Talent Assessment Multi-criteria Decision Method with Multiple Fuzzy Numbers Based on TOPSIS

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Abstract: In the context of introducing high-level talents, the issue of talent evaluation has always been a challenge for decision-makers. Selecting exceptional candidates from a pool of applicants, based on scientific assessment, has been a perplexing task. This article proposes that talent assessment is a complex process, and suggests using the TOPSIS method to address this challenge. By employing a mixed fuzzy number multi-criteria decision-making approach, a ranking plan for talent selection can be formulated, thereby aiding decision-makers in determining the most suitable candidate based on the optimal solution of the criteria.

Keywords: Fuzzy; Random Variable; TOPSIS; Multi-criteria Decision-Making; Talent Introduction

1. Introduction

Fuzzy multi-criteria decision making has been a prominent topic in academic circles in recent years. Scholars have been addressing the challenges of solving multi-attribute decision making problems that involve various types of fuzzy numbers and random variables, including exact numbers, intuitionistic fuzzy numbers, interval numbers, triangular fuzzy numbers, language values, and trapezoidal fuzzy numbers.

For instance, Haris Doukas [1] proposed a linguistic qualitative aggregation and reasoning framework to tackle the linguistic value multi-criteria decision making problem. Chen[2] developed a fuzzy multi-criteria decision making method that incorporates interval numbers for both criterion values and criterion weights. Renato A Krohling and André G. C. [3] introduced an extended TODIM method to handle intuitionistic fuzzy information processing. Gao jian-wei and Guo feng-Jia[4] explored an intuitionistic fuzzy stochastic multi-criteria decision making method based on an improved prospect theory. Yuan Chunming et al. [5] studied talent evaluation using the TOPSIS method. Lisa Y Chen and Tien-Chin Wang[6] utilized triangular fuzzy numbers to evaluate IS/IT outsourcing project partner selection. Xia[7] investigated mixed multi-attribute decision making scenarios that involve exact numbers, interval numbers, triangular fuzzy numbers, and linguistic types. Serafim Opricovic [8] conducted a study on the VIKOR method, which is based on triangular fuzzy numbers. Zhou Jianheng et al. [9] investigated customer satisfaction using a fuzzy evaluation method. Lou Yafang et al. [10] explored the application of fuzzy comprehensive evaluation in the structural design of fitted insertion Angle sleeve. A TOPSIS model have been designed by ZHANG Zhuo, et al[11] that calculated the ideal closeness as the dynamic weight, Guangying Jin[12] have developed a technique for order performance by similarity to ideal solution (TOPSIS) to help port companies select the optimal team members in a virtual environment. The VIKOR method, known as an eclectic sorting method for multi-criteria decision making of complex systems, has attracted significant attention from both domestic and international scholars [13]. However, applying the VIKOR method to evaluate multi-criteria decision making problems with triangular fuzzy numbers may contradict the fundamental characteristics of triangular fuzzy numbers, where the left, middle, and right end point values gradually increase [14].

The proposed defuzzification solution strategy for triangle fuzzy numbers in the FVIKOR method effectively addresses the issue of the VIKOR method violating the fundamental characteristics of triangle fuzzy numbers as the left, middle, and right endpoints increase gradually. However, FVIKOR only considers defuzzification processing and fails to account for the mixed existence of criterion values in various practical problems involving fuzzy numbers. Therefore, this paper introduces the TVIKOR method, a hybrid fuzzy number multi-criteria decision-making approach based on the VIKOR method, to tackle the challenges of hybrid fuzzy number multi-criteria decision-making and its application in talent evaluation in practical scenarios.

2. Property Analysis of Fuzzy Number Type

2.1 Interval Number

2.1.1 Interval number definition

Definition 1[15] Let R be a field of real numbers, and the closed interval $[a_1, a_2]$ be the interval number, where a_1 is the lower and a_2 is the upper bound of the interval number, $a_1, a_2 \in R$, $a_1 \le a_2$. The interval number is reduced to a real number when $a_1 = a_2$.

