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Research Article

Triangular Fuzzy Number Multi-attribute Decision-making Method Based on Set-pair Analysis

Sha Fu and Hangjun Zhou

Department of Information Management, Hunan University of Finance and Economics, 410205, People's Republic of China

Abstract

Background: This study proposes a triangular fuzzy number multi-attribute decision-making method based on set-pair analysis, to solve the problems with multi-attribute decision-making, with both the attribute value and the attribute weight being triangular fuzzy numbers. **Materials and Methods:** This method integrates the set-pair analysis theory and converts the attribute values and the attribute weight of the triangular fuzzy number into identical-different dual connection numbers, in an effort to build the absolute positive ideal connection number and absolute negative ideal connection number of the attribute values and calculate the absolute positive and negative ideal connection number distance in various schemes. **Results:** This way, the relative connection number distance can be determined and used to rank the schemes. **Conclusion:** At last, the study results demonstrate the feasibility and validity of the proposed method through analysis of examples.

Key words: Set-pair analysis, triangular fuzzy number, multi-attribute decision-making, dual connection number, connection number distance

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Corresponding Author: Sha Fu, Department of Information Management, Hunan University of Finance and Economics, 410205, People's Republic of China Tel: 86+13875982792

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INTRODUCTION

Multi-attribute decision-making (MADM) is widely used in investment decision making, project evaluation, quality assessment and economic benefit evaluation in various fields, including society, economy and management. In real life, due to complicatedness and uncertainty of the objective things and the fuzziness of human thinking, it is very difficult to get an accurate numerical number for the evaluated things during decision making. To reflect the decision making information in an objective way, the triangular fuzzy number can be used to express the attribute value. This can not only maintain the taking value interval of the variables but can also highlight the possibility of various values within this interval.

The study of multi-attribute decision making problems with the attribute value being a triangular fuzzy number has been drawing very much attention of domestic and foreign scholars and experts. By now, remarkable achievements have been made in academic researches. Carlsson and Fuller[1] introduced the notations of lower possibilistic and upper possibilistic mean values they define the interval-valued possibilistic mean and investigate its relationship to the interval-valued probabilistic mean[2]. Dubois *et al*.[3] provided a justification of symmetric triangular fuzzy numbers in the spirit of such inequalities. It shows that the cuts of such a triangular fuzzy number contain the "Confidence intervals" of any symmetric probability distribution with the same mode and support[4]. Cheng[5] proposed a novel method to derive the collective opinion of a group of members as expressed in a grading process in which individual group members evaluate objects or events by assigning numerical scores. The collective opinions are represented using triangular fuzzy numbers whose construction is based on the possibility distribution of the grading process. Liu *et al*.[6] proposed a triangular fuzzy number multi-attribute decision making evaluation model based on he connection number by expressing the triangular fuzzy number as the connection number. Wang and Gong[7] proposed a decision making method based on the set-pair analysis to solve the multi-criteria decision making problems with ascertained criteria weight and the criteria value being an interval probability interval random variable. This method used the set-pair analysis to build a planning model and expressed the interval status value as a connection number and ranked the schemes based on the set-pair order potential criteria. Zhao and Zhang[8] proposed decision-making method of a black-start vague set is based on connection number analysis of set-pair. Practical application shows that the method can deal with the problem of optimizing black-start schemes of the correlation and uncertainty in the selected evaluation indexes effectively and clearly. Huang and Luo[9] proposed the index weight measure based on the triangular fuzzy number comparison possibility degree relation to solve the uncertain multi-attribute decision making (UMADM) problem with the index value being a triangular fuzzy number and proposed a comparison possibility degree relation method of the triangular fuzzy number type UMADM that can be used to judge and rank the superiority and inferiority of the decision making scheme set. Based on the existing research foundation, this study utilizes the characteristics of the triangular fuzzy number to convert the data processing problem of triangular fuzzy number to a problem processing problem of identical-different dual connection number and build the absolute positive ideal connection number and the absolute negative ideal connection number of the attribute values. This way, the relative connection number distance is obtained. The research of such problems is of great theoretical significance and practical application value. It is now becoming a key hot topic in the decision-making science field.

MATERIALS AND METHODS

Preliminaries

Set-pair analysis: The set-pair analysis was proposed by Zhao Keqin, a Chinese scholar, in 1989. It refers to a systematic mathematic method used to probe into and solve the uncertainty in complicated systems. This mathematic theory can be used to deal with the interaction between the certainty and uncertainty in a system. The main mathematical tool of this method is the connection number. Now, the set-pair analysis is being widely used in a number of fields like natural science and social science.

