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FUZZY EXTENSION OF THE CODAS METHOD FOR MULTI-CRITERIA MARKET SEGMENT EVALUATION

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Abstract. One of the important activities of a company that can increase its competitiveness is market segment evaluation and selection (MSE/MSS). We can usually consider MSE/MSS as a multi-criteria decision-making (MCDM) problem, and so we need to use an MCDM method to handle it. Uncertainty is one of the important factors that can affect the process of decision-making. Fuzzy MCDM approached have been designed to deal with the uncertainty of decision-making problems. In this study, a fuzzy extension of the CODAS (COmbinative Distance-based ASsessment) method is proposed to solve multi-criteria group decision-making problems. We use linguistic variables and trapezoidal fuzzy numbers to extend the CODAS method. The proposed fuzzy CODAS method is applied to an example of market segment evaluation and selection problem under uncertainty. To validate the results, a comparison is performed between the fuzzy CODAS and two other MCDM methods (fuzzy EDAS and fuzzy TOPSIS). A sensitivity analysis is also carried out to demonstrate the stability of the results of the fuzz CODAS. For this aim, ten sets of criteria weights are randomly generated and the example is solved using each set separately. The results of the comparison and the sensitivity analysis show that the proposed fuzzy CODAS method gives valid and stable results.

Keywords: market segment evaluation, market segment selection, MCDM, decision-making, fuzzy MCDM, fuzzy CODAS.

JEL Classification: D40, M30, D81, C44, C61.

Introduction

Market segmentation becomes an essential element of marketing in industrial companies, since it helps to find homogeneous market segments and to expand company's market (Wedel, Kamakura 2012). The dividing process of a business market into some sub-groups of consumers, which are known as segments, is defined as market segmentation. In this definition, the business market can consist of existing and potential customers, and the segmentation is performed based on some characteristics which are common in the sub-groups. The resulted market segments are expected to have similar purchasing behavior (Dibb, Simkin 2008). Porter (2008) pointed out three generic types of strategies: cost leadership, differentiation and market segmentation which are usually used by diversified businesses to achieve competitive advantages. Geographic, demographic, psychographic, benefits sought and usage rate are some of different bases for market segmentation (Lamb *et al.* 2011). Montoya-Weiss and Calantone (1999) described four steps in the market segmentation process which include problem structuring, segment formation, segment evaluation and selection and description of segment strategy. After performing market segmentation, companies need to evaluate the resulted segments and select the most appropriate one(s). This evaluation and selection process can be considered as a critical managerial decision because it may affect other decisions related to marketing strategy (Wind, Thomas 1994). An overall review of academic researches indicates that existing studies have relatively neglected the process of market segment evaluation and selection.

Market segment evaluation and selection (MSE/MSS) problem usually involves some potential alternatives which need to be evaluated with respect to some potential criteria. Therefore, the MSE/MSS problem can be viewed as a multi-criteria decision-making (MCDM) problem. MCDM approaches are very useful in many disciplines of engineering and management such as transportation (Camargo Pérez *et al.* 2015; Barić *et al.* 2016), location selection (Kouchaksaraei *et al.* 2015; Ebrahimi, Mirzayi Modam 2016), tourism management (Hashemkhani Zolfani *et al.* 2015; Ranjan *et al.* 2016), supply chain management (Shahryari Nia *et al.* 2016), inventory management (Keshavarz Ghorabaee *et al.* 2015) and financial management (Shen, Tzeng 2016). Interested readers are referred to the recent review article about MCDM methods and their applications (Mardani *et al.* 2015), review of MCDM applications in transportation systems (Mardani *et al.* 2016) and developments of the TOPSIS method for decision-making problems (Zavadskas *et al.* 2016).

Some researchers have also studied on the application of MCDM methods in MSE/MSS problem. Dat *et al.* (2015) proposed an integrated MCDM method based on the quality function deployment (QFD) and TOPSIS (Technique for Order of Preference by Similarity to Ideal Solution) method for market segments evaluation and selection. Aghdaie and Alimardani (2015) presented a hybrid approach based on the AHP and TOPSIS methods for multi-criteria evaluation of market segments and validated in by using a case study. Mohammadi Nasrabadi *et al.* (2013) used the SPACE (Strategic Position & ACtion Evaluation) and dynamic network process (DNP) to propose a modular decision support system for MSE/MSS problem. In a research, Ou *et al.* (2009) developed a fuzzy MCDM approach for strategy-aligned market segment evaluation and selection. Based on the Porter's five forces model of competition (Porter 1979), which is depicted in Figure 1, Ou *et al.* (2009) presented the criteria and sub-criteria for evaluation and selection of market segments. Table 1 shows these criteria and sub-criteria which are used in the current study for evaluation process.

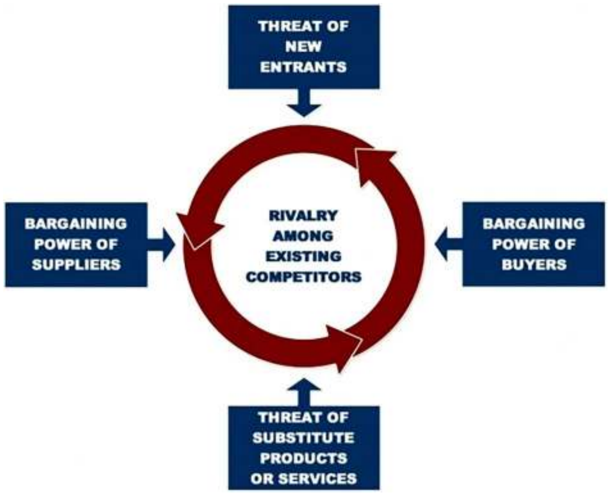

Fig. 1. Porter's five forces of competition

In the process of decision-making, we are usually confronted with uncertain information related to human thinking, judgment and reasoning. This type of uncertainty is usually handled by using the fuzzy sets theory in the MCDM problems. Many researchers have developed and applied some methods and techniques to deal with MCDM problems in fuzzy environments. Fuzzy TOPSIS method (Chen 2000), fuzzy AHP (Chang 1996), fuzzy VIKOR (VIseKriterijumska Optimizacija I Kompromisno Resenje) (Wang and Chang 2005), and fuzzy EDAS (Evaluation based on Distance from Average Solution) (Keshavarz Ghorabaee *et al.* 2016a) are some of extended MCDM methods in fuzzy environment. The fuzzy MCDM methods have been applied to many real-life problems (Aliakbari Nouri *et al.* 2015; Khandekar, Chakraborty 2015; Hosseini *et al.* 2016; Vinodh *et al.* 2016). Kahraman *et al.* (2015) performed a review on the fuzzy MCDM methods and their applications. We can see that some of the above mentioned studies on market segment evaluation and selection also utilized the fuzzy set theory to model the uncertainty of problem, and this fact shows the importance of using fuzzy MCDM approaches in MSE/MSS problems.