2.1.2 Interval number operation

Definition 2 Assume $\tilde{a} = [a_1, a_2]$, $\tilde{b} = [b_1, b_2]$ are all two regions, the basic operation of the number of regions is defined as follows:

$$\tilde{a} = \tilde{b}, \text{only if } a_1 = b_1,\ a_2 = b_2; \quad (1)$$

$$\tilde{a} + \tilde{b} = [a_1 + b_1,\ a_2 + b_2]; \quad (2)$$

$$\tilde{a} \times \tilde{b} = [a_1 b_1,\ a_2 b_2]; \quad (3)$$

$$\frac{\tilde{a}}{\tilde{b}} = \left[\frac{a_1}{b_2},\ \frac{a_2}{b_1}\right], b_1 \neq 0, b_2 \neq 0; \quad (4)$$

$$\lambda\tilde{a} = [\lambda a_1, \lambda a_2],\ \lambda \text{ is constant.} \quad (5)$$

2.1.3 Probability of interval number

Definition 3 When both $\tilde{a}$ and $\tilde{b}$ are intervals or one of them is intervals, assume $\tilde{a} = [a_1, a_2]$, $\tilde{b} = [b_1, b_2]$, remember $l_a = a_2 - a_1, l_b = b_2 - b_1$, we call

$$P(\tilde{a} \ge \tilde{b}) = \frac{min\{l_a + l_b, max(a_2 - b_1, 0)\}}{l_a + l_b} \quad (6)$$

Probability of $\tilde{a} \ge \tilde{b}$[16].

2.2 Triangular Fuzzy Number

2.2.1 Definition of triangular fuzzy number

Definition 4 [17] If $\tilde{a} = (a_1, a_2, a_3)$, where $0 < a_1 < a_2 < a_3$, then we call $\tilde{a}$ is a triangular fuzzy number, the membership function can be expressed as:

$$u_{\tilde{a}}(x) = \begin{cases} \frac{x - a_1}{a_2 - a_1}, & x \in (a_1, a_2) \\ \frac{x - a_3}{a_3 - a_2}, & x \in (a_2, a_3) \\ 0, & \text{others} \end{cases} \quad (7)$$

2.2.2 Operation of triangular fuzzy numbers

Definition 5 Assume $\widetilde{A} = (a_1, a_2, a_3), \widetilde{B} = (b_1, b_2, b_3)$ are two triangular fuzzy numbers, then

$$\widetilde{A} + \widetilde{B} = (a_1 + b_1, a_2 + b_2, a_3 + b_3); \quad (8)$$

$$\widetilde{A} - \widetilde{B} = (a_1 - b_1, a_2 - b_2, a_3 - b_3); \quad (9)$$

$$\widetilde{A} \times \widetilde{B} = (a_1 b_1, a_2 b_2, a_3 b_3); \quad (10)$$

$$\frac{\widetilde{A}}{\widetilde{B}} = \left(\frac{a_1}{b_3}, \frac{a_2}{b_2}, \frac{a_3}{b_1}\right), \text{When } a_1 = a_2 = a_3,\ \widetilde{A} \text{ is constant.} \quad (11)$$

$$\lambda \widetilde{A} = (\lambda_1 a_1,\ a_2, \lambda_3 a_3), \quad (12)$$

where $\lambda = (\lambda_1,\ \lambda_2,\ \lambda_3)$, $(\lambda_1 = \lambda_2 = \lambda_3)$ are constants, it's mean that the left , middle and right endpoints are equal.