In the set-pair analysis, uncertainty and certainty are studied as one system. It aims at probing into the value taking laws of the uncertainty in a specific condition by describing, analyzing and processing the interdependence, interrelation and inter-infiltration between uncertainty and certainty and the mutual transformation between the two under certain conditions[10]. The basic idea is to conduct a systematic and mathematical analysis of the uncertainty and certainty of the two sets in a set pair and their interaction in a certain question setting. This generally includes analysis of the characteristics, relation, structure, status and trend of the two sets in a set pair and the interrelation mode between the two[11].

Triangular fuzzy number and dual connection number

Definition 1: Assume, $\hat{a} = [a^L, a^M, a^U]$ where, $0<a^L\leq a^M\leq ^U$; let $\hat{a}$ be a triangular fuzzy number, then its subordinate function and be expressed as[7]:

$$\mu_{\hat{a}}(x)=\begin{cases}0, & x<a^L\\ \dfrac{x-a^L}{a^M-a^L}, & a^L\le x\le a^M\\ \dfrac{x-a^U}{a^M-a^U}, & a^M\le x\le a^U\\ 0, & x>a^U\end{cases} \quad (1)$$

where, a^L and a^U are respectively the upper limit value and lower limit value of the triangular fuzzy number $\hat{a}$ and a^M is the mid value.

Definition 2: Assume $\hat{a}=[a^L, a^M, a^U]$ and $\hat{b}=[b^L, b^M, b^U]$ are two random triangular fuzzy numbers. Then their algorithms are as follows[9]:

- $\hat{a}+\hat{b}=[a^L+b^L, a^M+b^M, a^U+b^U]$
- $\hat{a}\times\hat{b}=[a^Lb^L, a^Mb^M, a^Ub^U]$
- $\lambda\hat{a}=[\lambda a^L, \lambda a^M, \lambda a^U], \lambda\ge 0$
- $\dfrac{1}{\hat{a}}=[\dfrac{1}{a^U}, \dfrac{1}{a^M}, \dfrac{1}{a^L}], a^L, a^M, a^U\ne 0$

Definition 3: Assume R^+ is a positive real number set, a, b, $c\epsilon R^+$, $i\epsilon[-1, 1]$ and j = -1, then u = a+bi+cj is an identical discrepancy contrary three-unit connection number, a connection number for short. The a, b, c are respectively called the identical degree, different degree and contrary degree of the connection number.

When c = 0, u = a+bi is an identical-different dual connection number, when a+b+c = 1, u = a+bi+cj is a normalized identical discrepancy contrary three-unit connection number[12].

Definition 4: Assume $u_1 = a_1+b_1i$ and $u_2 = a_2+b_2i$ are two dual connection numbers, then the algorithm is as follows:

- $u_1+u_2 = (a_1+a_2)+(b_1+b_2)i$
- $u_1\times u_2 = a_1a_2+(a_1b_2+b_1b_2+a_2b_1)i$

Definition 5: Assume R^+ is a positive real number set. If $a^L<a^M<a^U\epsilon R^+$ and the triangular fuzzy number is $\hat{a}=[a^L, a^M, a^U]$, then the triangular fuzzy number can be converted into an identical-different dual connection number:

$$u=a^M+\frac{\sqrt{(a^M-a^L)^2+(a^M-a^U)^2}}{2}i \quad (2)$$

where, $i\epsilon$ [-1, 1].

Definition 6: Assume the dual connection numbers $u_1 = a_1+b_1i$ and $u_2 = a_2+b_2i$, then the connection number distance between u_1 and u_2 should be:

$$L(u_1, u_2) = |a_1-a_2|+|b_1-b_2| \quad (3)$$

Triangular fuzzy number multi-attribute decision-making method based on set-pair analysis

Description of the research problem: Assume the scheme set of triangular fuzzy number multi-attribute decision making is $A = \{A_1, A_2,...,A_m\}$. Each scheme has n attribute indexes. The attribute set is $C=\{C_1, C_2, C_3,...,C_n\}$. $\hat{a}_{kt}=[a^L_{kt}, a^M_{kt}, a^U_{kt}]$ is the triangular fuzzy number attribute value of attribute t C_t (t = 1, 2,...,n) of scheme k A_k (k = 1, 2,...,m), $\hat{w}_t=[w^L_t, w^M_t, w^U_t]$ where, $\hat{w}_t$ is the weight of attribute t C_x and $0\le w^L_t\le w^U_t\le 1$,

$$\sum_{t=1}^{n} w^L_t\le 1$$

and

$$\sum_{t=1}^{n} w^U_t\ge 1$$

Now, it is required to conduct multi-attribute decision-making analysis of m schemes to rank them and find out the optimal scheme.

