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Research Article
Interval Number Multi-attribute Grey Target Decision Making Method Based on Positive and Negative Clouts

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Abstract

Aimed at the multi-attribute decision making problem that the weight information is uncertain completely and the attribute value is interval number, an interval number multi-attribute decision making method based on positive and negative clouts is proposed. First, in this method, the interval number linear transformation operator is used for normalized processing of the original decision-making information and the interval number positive and negative clouts of grey target intervals are designed; second, in full consideration of the spatial projection distance between each plan and the positive and negative clouts, the off-target distance is taken as the basis for the spatial analysis of vector and a new comprehensive off-target distance is obtained; then, with the criterion of minimum comprehensive off-target distance as the objective, a target planning model is constructed to calculate the attribute weight and finally the sequencing of the plan is determined. Finally, the feasibility and effectiveness of the grey target decision making model is verified through an example.

Key words: Positive and negative clouts, interval grey number, grey target decision making, linear transformation operator, comprehensive off-target distance

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INTRODUCTION

As an important part of modern decision making science, the multi-attribute decision making is mainly used to solve the problem of limited plan decision making under the condition of multiple attributes and its theories and methods are widely applied in social, economic, military and management fields (Mundaca and Neij, 2009; Willems, 2009). Deng Ju-long, the theoretical founder of grey system first proposed the concept of grey target and deeply researched the grey target theory and a lot of experts and scholars also have engaged in the research on grey target decision making. With the increasing complication of the decision making problems, the uncertainty in problem evaluation also has been increasing and the multi-attribute decision making research on the uncertain decision making background (like interval grey number) is becoming a hot research topic. For example, Ho *et al.* (2010) proposed the literature of the multi-criteria decision making approaches for supplier evaluation and selection. Wu *et al.* (2005) presented an alternative evaluation procedure to help retailers, especially hyper marketers, make a location decision by using the grey multi-objective decision method. Eshlaghy and Razi (2015) presented an integrated framework for project selection and project management approach using grey-based k-means and genetic algorithms. The proposed approach of this study first cluster different projects based on k-means algorithm and then ranks R and D projects by grey relational analysis model. Wang *et al.* (2009) considered the influence of correlation between indicators, different dimension and importance difference on decision making effect, employed weighted Mahalanobis distance to improve the traditional grey target decision making method, thus avoiding the influence of correlation between decision making indicators, different dimension and importance difference on the decision making effect. Liang *et al.* (2012) aimed at the uncertainty and multiple time point of multi-attribute decision making, proposed the multi-time point multi-attribute grey decision making model based on interval number. Luo and Wang (2012) based on the grey system theory and methods, the grey-target decision-making problem is discussed, in which the attribute values are grey numbers and the maximum probability of the value of grey number is known. Liu *et al.* (2013a) proposed a novel multi-attribute grey target decision model and demonstrated with a practical case study. Dai and Li (2014) aimed at the fact that the class 1 attribute values, attribute weight and decision maker weight are all the group decision making problem of interval grey number, introduced the concept of positive and negative clouts and group deviation approaching degree and proposed the group decision making method of grey multi-attribute deviation approaching degree. Jianyou and Hua (2006) constructed a bonus and forfeit operator which can amplify the indicator difference in case of indicator non-dimensionalization changing and established the weighted grey target decision making model on this basis. Yan and Liu (2014) considered the influence of decision maker's expectancy grey target on the group decision making, proposed a group grey target decision making method based on the prospect theory. In this method, the expectancy grey target used as the reference point to define the prospect value function and the linear transformation operator of bonus and forfeit is used for normalized treatment of prospect value, which can fully reflect whether the evaluation value hits the target. The above researches provide some thoughts to decision the grey target decision making problem but it can also found that there are fewer researchers on the grey target decision making in which the decision making information is of interval grey number form and the attribute weight is uncertain, as such, a corresponding grey target decision making model is proposed in this study to meet the demand of such decision making.

There are n decision making plans in many attribute decision making problems, which form a decision making plan set $A = \{A_1, A_2,..., A_n\}$ and m evaluation indicators (attributes) which form an attribute set $C = \{C_1, C_2,...,C_m\}$. The decision making information is not a specific accurate number but an interval grey number, the attribute value of plan A_i to attribute C_j is $x_{ij}(\otimes) \in [\underline{x}_{ij}, \overline{x}_{ij}]$ where, $0 \le \underline{x}_{ij} \le \overline{x}_{ij}$, i = 1, 2,..., n; $j = 1, 2, \cdots, m$ then the effect sample matrix X of plan set A to attribute set C is:

$$X = \begin{bmatrix} x_{11}(\otimes) & x_{12}(\otimes) & \cdots & x_{1m}(\otimes) \\ x_{21}(\otimes) & x_{22}(\otimes) & \cdots & x_{2m}(\otimes) \\ \vdots & \vdots & \ddots & \vdots \\ x_{n1}(\otimes) & x_{n2}(\otimes) & \cdots & x_{nm}(\otimes) \end{bmatrix}$$