2.2.3 Possibility degree of triangular fuzzy number

Definition 6 For any two triangular fuzzy numbers $\widetilde{A} = (a_1, a_2, a_3)$, $\widetilde{B} = (b_1, b_2, b_3)$, Possibility of $\widetilde{A} \ge \widetilde{B}$ is

$$P(\widetilde{A} \ge \widetilde{B}) = \lambda \frac{min\{a_2 - a_1 + b_2 - b_1, max(a_2 - b_1, 0)\}}{a_2 - a_1 + b_2 - b_1} + (1 - \lambda) \frac{min\{a_3 - a_2 + b_3 - b_2, max(a_3 - b_2, 0)\}}{a_2 - a_1 + b_2 - b_1}. \quad (13)$$

λ depends on the decision maker's risk attitude. If the decision maker pursues risk, λ>0.5. If the decision-maker is risk-neutral, λ=0.5; If the decision maker is risk-averse, λ<0.5.

In the above triangle fuzzy number probability formula:

(i) if $a_1 \ge b_2$ and $a_2 \ge b_3$, then $P(\widetilde{A} \ge \widetilde{B}) = 1 (\widetilde{A} > \widetilde{B})$.

(ii) if $a_1 < b_3$, then $P(\widetilde{A} \ge \widetilde{B}) = 1$ also true, but the left endpoint of $\widetilde{A} - \widetilde{B}$ is negative.

2.1.4 The distance of triangle fuzzy number

Definition 7 Assume $\widetilde{A} = (a_1, a_2, a_3)$, $\widetilde{B} = (b_1, b_2, b_3)$ are two Triangle fuzzy numbers, then

$$d(\widetilde{A}, \widetilde{B}) = \sqrt{\frac{(a_1 - b_1)^2 + (a_2 - b_2)^2 + (a_3 - b_3)^2}{3}} \quad (14)$$

is the distance between $\widetilde{A}$ and $\widetilde{B}$.

3. The 3δ Principle of Random Variable Obey Normal Distribution

Definition 8 **ξ is a random variable on a complete probability space** $(\boldsymbol{\Omega}, \boldsymbol{A}, \boldsymbol{P})$ obey normal distribution, that is $\boldsymbol{\xi \sim N(\mu, \sigma^2)}$, then

$$\boldsymbol{P(\xi \in (\mu - 3\delta, \mu + 3\delta)) = \Phi\left(\frac{\xi + 3\sigma - \mu}{\sigma}\right) - \Phi\left(\frac{\xi - 3\sigma - \mu}{\sigma}\right) = 2\Phi(3) - 1 \approx 0.9974}. \quad (15)$$

The actual range of random variables that obey normal distribution is $(\boldsymbol{\mu}-\mathbf{3}\boldsymbol{\delta},\boldsymbol{\mu}+\mathbf{3}\boldsymbol{\delta})$, tthe probability of this value out of the range becomes a low-probability event. So we define random variable $\boldsymbol{\xi}$ which obey normal distribution real interval is $(\boldsymbol{\mu}-\mathbf{3}\boldsymbol{\delta},\boldsymbol{\mu}+\mathbf{3}\boldsymbol{\delta})$, this is the $\mathbf{3}\boldsymbol{\delta}$ principle of normal distribution. According to the $\mathbf{3}\boldsymbol{\delta}$ principle of normal distribution, when the criterion value is a random
variable subject to normal distribution, without considering other attribute information, it can be regarded as a random variable subject to uniform distribution on a finite interval.
We use interval number

$$\boldsymbol{a}=[\boldsymbol{a}_1,\boldsymbol{a}_2]=[\boldsymbol{\mu}-\mathbf{3}\boldsymbol{\delta},\boldsymbol{\mu}+\mathbf{3}\boldsymbol{\delta}]$$

represents such a finite random interval that satisfies the following conditions:

$$\boldsymbol{a}_1=\boldsymbol{\mu}-\mathbf{3}\boldsymbol{\delta},\ \ \boldsymbol{a}_2=\boldsymbol{\mu}+\mathbf{3}\boldsymbol{\delta}.$$