Step of multi-attribute decision-making: The steps of this decision-making method are described below:

Step 1: Normalized processing of decision-making matrix: To remove the impact of dimension difference on the result of decision making between attributes, the following equation can be used to process triangular fuzzy number in $\hat{a}_{kt}=[a^L_{kt}, a^M_{kt}, a^U_{kt}]$ a normalized way. The common attribute types in the multi-attribute decision making problem include the benefit type and the cost type. For the benefit type attributes, a greater value indicates a better result; but for the cost type attributes, the situation is the reverse

For benefit type attributes:

$$y^L_{kt}=\frac{a^L_{kt}}{\sum_{k=1}^{m}a^U_{kt}},\ y^M_{kt}=\frac{a^M_{kt}}{\sum_{k=1}^{m}a^M_{kt}},\ y^U_{kt}=\frac{a^U_{kt}}{\sum_{k=1}^{m}a^L_{kt}} \quad (4)$$

For cost type attributes:

$$y_{kt}^{L} = \frac{\frac{1}{a_{kt}^{U}}}{\sum_{k=1}^{m}\frac{1}{a_{kt}^{L}}},\ y_{kt}^{M} = \frac{\frac{1}{a_{kt}^{M}}}{\sum_{k=1}^{m}\frac{1}{a_{kt}^{M}}},\ y_{kt}^{U} = \frac{\frac{1}{a_{kt}^{L}}}{\sum_{k=1}^{m}\frac{1}{a_{kt}^{U}}} \tag{5}$$

Step 2: After normalized processing of the attributes, their values are converted from triangular fuzzy numbers to identical-different dual connection numbers in accordance with definition 5:

$$u_{kt} = a_{kt}+b_{kt}i \tag{6}$$

Where:

$$b_{kt} = \frac{\sqrt{(y_{kt}^{L}-y_{kt}^{M})^2+(y_{kt}^{U}-y_{kt}^{M})^2}}{2};\ i\in[-1,1];\ a_{kt} = y_{kt}^{M}$$

Step 3: Determine the absolute positive ideal connection number and absolute negative ideal connection number of the attribute values. Build respectively the absolute positive ideal connection number and absolute negative ideal connection number of the attribute values with attribute values being expressed as identical-different dual connection numbers

Absolute positive ideal connection number of the attribute values:

$$u_t^{+} = a_t^{+}+b_t^{+}i \tag{7}$$

Where:

$$a_t^{+} = \max_{1\le k\le m} a_{kt};\ b_t^{+} = \min_{1\le k\le m} b_{kt}$$

Absolute negative ideal connection number of the attribute values:

$$u_t^{-} = a_t^{-}+b_t^{-}i \tag{8}$$

Where:

$$a_t^{-} = \min_{1\le k\le m} a_{kt};\ b_t^{-} = \max_{1\le k\le m} b_{kt}$$

Step 4: Determine the distance between the attribute value connection number and the absolute positive ideal connection number and that between the attribute value connection number and the absolute negative ideal connection number in each scheme. Determine the distance L_{kt}^{+} and L_{kt}^{-} between the attribute weight connection number and the absolute positive (negative) ideal weight connection number as described in definition 6. Obtain the distance with the absolute positive ideal connection number:

$$L_k^{+} = \sum_{t=1}^{n} L_{kt}^{+}$$

of each scheme and the distance with the absolute negative ideal connection number:

$$L_k^{-} = \sum_{t=1}^{n} L_{kt}^{-}$$

of each scheme through accumulated calculation based on the attribute[13].

Step 5: Calculate the relative connection number distance D_k and rank the superiority and inferiority of each scheme based on the values of D_k. A greater value means a better scheme

$$D_k = \frac{L_k^{-}}{L_k^{+}+L_k^{-}} \tag{9}$$

RESULTS AND DISCUSSION

Ye *et al.*[14] proposed a ranking method based on set-pair analysis to solve the multi-attribute decision making problem of interval number. Liu and Zhao[15] proposed the dual connection number concept based on the connection number basic decision-making model and utilized the change of dual connection numerical number to study and analyze the uncertainty in the interval-multiple attribute decision making, so as to get the decision-making process based on the dual connection number. The study results prove feasibility and effectiveness of this approach, from the computational analysis step and process, compared to method used in the reference literature[7,14,15], the study proposed approach can better meet practical needs, more in line with actual situation of MADM problem and with stronger operability.

