Fuzzy Genetic Algorithm for Prioritization Determination with Technique for Order Preference by Similarity to Ideal Solution

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Summary
A new multi-criteria decision making method (Fuzzy Genetic Algorithm-Technique for Order Preference by Similarity to Ideal Solution: FGA-TOPSIS) is proposed for dealing with criteria and alternatives in a fuzzy environment. Genetic Algorithm (GA) is used to address the weights of criteria and then the best solution is determined by using the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) method. A numerical experiment is also conducted to demonstrate the procedure of the proposed FGA-TOPSIS method in the decision making processes.

Keywords:
Fuzzy Decision Making, Linguistic Preference, Fuzzy Genetic Algorithm, Fuzzy TOPSIS

1. Introduction

Multi-criteria Decision Making (MCDM) is the process to define the ranking of all possible alternatives respective to the goal and criteria. In real-life applications of MCDM method, data are usually imprecise, uncertain and/or vague. In such applications, decision makers usually give preferences in linguistic variables and linguistic variables will be then converted to Fuzzy number for further evaluation. The Fuzzy Set Theory is an efficient way to model uncertainty and imprecision in terms of linguistic variable [1-3]. From concepts of MCDM method of Analytical Hierarchy Process (AHP), Van Laarhoven et al, J.Buckley, C.Boender et al, Chang, Mikhailov et al., and others have developed the Fuzzy AHP to handle the fuzziness in decision making [4-9].

The aim of this paper is to propose a new MCDM method (FGA-TOPSIS) to deal with linguistic preferences in a Fuzzy environment. The decision making problem is presented in hierarchical structure similar to those in the AHP method. Calculating priority vector of criteria which is presented as an optimization problem can be solved by using FGA to find the priority vector, which maximizes the triangular membership function. The ranking of alternatives is then defined by the TOPSIS method in terms of calculating the Fuzzy distance among ideal alternative and other alternatives. FGA-TOPSIS method utilizes the advantages of Fuzzy Set Theory, GA and TOPSIS, allows the decision making processes to become realistic and effective.

The remainder of the paper is organized as follows. Section 2 presents the linguistic variable and Fuzzy number. Section 3 examines the FUZZY TOPSIS approach dealing with the Triangular Fuzzy Number. Section 4 presents the new method FGA-TOPSIS. Section 5 illustrates an example of the new method. Finally, section 6 summarizes the work of this paper.

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2. Linguistic Variable and Fuzzy Number

2.1 Linguistic variable

A linguistic variable is a "variable whose values are not numbers but words or sentences in a natural or artificial language" [1]. Using linguistic values (words or sentences) expresses less specific than numerical ones, but it is closely related to the way that humans express and use their knowledge. In order to deal with the uncertainty and vagueness in the linguistic evaluation, many researchers have applied Fuzzy Set Theory to convert linguistic variable to Fuzzy number [3, 10-13].
W. Liu and P. Liu [13] proposed "Triangular Fuzzy Expression of Linguistic Variable" as follows:

Suppose S is a set of ordered natural linguistic label which is consisted of odd elements k. Let $S = s_0, s_1, ..., s_{k-1}$ and the Triangular Fuzzy Expression of Linguistic Variable is $S_i = (s_i^l, s_i^m, s_i^u)$, then:

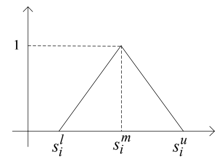

Figure 1: Triangular Fuzzy Number $S_i = (s_i^l, s_i^m, s_i^u)$

s_i^l, s_i^m and s_i^u are defined as follows:

$$\begin{cases} s_0^l = 0 \\ s_i^l = \dfrac{i-1}{k-1} \quad (1 \le i \le k-1) \\ s_i^m = \dfrac{i}{k-1} \quad (0 \le i \le k-1) \\ s_i^u = \dfrac{i+1}{k-1} \quad (0 \le i \le k-2) \\ s_{k-1}^u = 1 \end{cases} \tag{1}$$

By applying equation (1), linguistic variable is converted to triangular fuzzy number for corresponding fuzzy label. Table 1 shows converting seven-linguistic expression to triangular fuzzy numbers while Figure 2 shows seven-linguistic variables with triangular fuzzy membership function. Meanwhile Table 2 shows the conversion of nine-linguistic expressions to triangular fuzzy numbers and Figure 3 shows nine-linguistic variables with triangular fuzzy membership function [13].