4. TOPSIS Method with Mixed Fuzzy Numbers Type

For a multi-criteria problem of mixed fuzzy number type with exact value, interval number, triangular fuzzy number and random variables subject to normal distribution, the decision schemes are $a_i, i\in(1,2,\cdots,m)$, decision criterions are $c_j, j\in(1,2,\cdots,n)$, criterion weights are
$\omega_j, j\in(1,2,\cdots,n)$, the fuzzy number of decision scheme a_i under the criterion c_j is x_{ij}, which is of mixed fuzzy number type, and the decision matrix is expressed as

$$\mathrm{X}=\left(x_{ij}\right)_{mn}.$$

When x_{ij} is all triangular fuzzy number, it is degraded to the decision matrix in literature [10], and the FVIKOR method is applied to solve it directly.

Step 1 Fuzzy random variables

The random type criterion value x_{ij} which obey the normal distribution $N\left(\mu_{ij},\sigma_{ij}^2\right)$ is transformed into interval type criterion value Eij, The decision matrix becomes:

$$E=\begin{bmatrix} e_{11} & \cdots & e_{1\mathrm{n}} \\ \vdots & \ddots & \vdots \\ e_{m1} & \cdots & e_{mn} \end{bmatrix}, \quad (16)$$

where $e_{ij}=\left(e_{ij}^L,e_{ij}^U\right)$, $e_{ij}^L=\mu_{ij}-3\sigma$, $e_{ij}^R=\mu_{ij}+3\sigma$, $(i=1,\cdots,m; j\in N_5)$,the exact value, interval number and triangular fuzzy number remain unchanged.

Step 2 Decision matrix normalization

The fuzzy decision matrix E is normalized, the normalized decision matrix Z is obtained,

$$Z=\begin{bmatrix} z_{11} & \cdots & z_{11} \\ \vdots & \ddots & \vdots \\ z_{m1} & \cdots & z_{mn} \end{bmatrix}. \quad (17)$$

It is assumed that the criterion values are all benefit type , the real criterion values normalized formulas is

$$\tilde{z}_{ij}=\frac{e_{\mathrm{ij}}}{\sqrt{\sum_{i=1}^m e_{ij}^2}} \quad (18)$$

Triangular fuzzy number $(e_{ij}^L, e_{ij}^M, e_{ij}^U)$ criterion value normalization formula is

$$\tilde{z}_{ij}=\left(\frac{e_{ij}^L}{\max_i e_{ij}^U},\frac{e_{ij}^M}{\max_i e_{ij}^M},\frac{e_{ij}^U}{\max_i e_{ij}^L}\wedge 1\right) \quad (19)$$

Interval number criterion value normalization formula:

$$\begin{cases} z_{ij}^L=\dfrac{e_{ij}^L}{\sum_{i=1}^m e_{ij}^U} \\ z_{ij}^U=\dfrac{e_{ij}^U}{\sum_{i=1}^m e_{ij}^L} \end{cases},\ z_{ij}^L, z_{ij}^R\in[0,1]. \quad (20)$$

Step 3 Determine the positive and negative ideal schemes

According to the probability formula of interval number and triangle fuzzy number, the criterion values under each criterion are compared respectively to determine the positive ideal point and the negative ideal point

$$f^+=(e_1^+,e_2^+,\cdots,e_n^+),\ e_i^+=\left(\max_i e_{1i},\cdots,\max_i e_{ni}\right), \quad (21)$$

$$f^-=(e_1^-,e_2^-,\cdots,e_n^-),\ e_i^-=\left(\min_i e_{1i},\cdots,\max_i e_{ni}\right)\mathrm{cc} \quad (22)$$

The weighted distance of Schemes a_i and positive ideal schemes Z^+,

$$d^+(a_i,Z^+)=\sqrt{\sum_{j=1}^n\left[\omega_j d\left(z_j^+,z_{ij}\right)\right]^2} \quad (23)$$