In this study, a fuzzy extension of the CODAS (COmbinative Distance-based ASsessment) method is developed to deal with multi-criteria decision-making problems in an uncertain environment. The CODAS methods is a new and efficient method which was proposed by Keshavarz Ghorabaee *et al.* (2016b). In the current research, we use the linguistic variables and trapezoidal fuzzy numbers to extend the CODAS method

Table 1. Segment evaluation and selection criteria (Ou *et al.* 2009)

Criteria	Sub-criteria
The bargaining power of customers	Buyer concentration to firm concentration ratio
	Bargaining leverage
	Buyer volume
	Buyer switching costs relative to firm switching costs
	Buyer information availability
	Ability to backward integrate
	Availability of existing substitute products
	Buyer price sensitivity
	Price of total purchase
The bargaining power of suppliers	Supplier switching costs relative to firm switching costs
	Degree of differentiation of inputs
	Presence of substitute inputs
	Supplier concentration to firm concentration ratio
	Threat of forward integration by suppliers relative to the threat of backward integration by firms
	Cost of inputs relative to selling price of the product
	Importance of volume to supplier
The threat of new entrants	The existence of barriers to entry
	Economies of product differences
	Brand equity
	Switching costs
	Capital requirements
	Expected retaliation
	Absolute cost advantages
	Learning curve advantages
	Government policies
The threat of substitute products	Buyer propensity to substitute
	Relative price performance of substitutes
	Buyer switching costs
	Perceived level of product differentiation
The intensity of competitive rivalry	Number of competitors
	Rate of industry growth
	Intermittent industry overcapacity
	Exit barriers
	Diversity of competitors
	Informational complexity and asymmetry
	Fixed cost allocation per value added
	Level of advertising expense

and propose a multi-criteria group decision-making approach. A numerical example of a shoe company is utilized to show the applicability of the fuzzy CODAS method in multi-criteria market segment evaluation and selection. For validating the proposed method, we compare the results with the results of the fuzzy EDAS and fuzzy TOPSIS methods. A sensitivity analysis is also performed to demonstrate the stability of the ranking results of the fuzzy CODAS method.

The rest of this paper is organized as follows. In Section 1, some basic concepts and definitions of fuzzy sets and fuzzy numbers are presented. In Section 2, an extension of the CODAS method is proposed to handle fuzzy multi-criteria group decision-making. Then the proposed fuzzy CODAS method is applied to an example of multi-criteria evaluation of market segments in Section 3. In this section, we also perform a comparison and a sensitivity analysis to demonstrate the validity and stability of the results. Sensitivity analysis results are discussed in Section 4. Finally, the conclusions are presented.

1. Preliminaries

The fuzzy sets theory, which was proposed by Zadeh (1965), is the most efficient tool to handle the uncertainty in many real-life problems and different disciplines of science and engineering. Fuzzy logic provides an inference morphology that enables approximate human reasoning capabilities to be applied to knowledge-based systems. The theory of fuzzy sets provides a mathematical tool to capture the uncertainties associated with human cognitive processes, such as thinking and reasoning. Multi- criteria decision-making is one of the important processes that involve human thinking and reasoning. Thus the theory of fuzzy sets could be very useful to model the uncertainty of MCDM problems. In the following, we present some definitions related to this theory.

Definition 1. In a universal set *X*, a fuzzy subset $\tilde{M}$ is defined by a membership function $\mu_{\tilde{M}}(x)$ as follows (Zimmermann 2010):

$$\tilde{M} = \left\{ \left(x, \mu_{\tilde{M}}(x) \right) | x \in X \right\}, \tag{1}$$

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

Definition 2. A fuzzy number is a special case of a convex, normalized fuzzy subset ($\sup \mu_{\tilde{M}}(x) = 1$) of the real line $\mathbb{R}$ ($\mu_{\tilde{M}}(x): \mathbb{R} \to [0,1]$) (Wang, Lee 2007).

Definition 3. If the membership function of a fuzzy number $\tilde{M}$ follows the following form, it is called the trapezoidal fuzzy number (Ölçer, Odabaşi 2005):

$$\mu_{\tilde{M}}(x) = \begin{cases} (x - m_1)/(m_2 - m_1), & m_1 \le x \le m_2 \\ 1, & m_2 \le x \le m_3 \\ (m_4 - x)/(m_4 - m_3), & m_3 \le x \le m_4 \\ 0, & \text{otherwise} \end{cases}. \tag{2}$$

A quadruplet $\tilde{M} = (m_1, m_2, m_3, m_4)$ can also be used to define this fuzzy number. Figure 2 shows an example of this type of fuzzy numbers.

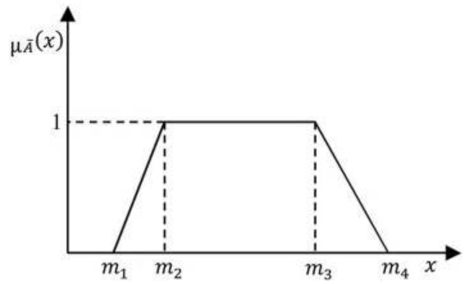

Fig. 2. Trapezoidal fuzzy number

Definition 4. Suppose that k is a crisp number. The arithmetic operations of two positive trapezoidal fuzzy numbers $\tilde{M} = (m_1, m_2, m_3, m_4)$ and $\tilde{N} = (n_1, n_2, n_3, n_4)$ where $m_1 \geq 0$ and $n_1 \geq 0$ are defined as follows (Chen, Hwang 1992):

