.68)	(0.74, 0.84, 0.88, 0.94)	(0.08, 0.14, 0.2, 0.3)	(0.16, 0.26, 0.32, 0.42)	(0.66, 0.76, 0.78, 0.88)	(0.42, 0.51, 0.55, 0.64)
C_{42}	(0.16, 0.26, 0.32, 0.42)	(0.42, 0.52, 0.54, 0.64)	(0.58, 0.68, 0.74, 0.84)	(0.76, 0.86, 0.92, 0.96)	(0.32, 0.42, 0.46, 0.56)	(0.45, 0.55, 0.6, 0.68)
C_{51}	(0.76, 0.86, 0.92, 0.96)	(0.06, 0.12, 0.16, 0.26)	(0.04, 0.08, 0.14, 0.24)	(0.44, 0.54, 0.58, 0.68)	(0.52, 0.62, 0.68, 0.78)	(0.36, 0.44, 0.5, 0.58)
C_{52}	(0.62, 0.72, 0.76, 0.86)	(0.58, 0.68, 0.74, 0.84)	(0.14, 0.24, 0.28, 0.38)	(0.24, 0.34, 0.42, 0.52)	(0.72, 0.82, 0.84, 0.92)	(0.46, 0.56, 0.61, 0.7)
C_{61}	(0.62, 0.72, 0.76, 0.86)	(0.06, 0.12, 0.16, 0.26)	(0.44, 0.54, 0.58, 0.68)	(0.04, 0.08, 0.14, 0.24)	(0.02, 0.04, 0.12, 0.22)	(0.24, 0.3, 0.35, 0.45)
C_{62}	(0.66, 0.76, 0.84, 0.9)	(0.46, 0.56, 0.62, 0.72)	(0.08, 0.16, 0.18, 0.28)	(0.62, 0.72, 0.76, 0.86)	(0.46, 0.56, 0.62, 0.72)	(0.46, 0.55, 0.6, 0.7)

Table 5: The weighted sum of distances, the normalized values of them and the appraisal scores

	$\widetilde{sp}_i$	$\widetilde{sn}_i$	$\widetilde{ns}_i$	$\widetilde{nsn}_i$	$\widetilde{as}_i$	$\kappa(\widetilde{sp}_i)$
A_1	(-0.83, 1.8, 3.2, 6.3)	(0.012, 0.15, 0.3, 0.62)	(-0.32, 0.69, 1.2, 2.4)	(0.76, 0.88, 0.94, 1.0)	(0.22, 0.79, 1.1, 1.7)	0.95
A_2	(-1.3, 0.34, 1.1, 3.1)	(-0.57, 0.54, 1.1, 2.4)	(-0.51, 0.13, 0.44, 1.2)	(0.063, 0.57, 0.79, 1.2)	(-0.22, 0.35, 0.61, 1.2)	0.49
A_3	(-0.57, 0.26, 0.72, 1.8)	(0.097, 1.9, 3.0, 5.4)	(-0.22, 0.1, 0.27, 0.7)	(-1.1, -0.13, 0.28, 0.96)	(-0.64, -0.018, 0.28, 0.83)	0.11
A_4	(-0.48, 0.35, 0.88, 2.0)	(-0.19, 1.5, 2.7, 4.9)	(-0.18, 0.13, 0.33, 0.75)	(-0.9, -0.031, 0.41, 1.1)	(-0.54, 0.051, 0.37, 0.91)	0.20
A_5	(-0.72, 1.2, 2.2, 4.6)	(-0.49, 0.21, 0.66, 1.6)	(-0.27, 0.46, 0.84, 1.8)	(0.4, 0.75, 0.92, 1.2)	(0.064, 0.6, 0.88, 1.5)	0.76