Analysis of examples: The cadre assessment and selection case in Literature[16] is taken as an example for analysis. An organization sets up 6 assessment indexes (attributes) for assessment and selection of cadres: Ideology and morality (C_1), working attitude (C_2), work style (C_3), educational level and knowledge structure (C_4), leadership (C_5) and exploitation ability (C_6). The public appraisal method is used to obtain the assessment scores. Assume that 5 candidates have been selected A_i (i = 1, 2,...,5) after statistical processing and the attribute values of each attribute (index) for each candidate are expressed in the form of triangular fuzzy numbers. The specific intuitionistic quantified index values are shown in Table 1.

The weight of each attribute is also a triangular fuzzy number as shown in Table 2:

Step 1: As each attribute falls into the category of benefit type attribute, to remove the impact of dimension difference between attributes on the decision making result, Eq. 4 and 5 can be used to process the triangular fuzzy number matrix in a normalized manner to get the normalized triangular fuzzy number decision-making matrix as shown in Table 3

Step 2: Convert the attribute values in the normalized decision-making attribute from triangular fuzzy numbers to identical-different dual connection numbers using Eq. 6. The specific data are shown in Table 4

Step 3: Use Eq. 7 and 8 to determine the absolute positive ideal connection number u_t^+ and absolute negative ideal connection number u_t^- of each attribute based on the identical-different dual connection numbers of attribute date in Table 4

The absolute positive ideal connection number u_t^+ should be:

0.2125+0.0102i, 0.2053+0.0069i, 0.2052+0.0073i
0.1902+0.0147i, 0.1898+0.0083i, 0.1901+0.0097i

The absolute negative ideal connection number u_t^- should be:

0.2069+0.0072i, 0.2113+0.0054i, 0.2100+0.0055i
0.1918+0.0093i, 0.1939+0.0092i, 0.1883+0.0071i

Step 4: Calculate the distance between the attribute values weighed connection number and the absolute positive ideal connection number for each scheme. Calculate the distance between the attribute values weighed connection number and the absolute negative ideal connection number as shown in Table 5 and 6

Table 1: Initial value observation quantification matrix

	C_1	C_2	C_3	C_4	C_5	C_6
A_1	[0.80, 0.85, 0.90]	[0.90, 0.92, 0.95]	[0.91, 0.94, 0.95]	[0.93, 0.96, 0.99]	[0.90, 0.91, 0.92]	[0.95, 0.97, 0.99]
A_2	[0.90, 0.95, 1.00]	[0.89, 0.90, 0.93]	[0.90, 0.92, 0.95]	[0.90, 0.92, 0.95]	[0.94, 0.97, 0.98]	[0.90, 0.93, 0.95]
A_3	[0.88, 0.91, 0.95]	[0.84, 0.86, 0.90]	[0.91, 0.94, 0.97]	[0.91, 0.94, 0.96]	[0.86, 0.89, 0.92]	[0.91, 0.92, 0.94]
A_4	[0.85, 0.87, 0.90]	[0.91, 0.93, 0.95]	[0.85, 0.88, 0.90]	[0.86, 0.89, 0.93]	[0.87, 0.90, 0.94]	[0.92, 0.93, 0.96]
A_5	[0.86, 0.89, 0.95]	[0.90, 0.92, 0.95]	[0.90, 0.95, 0.97]	[0.91, 0.93, 0.95]	[0.90, 0.92, 0.96]	[0.85, 0.87, 0.90]

Table 2: Attribute weight

	C_1	C_2	C_3	C_4	C_5	C_6
Attribute weight	[0.19, 0.21, 0.23]	[0.15, 0.17, 0.19]	[0.10, 0.13, 0.15]	[0.15, 0.17, 0.19]	[0.10, 0.13, 0.15]	[0.23, 0.24, 0.25]