– Addition:

$$\tilde{M} \oplus \tilde{N} = (m_1 + n_1, m_2 + n_2, m_3 + n_3, m_4 + m_4); \tag{3}$$

$$\tilde{M} + k = (m_1 + k, m_2 + k, m_3 + k, m_4 + k). \tag{4}$$

– Subtraction:

$$\tilde{M} \ominus \tilde{N} = (m_1 - n_4, m_2 - n_3, m_3 - n_2, m_4 - n_1); \tag{5}$$

$$\tilde{M} - k = (m_1 - k, m_2 - k, m_3 - k, m_4 - k). \tag{6}$$

– Multiplication:

$$\tilde{M} \otimes \tilde{N} = (m_1 \times n_1, m_2 \times n_2, m_3 \times n_3, m_4 \times n_4); \tag{7}$$

$$\tilde{M} \times k = \begin{cases} (m_1 \times k, m_2 \times k, m_3 \times k, m_4 \times k) & if \quad k \geq 0 \\ (m_4 \times k, m_3 \times k, m_2 \times k, m_1 \times k) & if \quad k < 0 \end{cases}. \tag{8}$$

– Division:

$$\tilde{M} \oslash \tilde{M} = (m_1 / n_4, m_2 / m_3, m_3 / n_2, m_4 / n_1); \tag{9}$$

$$\tilde{M} / k = \begin{cases} (m_1 / k, m_2 / k, m_3 / k, m_4 / k) & if \quad k > 0 \\ (m_4 / k, m_3 / k, m_2 / k, m_1 / k) & if \quad k < 0 \end{cases}. \tag{10}$$

Definition 5. The defuzzified (crisp) value of a fuzzy number $\tilde{M} = (m_1, m_2, m_3, m_4)$ is defined as follows (Wang *et al.* 2006):

$$\mathfrak{D}(\tilde{A}) = \frac{1}{3}\left(m_1 + m_2 + m_3 + m_4 - \frac{m_3 m_4 - m_1 m_2}{(m_3 + m_4) - (m_1 + m_2)} \right). \tag{11}$$

Definition 6. The weighted Euclidean (d_E) and weighted Hamming (d_H) distances between two trapezoidal fuzzy numbers $\tilde{M} = (m_1, m_2, m_3, m_4)$ and $\tilde{N} = (n_1, n_2, n_3, n_4)$ are defined as follows (Li 2007):

$$d_E(\tilde{M}, \tilde{N}) = \sqrt{\frac{(m_1 - n_1)^2 + 2(m_2 - n_2)^2 + 2(m_3 - n_3)^2 + (m_4 - n_4)^2}{6}}; \tag{12}$$

$$d_H\left(\tilde{M},\tilde{N}\right)=\frac{|m_1-n_1|+2|m_2-n_2|+2|m_3-n_3|+|m_4-n_4|}{6}. \tag{13}$$

2. Fuzzy CODAS method

In this section, we propose a fuzzy extension of the CODAS method to deal with multi-criteria decision-making problems. As previously stated, the CODAS method is a new and efficient MCDM method which introduced by Keshavarz Ghorabaee *et al.* (2016b) recently. The desirability of alternatives in the CODAS method is determined based on l^1-norm and l^2-norm indifference spaces for criteria. According to these spaces, in the procedure of this method, a combinative form of the Euclidean and Taxicab distances is utilized for calculation of the assessment score of alternatives. However, the Euclidean and Taxicab distances are defined in a crisp environment and we cannot use them in fuzzy problems. The aim of this study is to develop a fuzzy extension of the CODAS method. In order to reach this aim, we use the fuzzy weighted Euclidean distance and fuzzy weighted Hamming distance, which were presented by Li (2007) (Definition 6), instead of the crisp distances. Suppose that we have n alternatives and m criteria and q decision-makers (DMs). The steps of the fuzzy CODAS method for multi-criteria group decision-making are presented as follows:

Step 1. Construct the fuzzy decision matrix ($\tilde{X}_l$) of each decision-maker and compute the average fuzzy decision matrix ($\tilde{X}$) as follows:

$$\tilde{X}_l=\left[\tilde{x}_{ijl}\right]_{n\times m}=\begin{bmatrix}\tilde{x}_{11l} & \tilde{x}_{12l} & \cdots & \tilde{x}_{1ml}\\ \tilde{x}_{21l} & \tilde{x}_{22l} & \cdots & \tilde{x}_{2ml}\\ \vdots & \vdots & \vdots & \vdots\\ \tilde{x}_{n1l} & \tilde{x}_{n2l} & \cdots & \tilde{x}_{nml}\end{bmatrix}; \tag{14}$$

$$\tilde{X}=\left[\tilde{x}_{ij}\right]_{n\times m}=\begin{bmatrix}\tilde{x}_{11} & \tilde{x}_{12} & \cdots & \tilde{x}_{1m}\\ \tilde{x}_{21} & \tilde{x}_{22} & \cdots & \tilde{x}_{2m}\\ \vdots & \vdots & \vdots & \vdots\\ \tilde{x}_{n1} & \tilde{x}_{n2} & \cdots & \tilde{x}_{nm}\end{bmatrix}; \tag{15}$$

$$\tilde{x}_{ij}=\bigoplus_{l=1}^{q}\tilde{x}_{ijl}, \tag{16}$$

where $\tilde{x}_{ijl}$ denotes the fuzzy performance value of ith ($i\in 1,2,\ldots,n\}$) alternative with respect to jth criterion ($j\in\{1,2,\ldots,m\}$) and lth ($l\in 1,2,\ldots,q\}$) decision-maker, and $\tilde{x}_{ij}$ shows the average fuzzy performance value of ith alternative with respect to jth criterion.

Step 2. Obtain the fuzzy weight of each criterion from each decision-maker and calculate average fuzzy weights as follows:

$$\tilde{W}_l = \left[\tilde{w}_{jl} \right]_{1\times m}; \tag{17}$$

$$\tilde{W} = \left[\tilde{w}_j \right]_{1\times m}; \tag{18}$$

$$\tilde{w}_j = \bigoplus_{l=1}^{q} \tilde{w}_{jl}, \tag{19}$$

where $\tilde{w}_{jl}$ denotes the fuzzy weight of jth criterion ($j \in \{1,2,\ldots,m\}$) with respect to lth ($l \in \{1,2,\ldots,q\}$) decision-maker, and $\tilde{w}_j$ shows the average fuzzy weight of jth criterion.

Step 3. Determine fuzzy normalized decision matrix according to the type of each criterion using the following equations:

$$\tilde{N} = \left[\tilde{n}_{ij} \right]_{n\times m}; \tag{20}$$

$$\tilde{n}_{ij} = \begin{cases} \tilde{x}_{ij} / \max_i \mathfrak{D}\left(\tilde{x}_{ij}\right) & \text{if } j \in B \\ 1 - \left(\tilde{x}_{ij} / \max_i \mathfrak{D}\left(\tilde{x}_{ij}\right) \right) & \text{if } j \in C \end{cases}, \tag{21}$$

where B and C represent the sets of benefit and cost criteria, respectively, and $\tilde{n}_{ij}$ denotes the normalized fuzzy performance values.