Table 1: Converting seven-linguistic expressions to Triangular Fuzzy Numbers

Fuzzy label	**Fuzzy Linguistic Expression**	**Triangular Fuzzy Number**
S_0	Very poor	(0, 0, 0.167)
S_1	Poor	(0, 0.167, 0.333)
S_2	Moderately poor	(0.167, 0.333, 0.5)
S_3	Fair	(0.333, 0.5, 0.667)
S_4	Moderately good	(0.5, 0.667, 0.833)
S_5	Good	(0.667, 0.833, 1)
S_6	Very good	(0.833, 1, 1)

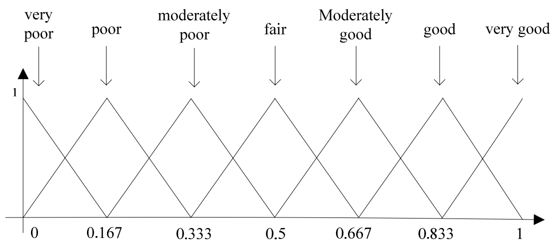

Figure 2: Seven-linguistic variables with Triangular Fuzzy membership function

Table 2: Converting nine-linguistic expressions to Triangular Fuzzy Numbers

Fuzzy Label	**Fuzzy Linguistic Expression**	**Triangular Fuzzy Number**
S_0	Absolute poor	(0, 0, 0.125)
S_1	Very poor	(0, 0.125, 0.25)
S_2	Poor	(0.125, 0.25, 0.375)
S_3	Moderately poor	(0.25, 0.375, 0.5)
S_4	Fair	(0.375, 0.5, 0.625)
S_5	Moderately good	(0.5, 0.625, 0.75)
S_6	Good	(0.625, 0.75, 0.875)
S_7	Very good	(0.75, 0.875, 1)
S_8	Absolute good	(0.875, 1, 1)

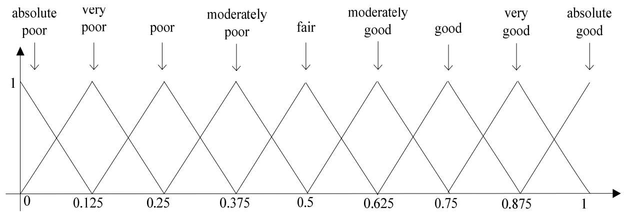

Figure 3: Nine-linguistic variables with Triangular Fuzzy membership function

2.2 Operation of Triangular Fuzzy Number

Let $a = (a^l, a^m, a^u)$ and $b = (b^l, b^m, b^u)$ be two Triangular Fuzzy Numbers and α is a positive real number, two important operations are used in this paper as follows:

1. $(a^l, a^m, a^u) \oplus (b^l, b^m, b^u) = (a^l + b^l, a^m + b^m, a^u + b^u)$
2. $\alpha \bullet (a^l, a^m, a^u) = (\alpha a^l, \alpha a^m, \alpha a^u)$

2.3 Normalization of Triangular Fuzzy Number

Let matrix $A = [a_{ij}]_{k \times n}$, which $a_{ij} = \left(a_{ij}^l, a_{ij}^m, a_{ij}^u\right)$ is the Triangular Fuzzy Number that is being normalized, and results in matrix $B = [b_{ij}]_{k \times n}$, which $b_{ij} = \left(b_{ij}^l, b_{ij}^m, b_{ij}^u\right)$ as follows:

$$\begin{cases} b_{ij}^l = a_{ij}^l \Big/ \sqrt{\sum_{i=1}^{k} \left(a_{ij}^u\right)^2} \\ b_{ij}^m = a_{ij}^m \Big/ \sqrt{\sum_{i=1}^{k} \left(a_{ij}^m\right)^2} \\ b_{ij}^u = a_{ij}^u \Big/ \sqrt{\sum_{i=1}^{k} \left(a_{ij}^l\right)^2} \end{cases} \tag{2}$$

3. FUZZY TOPSIS

The TOPSIS approach is a MCDM method, developed by Hwang and Yoon [14]; Lai et al [15] and many other researchers have been working in this field. Using the TOPSIS method, the best alternative must have the shortest distance to the positive ideal solution (PIS) and the longest distance to the negative ideal solution (NIS) [14].