Table 3: Normalized triangular fuzzy decision-making matrix

	C_1	C_2	C_3	C_4	C_5	C_6
A_1	[0.170, 0.190, 0.210]	[0.192, 0.203, 0.214]	[0.192, 0.203, 0.213]	[0.195, 0.207, 0.220]	[0.191, 0.198, 0.206]	[0.200, 0.210, 0.219]
A_2	[0.191, 0.213, 0.233]	[0.190, 0.199, 0.209]	[0.190, 0.199, 0.213]	[0.188, 0.198, 0.211]	[0.199, 0.211, 0.219]	[0.190, 0.201, 0.210]
A_3	[0.187, 0.204, 0.221]	[0.179, 0.190, 0.203]	[0.192, 0.203, 0.217]	[0.190, 0.203, 0.213]	[0.182, 0.194, 0.206]	[0.192, 0.199, 0.208]
A_4	[0.181, 0.195, 0.210]	[0.194, 0.205, 0.214]	[0.179, 0.190, 0.201]	[0.180, 0.192, 0.206]	[0.184, 0.196, 0.210]	[0.194, 0.201, 0.212]
A_5	[0.183, 0.199, 0.221]	[0.192, 0.203, 0.214]	[0.190, 0.205, 0.217]	[0.190, 0.200, 0.211]	[0.191, 0.200, 0.215]	[0.179, 0.188, 0.199]

Table 4: Identical-different dual connection number

	C_1	C_2	C_3	C_4	C_5	C_6
A_1	0.190+0.014i	0.203+0.008i	0.203+0.007i	0.207+0.009i	0.198+0.005i	0.210+0.006i
A_2	0.213+0.015i	0.199+0.007i	0.199+0.008i	0.198+0.008i	0.211+0.007i	0.201+0.007i
A_3	0.204+0.012i	0.190+0.008i	0.203+0.009i	0.203+0.008i	0.194+0.008i	0.199+0.006i
A_4	0.195+0.010i	0.205+0.007i	0.190+0.008i	0.192+0.009i	0.196+0.009i	0.201+0.006i
A_5	0.199+0.014i	0.203+0.008i	0.205+0.010i	0.200+0.007i	0.200+0.009i	0.188+0.007i
Attribute weight	0.210+0.014i	0.170+0.014i	0.130+0.018i	0.170+0.014i	0.130+0.018i	0.240+0.007i

Table 5: Distance between attribute value weighed connection number and absolute positive ideal connection number

	L^+_{k1}	L^+_{k2}	L^+_{k3}	L^+_{k4}	L^+_{k5}	L^+_{k6}	L^+_k
A_1	0.0048	0.0004	0.0003	0.0000	0.0017	0.0000	0.0072
A_2	0.0001	0.0011	0.0009	0.0015	0.0000	0.0021	0.0057
A_3	0.0019	0.0026	0.0003	0.0007	0.0023	0.0026	0.0104
A_4	0.0038	0.0000	0.0020	0.0026	0.0021	0.0021	0.0126
A_5	0.0029	0.0004	0.0000	0.0011	0.0015	0.0052	0.0111

Table 6: Distance between attribute value weighed connection number and absolute negative ideal connection number

	L^-_{k1}	L^-_{k2}	L^-_{k3}	L^-_{k4}	L^-_{k5}	L^-_{k6}	L^-_k
A_1	0.0000	0.0023	0.0017	0.0026	0.0006	0.0052	0.0124
A_2	0.0047	0.0015	0.0011	0.0011	0.0023	0.0031	0.0138
A_3	0.0029	0.0000	0.0017	0.0019	0.0000	0.0026	0.0091
A_4	0.0010	0.0026	0.0000	0.0000	0.0003	0.0031	0.0070
A_5	0.0019	0.0023	0.0020	0.0015	0.0009	0.0000	0.0086

Step 5: Calculate the relative connection number distance D_k of each scheme based on the data in Table 5 and Table 6

$$D_1 = 0.6327, D_2 = 0.7077, D_3 = 0.4667$$
$$D_4 = 0.3571, D_5 = 0.4365$$

Therefore, the final ranking result should be $A_2>A_1>A_3>A_5>A_4$ and the optimal scheme is A_2. Through computational analysis, the result obtained in this study is consistent with literature[16], which proves feasibility and effectiveness of the method. A review of specific steps and processes reveals that, compared to method proposed in literature of the same type, the method is more practical and reasonable. The assessment results can be used as scientific basis for decision makers of the organization.

CONCLUSION

This study proposes a triangular fuzzy number multi-attribute decision-making method based on set-pair analysis, to solve the problems with multi-attribute decision-making, with both the attribute value and the attribute weight being triangular fuzzy numbers. It also discussed the implementation steps in a detailed manner. Research and analysis of examples show that this method combines the relatively ascertained information and the relatively uncertain information in the decision making data in an organic way. The rules are clear, easily understandable and highly operable. This method better fits the thinking habit of people and the real situations and can be widely used for analysis and decision making in personal development, organization progress and social coordination.

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