Step 4. Calculate fuzzy weighted normalized decision matrix. The fuzzy weighted normalized performance values ($\tilde{r}_{ij}$) are calculated as follows:

$$\tilde{R} = \left[\tilde{r}_{ij} \right]_{n\times m}; \tag{22}$$

$$\tilde{r}_{ij} = \tilde{w}_j \otimes \tilde{n}_{ij}, \tag{23}$$

where $\tilde{w}_j$ denotes the fuzzy weight of jth criterion, and $0 < \mathfrak{D}\left(\tilde{w}_j\right) < 1$.

Step 5. Determine fuzzy negative-ideal solution as follows:

$$\widetilde{NS} = \left[\widetilde{ns}_j \right]_{1\times m}; \tag{24}$$

$$\widetilde{ns}_j = \min_i \tilde{r}_{ij}, \tag{25}$$

where $\min_i \tilde{r}_{ij} = \left\{ \tilde{r}_{kj} \mid \mathfrak{D}\left(\tilde{r}_{kj}\right) = \min_i \left(\mathfrak{D}\left(\tilde{r}_{ij}\right)\right),\ k \in \{1,2,\ldots,n\} \right\}$.

Step 6. Calculate the fuzzy weighted Euclidean (ED_i) and fuzzy weighted Hamming (HD_i) distances of alternatives from the fuzzy negative-ideal solution, shown as follows:

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

$$HD_i = \sum_{j=1}^{m} d_H\left(\tilde{r}_{ij}, \widetilde{ns}_j\right). \quad (27)$$

Step 7. Determine relative assessment matrix (*RA*), shown as follows:

$$RA = \left[p_{ik}\right]_{n \times n}; \quad (28)$$

$$p_{ik} = \left(ED_i - ED_k\right) + \left(t\left(ED_i - ED_k\right) \times \left(HD_i - HD_k\right)\right), \quad (29)$$

where $k \in \{1, 2, \ldots, n\}$ and t is a threshold function that is defined as follows:

$$t(x) = \begin{cases} 1 & if \quad |x| \geq \theta \\ 0 & if \quad |x| < \theta \end{cases}. \quad (30)$$

The threshold parameter (θ) of this function can be set by decision-maker. In this study, we use θ = 0.02 for the calculations.

Step 8. Calculate the assessment score (AS_i) of each alternative, shown as follows:

$$AS_i = \sum_{k=1}^{n} p_{ik}. \quad (31)$$

Step 9. According to the decreasing values of assessment scores, we can rank the alternatives. The alternative with the highest assessment score is the most desirable alternative.

3. Application of the fuzzy CODAS in MSS/MSE

In this section, we use an example of multi-criteria strategy-aligned market segment evaluation to show the applicability of the proposed fuzzy CODAS method. The example is related to a shoe company which decides to expand its market. The company needs to evaluate some potential market segments and select the most appropriate of them for future investment. In the first step, the executive director and general manager of the company made an initial evaluation on some potential market segments based on their expected profitability and reached five market segments (S_1 to S_5) for further evaluation. They formed a group of five experts (D_1 to D_5), which we call decision-making group, including marketing manager, financial manager, purchasing manager, customer service manager and research and development manager to perform the final evaluation. Then the decision-making group selected the most important evaluation criteria (sub-criteria) according to the criteria defined by Ou *et al.* (2009) and shown in Table 1. The hierarchical structure of the problem is represented in Figure 3. As can be seen in this figure, we have five alternatives that need to be evaluated with respect to sixteen criteria. To make this evaluation, the decision-makers express their assessments using linguistic variables. The linguistic variables for weighting criteria and the linguistics variables for rating alternatives are shown in Table 2. In the following, the steps of using the proposed fuzzy CODAS method for the evaluation of market segments are presented:

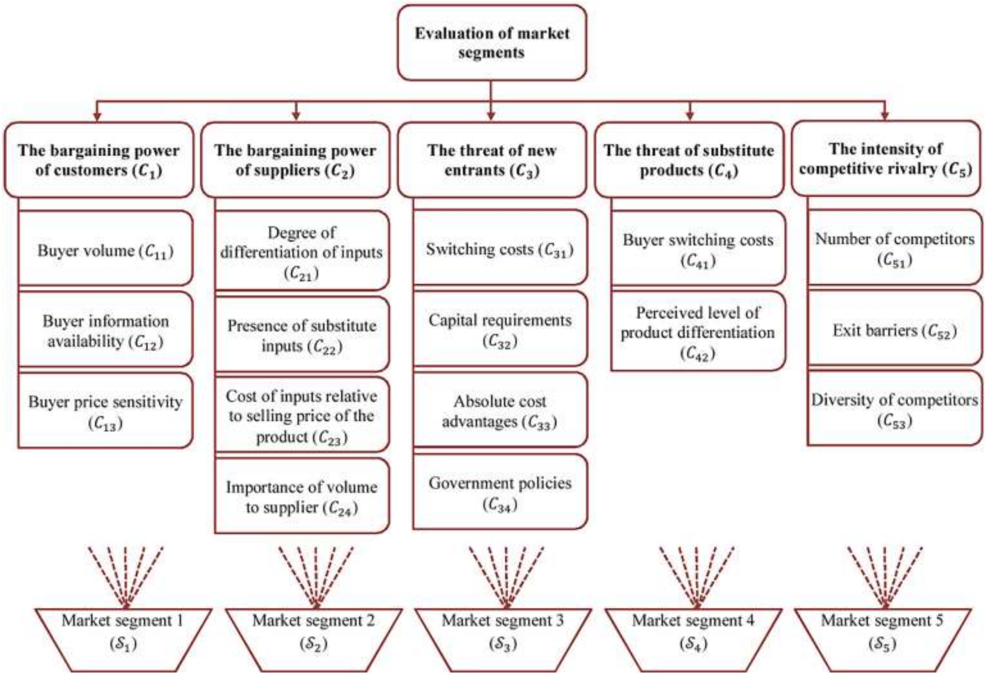

Fig. 3. Hierarchical structure of the problem

Table 2. Linguistic variables and their fuzzy numbers

Usage	Linguistic variable	Trapezoidal fuzzy number
For weighting criteria	Very low (VL)	(0,0, 0.1, 0.2)
	Low (L)	(0.1, 0.2, 0.2, 0.3)
	Medium low (ML)	(0.2, 0.3, 0.4, 0.5)
	Medium (M)	(0.4, 0.5, 0.5, 0.6)
	Medium high (MH)	(0.5, 0.6, 0.7, 0.8)
	High (H)	(0.7, 0.8, 0.8, 0.9)
	Very high (VH)	(0.8, 0.9, 1,1)
For rating alternatives	Very poor (VP)	(0, 0, 1, 2)
	Poor (P)	(1, 2, 2, 3)
	Medium poor (MP)	(2, 3, 4, 5)
	Fair (F)	(4, 5, 5, 6)
	Medium good (MG)	(5, 6, 7, 8)
	Good (G)	(7, 8, 8, 9)
	Very good (VG)	(8, 9, 10, 10)