Suppose that a decision making problem have k evaluation alternatives $A = (a_1, a_2, \ldots, a_k)$, n evaluation criteria $C = (c_1, c_2, \ldots, c_n)$, priority vector of criteria $w = (w_1, w_2, \ldots, w_n)$ and the evaluation matrix $X = [x_{ij}]_{k \times n}$ as follows:

$$X = \begin{array}{c c} & \begin{array}{cccc} c_1 & c_2 & c_j & c_n \end{array} \\ \begin{array}{c} a_1 \\ a_2 \\ a_i \\ a_k \end{array} & \begin{bmatrix} x_{11} & x_{12} & x_{1j} & x_{1n} \\ x_{21} & x_{22} & x_{2j} & x_{2n} \\ x_{i1} & x_{i2} & x_{ij} & x_{in} \\ x_{k1} & x_{k2} & x_{kj} & x_{kn} \end{bmatrix} \end{array}$$

x_{ij} expresses evaluation value of alternative a_i respective to criterion c_j . x_{ij} is presented in Linguistic Variable and Triangular Fuzzy Number $\mathrm{x_{ij}} = \left(x_{ij}^l, x_{ij}^m, x_{ij}^u\right)$.

3.1 Fuzzy ideal solution

The Fuzzy Positive Ideal Solution (FPIS) which has the best evaluation value respective to each criterion is determined as follows [13]:

$$\begin{aligned} &\mathrm{A}^+ = [\mathrm{x}_1^+, \mathrm{x}_2^+, ..., \mathrm{x}_n^+] \text{ where } \mathrm{x}_j^+ = \max_{i=1,...,k}(\mathrm{x}_{ij}) \\ &= (\max_{i=1,...,k}(\mathrm{x}_{ij}^l), \max_{i=1,...,k}(\mathrm{x}_{ij}^m), \max_{i=1,...,k}(\mathrm{x}_{ij}^u)) \quad j = 1,..., n \end{aligned} \tag{3}$$

The Fuzzy Negative Ideal Solution (FNIS) which has the worst evaluation value respective to each criterion is determined as follows [13]:

$$\begin{aligned} &\mathrm{A}^- = [\mathrm{x}_1^-, \mathrm{x}_2^-, ..., \mathrm{x}_n^-] \text{ where } \mathrm{x}_j^- = \min_{i=1,...,k}(x_{ij}) \\ &= (\min_{i=1,...,k}(x_{ij}^l), \min_{i=1,...,k}(x_{ij}^m), \min_{i=1,...,k}(x_{ij}^u)) \quad j = 1,..., n \end{aligned} \tag{4}$$

3.2 Distance to fuzzy ideal solution

Let $a = (a^l, a^m, a^u)$ and $b = (b^l, b^m, b^u)$ be two triangular fuzzy numbers. The distance between a and b can be calculated by using the vertex method [19].

$$\mathrm{d(a,b)} = \sqrt{\frac{1}{3}\left[\left(a^l - b^l\right)^2 + \left(a^m - b^m\right)^2 + \left(a^u - b^u\right)^2\right]} \tag{5}$$

Then, the distance from each alternative to FPIS and FNIS can be respectively derived from:

$$\begin{aligned} d_i^+ &= \sum_j^n d(x_{ij}, x_j^+) \qquad i = 1,2,...,k \\ d_i^- &= \sum_j^n d(x_{ij}, x_j^-) \qquad i = 1,2,...,k \end{aligned} \tag{6}$$

3.3 Closeness coefficient

Closeness coefficient $\mathrm{R_i}$ of each alternative is used to determine the ranking of all alternatives. The higher value of closeness coefficient indicates that corresponding alternative is closer to FPIS and farther from FNIS simultaneously [14].