The weighted distance of Schemes a_i and negative ideal schemes Z^-,

$$d^-(a_i,Z^-)=\sqrt{\sum_{j=1}^n\left[\omega_j d\left(z_j^-,z_{ij}\right)\right]^2} \quad (24)$$

Step 4 Determine decision weight

For each scheme a_i, a linear programming model is established,

$$mind^+(a_i,Z^+)=\sqrt{\sum_{j=1}^n\left[\omega_j d\left(z_j^+,z_{ij}\right)\right]^2} \quad (25)$$

$$s.t\begin{cases}\sum_{j=1}^n\omega_j=1\\ \omega_j\ge 0, b\ge 0\end{cases} \quad (26)$$

$$maxd^-(a_i,Z^-)=\sqrt{\sum_{j=1}^n\left[\omega_j d\left(z_j^-,z_{ij}\right)\right]^2} \quad (27)$$

$$s.t\begin{cases}\sum_{j=1}^n\omega_j=1\\ \omega_j\ge 0, b\ge 0\end{cases} \quad (28)$$

Because each scheme is in fair competition, the distances of positive ideal scheme, negative ideal scheme and other schemes all come from the same set of weight coefficients and have the same constraint conditions.

By synthesizing the above two equations, a model for solving the weight coefficient and ranking value of mixed indexes is obtained

$$minD_i = \frac{mind^+(a_i,Z^+)}{mind^+(a_i,Z^+)+maxd^-(a_i,Z^-)} \quad (29)$$

$$s.t\begin{cases} \sum_{j=1}^{n}\omega_j = 1 \\ \omega_j \geq 0, b \geq 0 \end{cases} \quad (30)$$

Using MATLAB to solve, the weight coefficient of mixed attribute value is obtained $\omega = (\omega_1, \omega_2, \cdots, \omega_n)$.

Step 5 comprehensive ranking

Let

$$Q_i = \frac{d^+(a_i,Z^+)}{d^+(a_i,Z^+)+d^-(a_i,Z^-)} \quad (31)$$

The weight coefficient of $\omega = (\omega_1, \omega_2, \cdots, \omega_n)$ res $d^+(a_i, Z^+)$, $d^-(a_i, Z^-)$, Q_i is Calculated , $0 \leq Q_i \leq 1$, $Q_i \to 0$, indicates that the optimal evaluation object, that is the smaller Q_i value representation scheme is optimized.

Or let

$$Q_i = \frac{d^-(a_i,Z^-)}{d^+(a_i,Z^+)+d^-(a_i,Z^-)} \quad (32)$$

The weight coefficient of $\omega = (\omega_1, \omega_2, \cdots, \omega_n)$ res $d^+(a_i, Z^+)$, $d^-(a_i, Z^-)$, $Q_i$is Calculated, $0 \leq Q_i \leq 1$, $Q_i \to 1$, indicates that the optimal evaluation object, that is the bigger Q_i value representation scheme is optimized.

5. Instance Analysis

To verify the accuracy and effectiveness of the proposed method, a practical example is presented to illustrate its application. The example focuses on evaluating high-level talents during the talent introduction process for an experimental specialty. Five criteria are considered: academic background C_1 , development prospect C_2, academic influence C_3 , innovation ability C_4 , and scientific research potential C_5 . Without taking other factors into account, the candidate selection is based on the optimal scheme derived from these criteria.

The human resources department is responsible for identifying four potential candidates. Initially, the parameters of each candidate's academic influence are determined using big data analysis. Subsequently, an expert group specializing in talent assessment is invited to evaluate the remaining three criteria based on the candidates' academic materials. The experts assign scores to each criterion for statistical analysis. Due to variations in the experts' evaluations for the same candidate, the criterion values for each candidate under each criterion are represented using different methods, such as triangular fuzzy numbers, random model indexes, interval numbers, and exact numbers. It is assumed that the criterion values are of the benefit type.

See Table 1 (Talent evaluation matrix) for details.