Step 1. The decision-makers expressed their assessments of alternatives on each criterion using the linguistic variables presented in Table 2. The assessments of decision-makers (decision matrix of each DM) are shown in Table 3. Based on this table and Eqs. (14) to (16) the average fuzzy decision matrix is calculated. The results are shown in Table 4.

Table 3. Ratings of the alternatives on each criterion by each DM

		C_{11}	C_{12}	C_{13}	C_{21}	C_{22}	C_{23}	C_{24}	C_{31}	C_{32}	C_{33}	C_{34}	C_{41}	C_{42}	C_{51}	C_{52}	C_{53}
D_1	S_1	P	G	MP	G	F	MG	VP	F	VG	G	F	MG	G	P	VG	F
	S_2	P	G	F	VG	F	F	P	MP	G	MG	F	F	G	P	G	G
	S_3	VP	MG	F	VG	MG	G	VP	MP	VG	G	MP	MG	F	MP	G	G
	S_4	MP	MG	MP	G	MG	G	P	F	VG	G	F	MG	MG	MP	VG	VG
	S_5	P	MG	F	MG	F	MG	MP	MP	G	MG	MP	F	F	F	MG	VG
D_2	S_1	F	G	F	G	MG	MP	MP	G	VG	G	F	MP	VG	MG	P	F
	S_2	F	G	MP	VG	MG	F	P	VG	VG	MG	F	F	G	MG	P	MG
	S_3	MG	VG	F	G	G	F	VP	G	G	MG	MG	F	G	G	MP	F
	S_4	MG	VG	MP	G	MG	F	VP	VG	VG	MG	F	MP	MG	G	P	MG
	S_5	F	G	F	MG	G	MP	MP	G	G	F	MG	F	MG	MG	MP	G
D_3	S_1	P	F	VP	MG	P	VP	G	MP	P	MG	MP	F	G	F	VP	F
	S_2	VP	MG	P	G	MP	VP	MG	F	MP	MG	VP	MG	MG	MP	VP	MG
	S_3	P	F	P	F	F	P	F	F	MP	F	P	F	MG	MP	P	F
	S_4	MP	F	MP	G	MP	P	F	MP	P	MG	MP	F	F	P	P	F
	S_5	P	F	VP	F	P	VP	MG	F	P	F	P	MP	F	F	VP	MG
D_4	S_1	VG	G	G	MG	P	VG	F	G	VG	F	MP	G	F	VG	F	MG
	S_2	VG	MG	VG	MG	MP	VG	F	G	G	F	F	F	G	VG	MP	MG
	S_3	G	MG	VG	F	F	G	MG	VG	MG	MG	F	F	F	G	MP	G
	S_4	G	G	VG	F	F	G	MG	G	MG	F	F	F	G	G	F	G
	S_5	VG	G	G	MG	F	MG	G	G	G	F	MP	MG	MG	VG	F	MG
D_5	S_1	P	VP	F	G	F	G	VP	MP	G	VP	VG	G	MP	G	P	VG
	S_2	MP	VP	F	G	MG	VG	VP	P	G	VP	VG	G	P	G	P	G
	S_3	MP	P	MG	VG	MG	VG	VP	P	MG	VP	G	MG	P	VG	F	G
	S_4	MP	P	G	VG	F	G	P	P	MG	P	MG	F	F	MG	MP	MG
	S_5	P	P	G	G	F	G	P	MP	MG	MP	G	F	F	MG	P	VG

Table 4. Average fuzzy decision matrix

	S_1	S_2	S_3	S_4	S_5
C_{11}	(1, 1.8, 2.2, 3.2)	(4.4, 5.4, 5.8, 6.8)	(1, 1.8, 2.2, 3.2)	(7.6, 8.6, 9.2, 9.6)	(1.6, 2.6, 3.2, 4.2)
C_{12}	(5.8, 6.8, 7.4, 8.4)	(7.4, 8.4, 8.8, 9.4)	(4.2, 5.2, 5.4, 6.4)	(6.2, 7.2, 7.6, 8.6)	(0.60, 1.2, 1.6, 2.6)
C_{13}	(3.2, 4.2, 4.6, 5.6)	(3.2, 4.2, 4.6, 5.6)	(0.80, 1.4, 2, 3)	(7.6, 8.6, 9.2, 9.6)	(5.4, 6.4, 6.6, 7.6)
C_{21}	(7, 8, 8.6, 9.2)	(6.8, 7.8, 8.2, 9)	(5.4, 6.4, 6.6, 7.6)	(4.6, 5.6, 6.2, 7.2)	(7.4, 8.4, 8.8, 9.4)
C_{22}	(4.4, 5.4, 5.8, 6.8)	(5.8, 6.8, 7.4, 8.4)	(2, 3, 3.4, 4.4)	(3, 4, 4.2, 5.2)	(4.4, 5.4, 5.8, 6.8)
C_{23}	(5.6, 6.6, 7, 8)	(3.2, 4.2, 4.6, 5.6)	(0.40, 0.80, 1.4, 2.4)	(7, 8, 8.6, 9.2)	(7.4, 8.4, 8.8, 9.4)
C_{24}	(0.80, 1.4, 2, 3)	(1, 1.6, 2.4, 3.4)	(5, 6, 6.4, 7.4)	(5, 6, 6.4, 7.4)	(0.40, 0.80, 1.4, 2.4)
C_{31}	(2.8, 3.8, 4.4, 5.4)	(7.4, 8.4, 8.8, 9.4)	(3.2, 4.2, 4.6, 5.6)	(7.2, 8.2, 8.4, 9.2)	(1.4, 2.4, 2.8, 3.8)
C_{32}	(7.6, 8.6, 9.2, 9.6)	(7.6, 8.6, 9.2, 9.6)	(1.4, 2.4, 2.8, 3.8)	(6.4, 7.4, 8, 8.8)	(5.8, 6.8, 7.4, 8.4)
C_{33}	(6.2, 7.2, 7.6, 8.6)	(5.2, 6.2, 6.8, 7.8)	(4.6, 5.6, 6.2, 7.2)	(4.2, 5.2, 5.4, 6.4)	(0.60, 1, 1.8, 2.8)
C_{34}	(3.2, 4.2, 4.6, 5.6)	(4.4, 5.4, 5.8, 6.8)	(1.2, 2, 2.6, 3.6)	(3.2, 4.2, 4.6, 5.6)	(7, 8, 8.6, 9.2)
C_{41}	(4.6, 5.6, 6.2, 7.2)	(3.2, 4.2, 4.6, 5.6)	(3.8, 4.8, 5.2, 6.2)	(4.8, 5.8, 6, 7)	(5.4, 6.4, 6.6, 7.6)
C_{42}	(5.4, 6.4, 6.6, 7.6)	(6.4, 7.4, 8, 8.8)	(5, 6, 6.4, 7.4)	(5.4, 6.4, 6.6, 7.6)	(2.4, 3.4, 3.6, 4.6)
C_{51}	(2, 3, 3.4, 4.4)	(5.8, 6.8, 7.4, 8.4)	(2.6, 3.6, 4, 5)	(7.6, 8.6, 9.2, 9.6)	(6.4, 7.4, 8, 8.8)
C_{52}	(7, 8, 8.6, 9.2)	(1.4, 2.4, 2.8, 3.8)	(0.40, 0.80, 1.4, 2.4)	(3.2, 4.2, 4.6, 5.6)	(1.8, 2.8, 3, 4)
C_{53}	(6.8, 7.8, 8.2, 8.8)	(5, 6, 6.4, 7.4)	(4.4, 5.4, 5.8, 6.8)	(5.8, 6.8, 7.4, 8.4)	(7, 8, 8.6, 9.2)