$$R_i = \frac{d_i^-}{d_i^- + d_i^+} \qquad i = 1,2,...,k \tag{7}$$

3.4 Fuzzy TOPSIS method

Chen, Chu, Saghafian et al [19-21] and other researchers have expanded the traditional TOPSIS method into the Fuzzy TOPSIS method in order to handle fuzziness in decision making problem. This paper proposes a modified Fuzzy TOPSIS method to deal with triangular fuzzy number (TFN) with modification of linguistic variable, TFN normalization and distance to ideal solution. Basic step of this Fuzzy TOPSIS method can be described follows:

1. Obtain fuzzy evaluation matrix $X = [x_{ij}]_{k \times n}$ for k alternatives over n criteria. Preference data is expressed first in linguistic variable, and then converted to TFN.
2. Normalize fuzzy evaluation matrix X by equation (2).
3. Multiply the priority vector of the criteria with the normalized evaluation fuzzy matrix resulting in matrix $Y = [y_{ij}]_{k \times n}$ with $y_{ij} = x_{ij} * w_j$.
4. Identify the fuzzy positive ideal solution (FPIS) A^+ and fuzzy negative ideal solution (FNIS) A^- of matrix Y referring to equations (3) and (4).
5. Calculate fuzzy distance d_i^+ and d_i^- over each alternative to FPIS and FNIS respectively referring to equations (5) and (6).
6. Determine the closeness coefficient R_i referring to equation (7) for each alternative.
7. Rank order of alternatives by maximizing closeness coefficient R_i .

4. FGA-TOPSIS Method

With k evaluation alternatives $A = (a_1, a_2,..., a_k)$, n evaluation criteria $C = (c_1, c_2,...,c_n)$, the decision making problem is outlined in hierarchical structure as shown in Figure 4.

$w = (w_1,w_2,...,w_n)$ is a priority vector of n criteria with respect to the goal. w_{ij} is important weight of alternative a_i respective to criterion c_j.

The main steps in FGA-TOPSIS decision making method are illustrated in Figure 5.

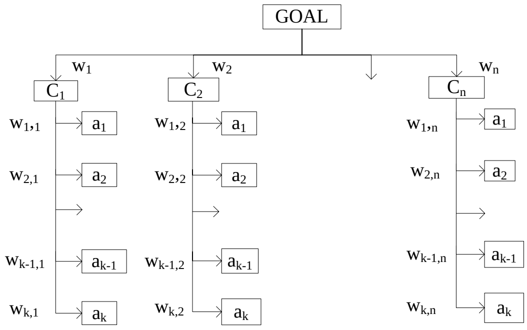

Figure 4: Hierarchical structure of decision making problem

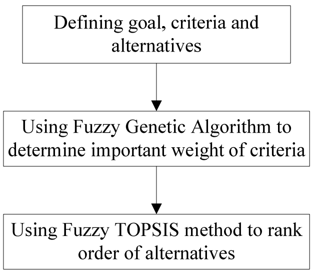

Figure 5: FGA-TOPSIS methods

4.1 Determination important weight of criteria

This step's objective is to determine the important weights of each criterion. With *n* criteria, there will be *n(n-1)/2* pair-wise comparison judgments in linguistic form. Let $w = (w_1, w_2, \ldots, w_n)$ be priority vector of criteria. $(0 < w_i < 1)$ and $\mathrm{EW}_{ij} = \left(x_{ij}^l, x_{ij}^m, x_{ij}^u\right)$ presents the importance of criteria c_i respective to criteria c_j in pair-wise comparison by decision maker (i < j). Finding the value of weight w_i is similar to the value of ratio w_i / w_j, which maximizes their membership function in the corresponding Fuzzy set EW_{ij} [16].

Triangular Fuzzy membership function μ_{ij} is defined as follows:

$$\mu_{ij}\left(w_i/w_j\right) = \begin{cases} \dfrac{w_i/w_j - x_{ij}^l}{x_{ij}^m - x_{ij}^l} & x_{ij}^l \le w_i/w_j \le x_{ij}^m \\ \dfrac{w_i/w_j - x_{ij}^u}{x_{ij}^m - x_{ij}^u} & x_{ij}^m \le w_i/w_j \le x_{ij}^u \\ 0 & otherwise \end{cases} \quad (8)$$

Moneim [16] proposed a fitness function:

$$G(w_1, w_2, \ldots, w_n) = \min_{i<j}\left(\mu_{12}, \mu_{13}, \ldots, \mu_{ij}, \ldots, \mu_{(n-1)n}\right) \quad (9)$$