Table 1. Talent Evaluation Matrix

	c_1	c_2	c_3	c_4	c_5
a_1	9.5	(0.7,0.8,0.9)	(0.8,0.9,1.0)	[60,80]	N(375,94)
a_2	7.5	(0.5,0.6,0.7)	(0.6,0.7,0.8)	[50,60]	N(356,150)
a_3	6.0	(0.6,0.7,0.8)	(0.4,0.5,0.6)	[35,45]	N(469,150)
a_4	8.5	(0.8,0.9,1.0)	(0.4,0.5,0.6)	[65,70]	N(394,131)

The incomplete information of the criterion weight coefficient is given as:

$$H = \{0.1 \leq \omega_1 \leq 0.35, 0.15 \leq \omega_2 \leq 0.45, 0.05 \leq \omega_3 \leq 0.2, 0.1 \leq \omega_4 \leq 0.3, 0.08 \leq \omega_5 \leq 0.15\}$$

Solve the optimal solution.

According to the principle of 3δ, interval numbers are used to represent random model indexes, as shown in Table 2.

Table 2. Decision Matrix

	c_1	c_2	c_3	c_4	c_5
a	9.5	(0.7,0.8,0.9)	(0.8,0.9,1.0)	[60,80]	[345.9139 404.0861]
a	7.5	(0.5,0.6,0.7)	(0.6,0.7,0.8)	[50,60]	[319.2577 392.7423]
a	6.0	(0.6,0.7,0.8)	(0.4,0.5,0.6)	[35,45]	[432.2577 505.7423]
a	8.5	(0.8,0.9,1.0)	(0.4,0.5,0.6)	[65,70]	[359.6634 428.3366]

(2) Normalize the decision matrix, See Table 3.

Table 3. Normalization Matrix

	c_1	c_2	c_3	c_4	c_5
(	0.5952	(0.2059,0.2667,0.3462)	(0.2667,0.3462,0.4545)	[0.2353, 0.3810]	[0.1998, 0.2773]
(	0.4699	(0.1471,0.2000,0.2692)	(0.2000,0.2692,0.3636)	[0.1961, 0.2857]	[0.1844, 0.2695]
(	0.3759	(0.1765,0.2333,0.3077)	(0.1333,0.1923,0.2727)	[0.1373, 0.2143]	[0.2497, 0.3471]

[illegible]	0.5326	(0.2353,0.3000,0.3846)	(0.1333,0.1923,0.2727)	[0.2549,0.3333]	[0.2078,0.2940]

(3)Determine positive and negative ideal schemes

Negative ideal scheme:

$$f^{-} = [0.3759, (0.1471,0.2000,0.2692), (0.1333,0.1923,0.2727), [0.1373,0.2143], [0.1844,0.2695]];$$

Positive ideal scheme:

$$f^{+} = [0.5952, (0.2353,0.3000,0.3846), (0.2667,0.3462,0.4545), [0.2549,0.3810], [0.2497,0.3471]].$$

(4) Using MATLAB software to get each scheme $\boldsymbol{D_i}$:

$$\boldsymbol{D_1}=0.1740;$$
$$\boldsymbol{D_2 = 0.6699};$$
$$\boldsymbol{D_3 = 0.8260};$$
$$\boldsymbol{D_4 = 0.3328}$$

The scheme ranking is obtained, according to $\boldsymbol{D_i}$ from the smallest to the largest,

$$\boldsymbol{a_1 \succ a_4 \succ a_2 \succ a_3}.$$

6. Conclusion

In the context of multi-criteria decision making problems involving mixed fuzzy number types, the application of the 3δ principle to the fuzzy processing of random model indexes is a crucial step in utilizing the TOPSIS method to obtain optimal solutions. Unlike traditional approaches that rely on defuzzification as a precondition, this paper leverages the qualitative description capabilities of fuzzy numbers to preserve the inherent characteristics of fuzzy decision making. The effectiveness of this method is demonstrated through illustrative examples.

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