Table 5. Importance of the criteria and average fuzzy weights

		D_1	D_2	D_3	D_4	D_5	Average
C_1	C_{11}	VL	L	L	ML	L	(0.1, 0.18, 0.22, 0.32)
	C_{12}	H	MH	H	M	MH	(0.56, 0.66, 0.7, 0.8)
	C_{13}	VH	VH	VH	H	H	(0.76, 0.86, 0.92, 0.96)
C_2	C_{21}	M	MH	M	M	MH	(0.44, 0.54, 0.58, 0.68)
	C_{22}	VL	ML	ML	L	L	(0.12, 0.2, 0.26, 0.36)
	C_{23}	H	H	MH	H	MH	(0.62, 0.72, 0.76, 0.86)
	C_{24}	MH	M	M	ML	M	(0.38, 0.48, 0.52, 0.62)
C_3	C_{31}	L	ML	L	M	ML	(0.2, 0.3, 0.34, 0.44)
	C_{32}	M	M	MH	MH	MH	(0.46, 0.56, 0.62, 0.72)
	C_{33}	VL	VL	L	VL	L	(0.04, 0.08, 0.14, 0.24)
	C_{34}	L	L	L	VL	VL	(0.06, 0.12, 0.16, 0.26)
C_4	C_{41}	H	H	VH	VH	H	(0.74, 0.84, 0.88, 0.94)
	C_{42}	VH	H	H	MH	MH	(0.64, 0.74, 0.8, 0.88)
C_5	C_{51}	ML	M	ML	M	M	(0.32, 0.42, 0.46, 0.56)
	C_{52}	L	ML	L	ML	ML	(0.16, 0.26, 0.32, 0.42)
	C_{53}	H	MH	M	MH	M	(0.5, 0.6, 0.64, 0.74)

Step 2. The decision-makers evaluated the selected criteria and weighted them by using linguistic variables. Based on the evaluations of DMs and Eqs. (17) to (19), the average fuzzy weights are calculated. Table 5 presents the evaluation of decision-makers and average fuzzy weights of the criteria.

Steps 3 to 6. According to the results of Step 1 and Eqs. (20) and (21), the fuzzy normalized decision matrix can be determined. Then the average fuzzy weights of criteria (Table 5) and Eqs. (22) and (23) are utilized for calculating the fuzzy weighted normalized decision matrix. Afterwards, we need to compute the fuzzy negative-ideal solution based on Eqs (24) and (25). By using the elements of the fuzzy weighted normalized decision matrix, the fuzzy negative-ideal solution and Eqs. (26) and (27), we can calculate the fuzzy weighted Euclidean and fuzzy weighted Hamming distances of each alternative. The results of these steps are shown in Table 6.