With μ_{ij} is defined in equation (8)

The problem of deriving a priority vector of *n* criteria can be given in the following optimization problem:

$$\begin{cases} Maximize \quad G(w_1, w_2, \ldots, w_n) \\ Subject\ to \quad \sum_{i=1}^{n} w_i = 1 \\ Where\ \ G(w_1, w_2, \ldots, w_n)\ is\ defined\ in\ formula\ (9). \end{cases} \quad (10)$$

The search technique of Genetic Algorithm (GA) can be used to solve the optimization problem formulated in (10). GA based on the genetic evolution of a species, was proposed by Holland [17] and later refined by Goldberg [18] and others. GA starts with encoding a set of decision variables as chromosomes. The quality of a solution is defined by the fitness function [16,17,18]. In this optimization problem, the priority vector of criteria is coded as chromosome. Each gene of the chromosome is coded by a real number between 0 and 1, representing the important weight of criterion. An initial population of chromosomes is randomly generated. By using genetic operators of crossover, mutation and selection, some new chromosomes with higher fitness appear and low fitness chromosomes are eliminated. The solution in chromosome form is shown in Figure 6.

Figure 6: Priority vector in chromosome form

The FGA is described in the following steps as shown in Figure 7:

1. Build a chromosome, by generating and normalizing *n* random numbers of genes uniformly distributed between 0 and 1.
2. Evaluate fitness function of chromosome referring to equations (8) and (9).
3. Repeat steps 1 and 2 until an initial population of chromosomes is formed.
4. Decide probabilities of crossover p_{cross} and mutation p_{mut} to start reproduction.
5. Select two highest fitness chromosomes from population as parent.
6. Generate *x*, a continuous random number between 0 and 1. If $x <= p_{over}$ then crossover is performed and two worst chromosomes are replaced by two offspring; otherwise go to step 8 to perform copying.
7. Generate *y,* a continuous random number between 0 and 1. If $y <= p_{mut}$ then mutation is performed by adding value *y* to first gene of two offspring, normalize them and go to step 9.
8. Copying is performed by replacing two of the worst chromosomes by the two selected chromosomes in step 5.
9. Go to step 5 and repeat until convergence is obtained.

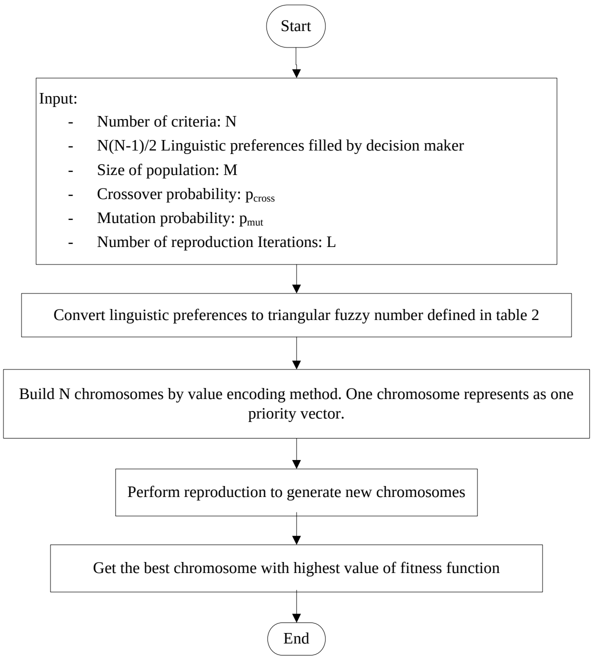

Figure 7: Main block diagram of the FGA

The solution is a chromosome which has the highest fitness value in the last generation.
The reproduction process is illustrated in Figure 8.

4.2 Ranking alternatives

After the priority vector of criteria is determined by the FGA, the Fuzzy TOPSIS method is used to rank the alternatives. Linguistic variables are applied to obtain the important preference of each alternative respective to each criterion. As a result, the evaluation matrix is formed. This step was illustrated by applying the procedure presented in section 3.