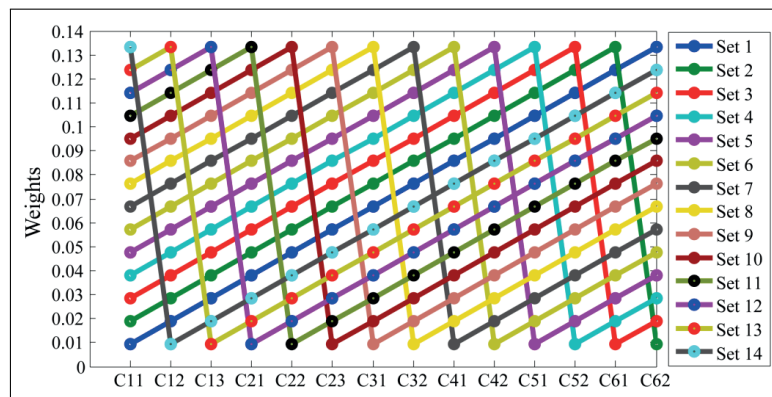


Figure 3: The simulated weights for sensitivity analysis

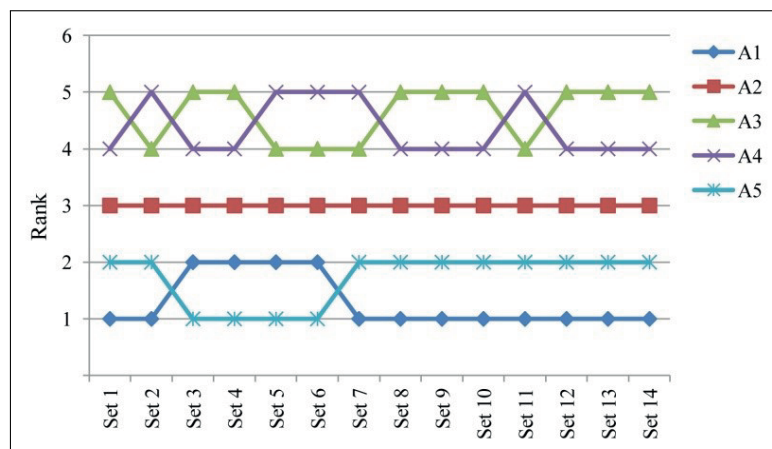


Figure 4: The rank of alternatives in different sets

weights. For example, the best alternative is A_1 or A_5 and the worst alternative is A_3 or A_4 in all sets. To show the changes clearly, the shapes of fuzzy appraisal scores are represented in Figure 5. The smooth changes which can be seen in this figure show that the results of the proposed method are stable when the weights of criteria (sub-criteria) are varied. Therefore, we can say that the proposed fuzzy method is efficient for ranking alternatives in an MCDM problem.

6 Conclusion

Multi-criteria decision-making is an important sub-discipline of operations research that considers multiple criteria in the decision-making process. Due to uncertainty of data in this process, the problems cannot precisely be modeled by crisp values. Fuzzy MCDM methods are efficient tools to deal with the uncertain decision-making problems and have been used widely because of their ability to solve a broad range of problems in different application fields. These methods can be used in the decision-making software to make some efficient decision support systems [1], [11], [32]. The method presented in this paper will be a basis for development of a novel fuzzy decision-making software or decision support systems, which supports fuzzy data and allows to solve different problems. In this research, the EDAS method, which is an efficient MCDM method, has been developed to handle fuzzy multi-criteria decision-making problems. Linguistic terms determined by trapezoidal fuzzy numbers have been utilized for extending this method. We have used this method in a case study of supplier selection to illustrate the proce-

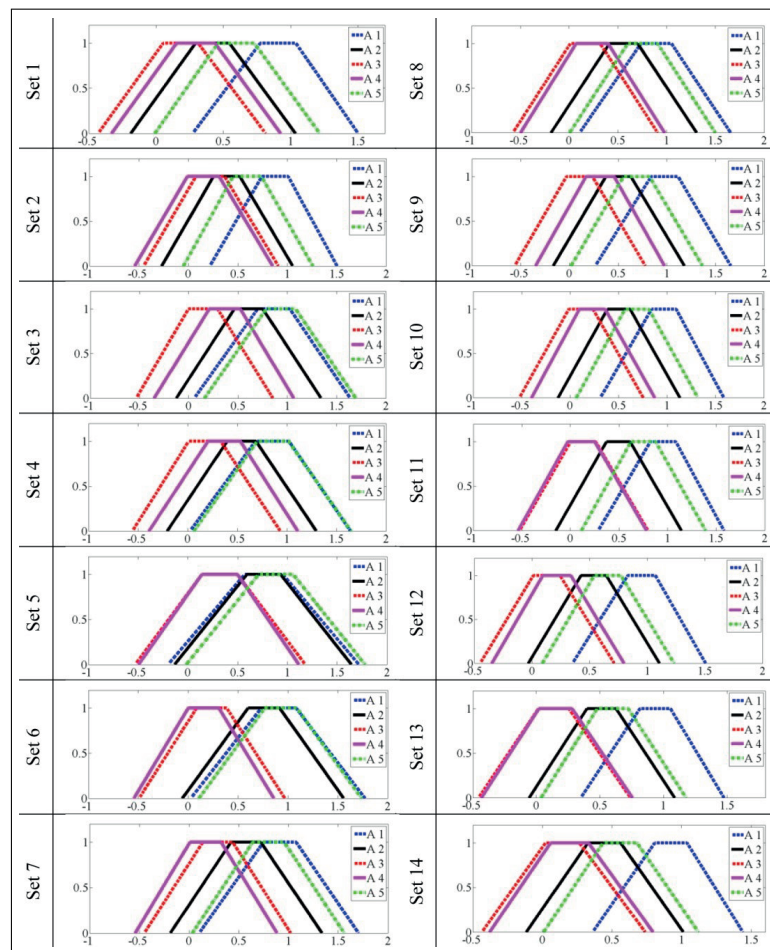


Figure 5: The fuzzy appraisal scores of alternatives in each sets of criteria weight

ture of the proposed method and show the applicability of it in the real-world MCDM problems. A sensitivity analysis has been performed to represent the stability of the results. We have simulated 14 sets of criteria weights to perform this analysis. In each of these sets, one criterion (sub-criterion) has the highest and one criterion (sub-criterion) has the lowest weight. The result of the sensitivity analysis shows the stability of the fuzzy EDAS method in solving multi-criteria decision-making problems.

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