Table 6. Fuzzy weighted normalized matrix, negative-ideal solution and distances

	S_1	S_2	S_3	S_4	S_5	$\widetilde{ns}_j$
C_{11}	(0.01, 0.04, 0.06, 0.12)	(0.05, 0.11, 0.15, 0.25)	(0.01, 0.04, 0.06, 0.12)	(0.09, 0.18, 0.23, 0.35)	(0.02, 0.05, 0.08, 0.15)	(0.01, 0.04, 0.06, 0.12)
C_{12}	(0.38, 0.53, 0.61, 0.79)	(0.49, 0.65, 0.73, 0.89)	(0.28, 0.4, 0.45, 0.6)	(0.41, 0.56, 0.63, 0.81)	(0.04, 0.09, 0.13, 0.25)	(0.04, 0.09, 0.13, 0.25)
C_{13}	(0.28, 0.41, 0.49, 0.62)	(0.28, 0.41, 0.49, 0.62)	(0.07, 0.14, 0.21, 0.33)	(0.66, 0.85, 0.97, 1.06)	(0.47, 0.63, 0.7, 0.84)	(0.07, 0.14, 0.21, 0.33)
C_{21}	(0.36, 0.51, 0.59, 0.74)	(0.35, 0.5, 0.56, 0.72)	(0.28, 0.41, 0.45, 0.61)	(0.24, 0.36, 0.42, 0.58)	(0.38, 0.54, 0.6, 0.75)	(0.24, 0.36, 0.42, 0.58)
C_{22}	(0.07, 0.15, 0.21, 0.34)	(0.1, 0.19, 0.27, 0.43)	(0.03, 0.08, 0.12, 0.22)	(0.05, 0.11, 0.15, 0.26)	(0.07, 0.15, 0.21, 0.34)	(0.03, 0.08, 0.12, 0.22)
C_{23}	(0.41, 0.56, 0.63, 0.81)	(0.23, 0.36, 0.41, 0.57)	(0.03, 0.07, 0.13, 0.24)	(0.51, 0.68, 0.77, 0.93)	(0.54, 0.71, 0.79, 0.95)	(0.03, 0.07, 0.13, 0.24)
C_{24}	(0.05, 0.11, 0.17, 0.3)	(0.06, 0.12, 0.2, 0.34)	(0.31, 0.46, 0.54, 0.74)	(0.31, 0.46, 0.54, 0.74)	(0.02, 0.06, 0.12, 0.24)	(0.02, 0.06, 0.12, 0.24)
C_{31}	(0.07, 0.13, 0.18, 0.28)	(0.17, 0.3, 0.35, 0.49)	(0.08, 0.15, 0.18, 0.29)	(0.17, 0.29, 0.34, 0.48)	(0.03, 0.08, 0.11, 0.2)	(0.03, 0.08, 0.11, 0.2)
C_{32}	(0.4, 0.55, 0.65, 0.79)	(0.4, 0.55, 0.65, 0.79)	(0.07, 0.15, 0.2, 0.31)	(0.34, 0.48, 0.57, 0.73)	(0.31, 0.44, 0.53, 0.69)	(0.07, 0.15, 0.2, 0.31)
C_{33}	(0.03, 0.08, 0.14, 0.28)	(0.03, 0.07, 0.13, 0.25)	(0.02, 0.06, 0.12, 0.23)	(0.02, 0.06, 0.1, 0.21)	(0, 0.01, 0.03, 0.09)	(0, 0.01, 0.03, 0.09)
C_{34}	(0.02, 0.06, 0.09, 0.18)	(0.03, 0.08, 0.11, 0.22)	(0.01, 0.03, 0.05, 0.11)	(0.02, 0.06, 0.09, 0.18)	(0.05, 0.12, 0.17, 0.29)	(0.01, 0.03, 0.05, 0.11)
C_{41}	(0.52, 0.72, 0.84, 1.04)	(0.36, 0.54, 0.62, 0.81)	(0.43, 0.62, 0.7, 0.9)	(0.55, 0.75, 0.81, 1.01)	(0.61, 0.83, 0.89, 1.1)	(0.36, 0.54, 0.62, 0.81)
C_{42}	(0.45, 0.62, 0.69, 0.88)	(0.54, 0.72, 0.84, 1.01)	(0.42, 0.58, 0.67, 0.85)	(0.45, 0.62, 0.69, 0.88)	(0.2, 0.33, 0.38, 0.53)	(0.2, 0.33, 0.38, 0.53)
C_{51}	(0.07, 0.14, 0.18, 0.28)	(0.21, 0.33, 0.39, 0.54)	(0.1, 0.17, 0.21, 0.32)	(0.28, 0.41, 0.49, 0.62)	(0.23, 0.36, 0.42, 0.56)	(0.07, 0.14, 0.18, 0.28)
C_{52}	(0.14, 0.25, 0.34, 0.47)	(0.03, 0.08, 0.11, 0.2)	(0.01, 0.03, 0.05, 0.12)	(0.06, 0.13, 0.18, 0.29)	(0.04, 0.09, 0.12, 0.21)	(0.01, 0.03, 0.05, 0.12)
C_{53}	(0.42, 0.57, 0.64, 0.8)	(0.31, 0.44, 0.5, 0.67)	(0.27, 0.4, 0.45, 0.62)	(0.35, 0.5, 0.58, 0.76)	(0.43, 0.59, 0.67, 0.83)	(0.27, 0.4, 0.45, 0.62)
ED_i	3.067	3.080	1.293	4.102	2.588	
HD_i	3.020	3.026	1.271	4.052	2.560	

Steps 7 to 9. Based on Table 6 and Eqs. (28) to (30) the relative assessment matrix (*RA*) is calculated. As previously mentioned, the value of θ in our computations is 0.02. By using Eq. (31) and the elements of the relative assessment matrix, the assessment score of the alternatives can be calculated. Then the ranking of the alternatives is made based on decreasing values of the assessment scores. The results of these steps are represented in Table 7. According to Table 7, we can say that the market segment 4 is more appropriate than the other alternatives for investment.

Table 7. Relative assessment matrix, appraisal scores and rank of the alternatives

	RA					AS_i	Rank		
	S_1	S_2	S_3	S_4	S_5		Fuzzy CODAS	Fuzzy EDAS	Fuzzy TOPSIS
S_1	0	–0.013	3.522	–2.067	0.938	2.380	3	3	3
S_2	0.013	0	3.541	–2.048	0.958	2.464	2	2	2
S_3	–3.522	–3.541	0	–5.590	–2.584	–15.237	5	5	5
S_4	2.067	2.048	5.590	0	3.006	12.711	1	1	1
S_5	–0.938	–0.958	2.584	–3.006	0	–2.318	4	4	4

To show the validity of the result, we compare it with the result of the fuzzy EDAS (Keshavarz Ghorabaee *et al.* 2016a) and fuzzy TOPSIS (Chen 2000; Roszkowska, Wachowicz 2015) methods. The results of the fuzzy EDAS and fuzzy TOPSIS methods are presented in the last two columns of Table 7. As can be seen, the ranking result of the fuzzy CODAS is completely consistent with the results of the fuzzy EDAS and fuzzy TOPSIS methods. A sensitivity analysis is also performed in this section to demonstrate the stability of the ranking result. Firstly, ten sets of criteria weights are generated randomly. Then we solve the problem by using each of these sets. The generated sets of criteria weights are shown in Table 8 and the ranking results are depicted in Figure 4.