5. Experiment with Numerical Example

Suppose that someone wants to find a location to open a restaurant and there are three potential restaurant's locations. In order to select an appropriate location, there are four criteria to consider: population base, parking area, accessibility and visibility (Mealey, 2010).
The hierarchical structure of decision making problem is formed as shown in Figure 9.

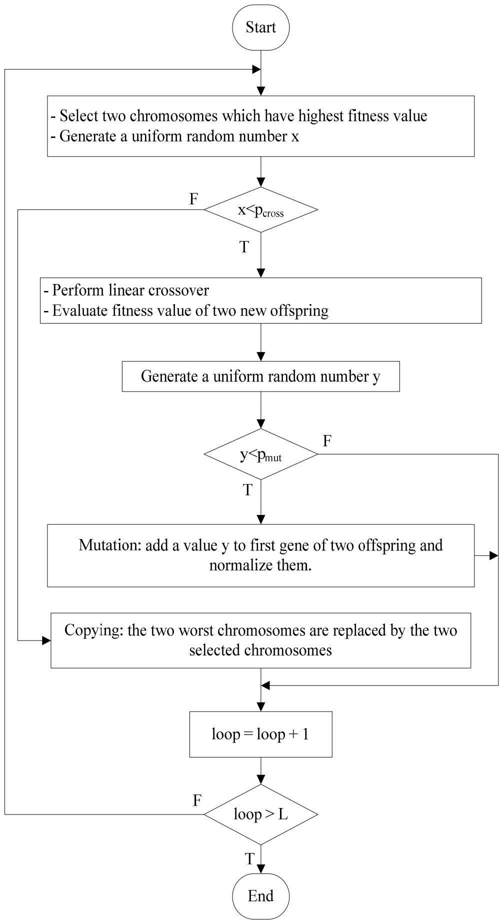

Figure 8: Reproduction process

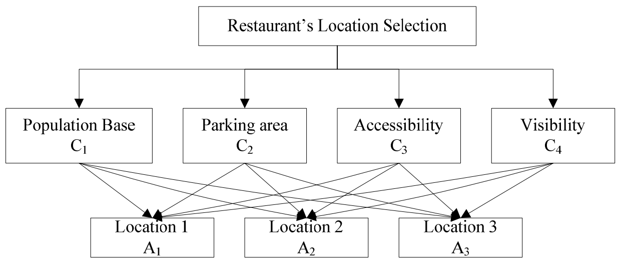

Figure 9: Hierarchical structure of restaurant's location decision making

Applying FGA method in section 4.1, the priority vector of criteria w = (w_1, w_2, w_3, w_4) can be calculated. Each chromosome will have four genes representing the important weight of criteria respective to the goal. Decision maker uses nine-linguistic expression to express six pair-wise comparisons among criteria as is shown in Table 3.

Table 3: Pair-wise comparison among criteria

Criterion	Linguistic preference	Fuzzy number	Criterion
C_1	Fair	(0.375, 0.5, 0.625)	C_2
C_1	Poor	(0.125, 0.25, 0.375)	C_3

C_1	Moderately poor	(0.25, 0.375, 0.5)	C_4
C_2	Poor	(0.125, 0.25, 0.375)	C_3
C_2	Very poor	(0, 0.125, 0.25)	C_4
C_3	Moderately poor	(0.25, 0.375, 0.5)	C_4

Referring to procedure in figures 7 and 8, a programming with c# had been created with the following inputs: number of criteria (N = 4); size of population (M = 30); crossover probability (p_{cross} = 90%); mutation probability (p_{mut} = 10%); and number of reproduction (L = 100). The solution obtained is w = (0.2209, 0.1767, 0.2811, 0.3213).

Applying Fuzzy TOPSIS method in section 3, ranking of alternatives will be determined. Decision maker uses nine-linguistic expressions to express the preference of alternatives respective to each criterion as shown in Table 4.

Table 4: Linguistic preferences of alternatives respective to each criterion

	C_1	C_2	C_3	C_4
A_1	Good	Moderately poor	Fair	Good
A_2	Poor	Very good	Good	Fair
A_3	Very good	Moderately good	Poor	Moderately poor

Referring to Table 2, linguistic preferences are converted to fuzzy number as shown in Table 5.

Table 5: Fuzzy number preference of alternatives respective to each criterion

	C_1	C_2	C_3	C_4
A_1	(0.625,0.75 , 0.875)	(0.25, 0.375 , 0.5)	(0.375, 0.5 , 0.625)	(0.625, 0.75 , 0.875)
A_2	(0.125, 0.25 , 0.375	(0.75, 0.875 , 1)	(0.625, 0.75 , 0.875)	(0.375, 0.5 , 0.625)
A_3	(0.75,0.875 ,1)	(0.5, 0.625 , 0.75)	(0.125, 0.25 , 0.375)	(0.25, 0.375 , 0.5)

Applying equation (2), the normalized Fuzzy decision matrix is formed as shown in Table 6.

Table 6: Normalized fuzzy number preference

	C_1 0.2209	C_2 0.1767	C_3 0.2811	C_4 0.3213
A_1	(0.453,0.636, 0.889)	(0.19,0.329 ,1)	(0.329,0.53 ,0.845)	(0.527,0.76 ,1.136)
A_2	(0.091,0.212, 0.381)	(0.56,0.768 ,2)	(0.549, 0.8 , 1.183)	(0.316,0.51 ,0.811)
A_3	(0.543,0.742, 1.016)	(0.37, 0.549 , 1.5)	(0.11, 0.27 , 0.507)	(0.211,0.38 ,0.649)

Multiply priority vector of criteria with normalized Fuzzy matrix which is shown in Table 7:

Table 7: Weighted normalized fuzzy number preference

	C_1	C_2	C_3	C_4
A_1	(0.1, 0.14 , 0.196)	(0.033,0.058, 0.177)	(0.093, 0.15 , 0.238)	(0.169,0.247, 0.365)
A_2	(0.02,0.047 , 0.084)	(0.098,0.136, 0.353)	(0.154,0.225, 0.333)	(0.102,0.165, 0.261)
A_3	(0.12,0.164 , 0.224)	(0.066,0.097, 0.265)	(0.031,0.075, 0.143)	(0.068,0.123, 0.208)

Referring to equations (3) and (4), Fuzzy positive ideal solution (FPIS) and Fuzzy negative ideal solution (FPIS) are calculated, respectively as follows:

FPIS A^+ = [(0.12, 0.164, 0.224), (0.098, 0.136, 0.353), (0.154, 0.225, 0.333), (0.169, 0.247, 0.365)]

FNIS A^- = [(0.02, 0.047, 0.084), (0.033, 0.058, 0.177), (0.031, 0.075, 0.143), (0.068, 0.123, 0.208)]

Referring to equations (5) and (6), the distances from each alternative to FPIS and FNIS, respectively, are calculated as follows:

	A_1	A_2	A_3
d^+	0.220	0.206	0.345
d^-	0.304	0.318	0.179

Lastly, referring to equation (7), the closeness coefficients are calculated as follows:

$$R_1 = \frac{d_1^-}{d_1^- + d_1^+} = 0.5802$$

$$R_2 = \frac{d_2^-}{d_2^- + d_2^+} = 0.607 \qquad R_3 = \frac{d_3^-}{d_3^- + d_3^+} = 0.342$$

According to the closeness coefficient of the three alternatives, the order of the three alternatives is $A_2 > A_1 > A_3$. Location 2 would be selected for opening the restaurant.

6. Conclusion

While other researchers used Fuzzy Genetic Algorithm and Fuzzy TOPSIS respectively to determine the weights of criteria and/or alternatives [15,16,19-21], we propose a new MCDM method (FGA-TOPSIS) by integrating FGA and Fuzzy TOPSIS to handle the decision making problems in a fuzzy environment where the information is uncertain and vague. The uncertain and vague preferences are first presented in linguistic variables and then converted to triangular fuzzy numbers. The problem with calculating priority vector of criteria is presented as an optimization problem and it is solved by using FGA to find the priority vector, which maximizes triangular membership function. After determining the priority vector of criteria, Fuzzy TOPSIS method is used to rank the order of alternatives. FGA-TOPSIS method utilizes the advantages of Fuzzy Set Theory, Genetic Algorithm and TOPSIS, therefore, the decision making becomes realistic and effective. A numerical example of selecting restaurant's location is also presented to clarify the procedure of the proposed method.

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