Table 8. Generated weights for sensitivity analysis

	Set 1	Set 2	Set 3	Set 4	Set 5	Set 6	Set 7	Set 8	Set 9	Set 10
C_{11}	0.015	0.006	0.079	0.085	0.054	0.019	0.011	0.053	0.077	0.019
C_{12}	0.043	0.041	0.087	0.110	0.040	0.082	0.029	0.034	0.061	0.126
C_{13}	0.093	0.007	0.093	0.117	0.094	0.068	0.116	0.107	0.012	0.062
C_{21}	0.081	0.015	0.034	0.067	0.066	0.003	0.020	0.058	0.036	0.040
C_{22}	0.097	0.121	0.083	0.017	0.062	0.049	0.104	0.121	0.019	0.066
C_{23}	0.067	0.102	0.081	0.018	0.103	0.024	0.068	0.025	0.028	0.016
C_{24}	0.004	0.047	0.021	0.032	0.033	0.115	0.126	0.036	0.036	0.022
C_{31}	0.086	0.140	0.015	0.104	0.085	0.046	0.010	0.020	0.062	0.152
C_{32}	0.095	0.006	0.061	0.032	0.085	0.076	0.057	0.018	0.007	0.154
C_{33}	0.069	0.064	0.117	0.100	0.044	0.024	0.014	0.115	0.135	0.093
C_{34}	0.077	0.057	0.043	0.030	0.064	0.088	0.122	0.077	0.141	0.010
C_{41}	0.076	0.112	0.072	0.113	0.009	0.039	0.001	0.073	0.074	0.038
C_{42}	0.040	0.117	0.028	0.043	0.007	0.095	0.098	0.020	0.073	0.058
C_{51}	0.067	0.028	0.093	0.024	0.061	0.099	0.103	0.113	0.050	0.133
C_{52}	0.018	0.072	0.032	0.032	0.088	0.108	0.109	0.083	0.135	0.003
C_{53}	0.072	0.066	0.062	0.076	0.105	0.066	0.011	0.047	0.055	0.008

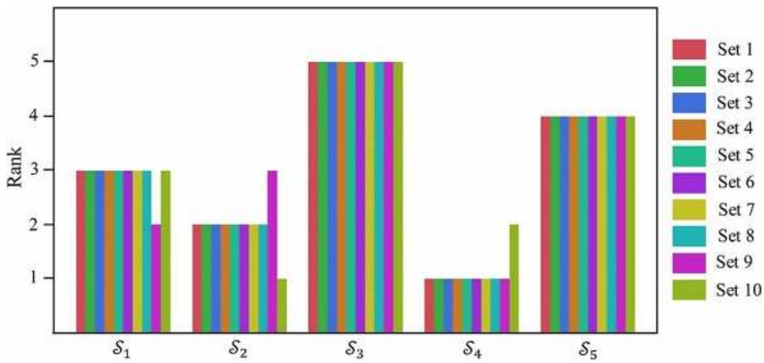

Fig. 4. Ranking results of the sensitivity analysis

According to Figure 4, the rank of the alternatives has a good stability against changing weights of the criteria. We can see that the market segment 4 (S_4) is the dominant alternative in all sets except set 10. Thus we can say that the initial ranking result is reliable.

4. Discussion

Uncertainty of information is usually an important issue to be dealt with in many MCDM problems like market segment evaluation and selection. The fuzzy sets theory is the most common tool to handle the uncertainty in such problems. In this study, we have proposed a fuzzy extension of the CODAS method based on the combination of fuzzy weighted Euclidean and fuzzy weighted Hamming distances. So far, most of the distance-based fuzzy MCDM methods have only used one type of distance in the evaluation process. The advantage of the proposed method over the other distance-based MCDM methods is its ability to involve two types of distance. Using two types of distance in evaluation process helps to increase the precision of ranking results. However, if the threshold parameter of the proposed method is set to a value more than a specific value related to the scale of problem (usually more than one), the proposed fuzzy CODAS will only utilize the fuzzy weighted Euclidean distance for evaluation process, and the fuzzy weighted Hamming distances will be ignored in computations. Unlike the other distance-based MCDM methods like TOPSIS and VIKOR, the evaluation process in the proposed fuzzy CODAS method is only based on negative-ideal solution, and the positive-ideal solution is not used in its process. To show the applicability of the proposed fuzzy CODAS method, a case study of market segment evaluation and selection has been considered. Sixteen sub-criteria related to five criteria, which have been defined according to the Porter's five forces model of competition, were selected by a group of five decision-makers (experts) of a shoe company to evaluate five market segments. Fuzzy linguistic variables have been used by decision-makers to express the importance (weight) of sub-criteria and the performance of alternatives with respect to each sub-criterion. Aggregating the assessments of the decision-makers about the importance of different sub-criteria has shown that "Buyer price sensitivity", "Buyer switching costs" and "Perceived level of product differentiation" were the first three important sub-criteria for the company to evaluate the market segments. The evaluation of alternatives has been done using the proposed fuzzy CODAS method and market segment 4 ($\mathcal{S}_4$) has been presented as the best alternative. Then the obtained ranking of alternatives has been compared with the results of the fuzzy EDAS and fuzzy TOPSIS approaches to validate the results of the proposed method. This analysis shows that the results of the fuzzy CODAS method are completely consistent with the results of the other methods, and the market segment 4 has the first rank in the fuzzy EDAS and fuzzy TOPSIS results too. To examine the effect of changing criteria (sub-criteria) weights on the ranking results, a sensitivity analysis has also been made by using ten generated sets of sub-criteria weights. Although some minor changes in the ranking of alternatives have been seen in different sets of sub-criteria weights, the market segment 4 has the first rank in the most cases. Thus the company can select this alternative with high degree of reliability. Moreover, according to the comparison and sensitivity analysis, if the company wants to select another market, it can consider the market segment 2 as a secondary option.

Conclusions

Market segment evaluation and selection has a significant effect on the competitiveness of a company. Because this process can be viewed as a multi-criteria decision-making problem, we usually need to use an efficient MCDM method for it. Moreover, uncertain environment of decision-making process can make this evaluation complicated. In this research, we have developed an extension of fuzzy CODAS method to deal with MCDM problems under uncertainty. We have used the fuzzy weighted Euclidean and fuzzy weighted Hamming distances to determine the desirability of alternatives with respect to a negative-ideal solution. Also, the linguistic variables which are defined by trapezoidal fuzzy numbers have been used to extend the crisp CODAS method. The proposed fuzzy CODAS method has been applied to an example of multi-criteria market segment evaluation and selection problem. The comparative analysis of evaluation results shows that the fuzzy CODAS method is efficient and consistent with the other methods, and the sensitivity analysis demonstrates the stability of the results of the proposed method. Because the interdependency of criteria is not considered in the proposed method, one of the limitations of this research can be choosing or defining independent criteria for evaluation and selection process. Future research can address the interdependency of criteria by using some usual methods like fuzzy analytic network process (ANP). Moreover, the proposed method can be applied to many other MCDM problems such as supplier selection, project selection, robot selection.

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