The matrix above can be converted into:

$$X = \begin{bmatrix} [\underline{x}_{11}, \overline{x}_{11}] & [\underline{x}_{12}, \overline{x}_{12}] & \cdots & [\underline{x}_{1m}, \overline{x}_{1m}] \\ [\underline{x}_{21}, \overline{x}_{21}] & [\underline{x}_{22}, \overline{x}_{22}] & \cdots & [\underline{x}_{2m}, \overline{x}_{2m}] \\ \vdots & \vdots & \ddots & \vdots \\ [\underline{x}_{n1}, \overline{x}_{n1}] & [\underline{x}_{n2}, \overline{x}_{n2}] & \cdots & [\underline{x}_{nm}, \overline{x}_{nm}] \end{bmatrix}$$

MATERIALS AND METHODS

Preliminaries

Grey target decision making: In 1982, the Chinese scholar Deng Ju-long established the grey system theory. Later, this theory was widely applied and generated a series of grey decision making methods, such as grey target decision making. Grey target decision making is the application and reflection of non-uniqueness principle in grey system theory in the decision making theory and its basic idea is to find out the standard indicator sequence most approach to the target value in a group of indicator sequences consisting of decision target and it is called the clout of grey target. The indicator sequence constituted by other decision making targets form a grey target jointly with the clout and the grey correlation between them and the clout is called approaching degree (Deng, 2002). The evaluation and ranking of the decision making target are mainly based on the size of approaching degree.

Distance of interval grey number: In the grey system theory, the number of which only the approximate range is known but the accurate value is known is called grey number and grey number is the basic unit of the grey system. The grey number with both lower bound $\underline{a}$ and upper bound $\overline{a}$ is called grey number, recorded as $a(\otimes)\in[\underline{a},\overline{a}]$.

Definition 1: Let that there are two interval grey numbers $a(\otimes)\in[\underline{a},\overline{a}]$ and $b(\otimes)\in[\underline{b},\overline{b}]$, k is a positive real number, then the operation rule is (Zeng *et al.*, 2013):

- $a(\otimes)+b(\otimes)\in[\underline{a}+\underline{b},\overline{a}+\overline{b}]$
- $a(\otimes)b(\otimes)\in[\min\{\underline{a}\underline{b},\underline{a}\overline{b},\overline{a}\underline{b},\overline{a}\overline{b}\},\max\{\underline{a}\underline{b},\underline{a}\overline{b},\overline{a}\underline{b},\overline{a}\overline{b}\}]$
- $k+a(\otimes)\in[k+\underline{a},k+\overline{a}]$
- $ka(\otimes)\in[k\underline{a},k\overline{a}]$

Definition 2: Let that there are two interval grey numbers $a(\otimes)\in[\underline{a},\overline{a}]$ and $b(\otimes)\in[\underline{b},\overline{b}]$, then the distance between the interval grey numbers $a(\otimes)$ and $b(\otimes)$ is (Song *et al.*, 2010):

$$L(a(\otimes),b(\otimes))=2^{-\frac{1}{2}}[(\underline{a}-\underline{b})^2+(\overline{a}-\overline{b})^2]^{\frac{1}{2}} \quad (1)$$

Multi-attribute grey targe decision making model

Establishment of multi-attribute grey target decision making model

Normalized treatment of decision-making matrix: As each attribute value in the decision making matrix has different weighing criteria and measuring units, for convenience of unified treatment, it is possible to generate the bonus and forfeit [-1, 1] linear transformation operator for dimensionless treatment of attribute with Vague set and set pair analysis theory and by reference to the idea of bonus and forfeit, so as to obtain a normalized decision making matrix.

Let:

$$z_j=\frac{1}{2n}\sum_{i=1}^{n}(\underline{x}_{ij},\overline{x}_{ij}) \quad (2)$$

$$i = 1, 2,..., n;\ j = 1, 2, ...,m$$

If it is efficiency attribute, then:

$$[\underline{y}_{ij},\overline{y}_{ij}]=\left[\frac{\underline{x}_{ij}-z_j}{|z_j|},\frac{\overline{x}_{ij}-z_j}{|z_j|}\right] \quad (3)$$

If it is cost efficiency, then:

$$[\underline{y}_{ij},\overline{y}_{ij}]=\left[\frac{z_j-\overline{x}_{ij}}{|z_j|},\frac{z_j-\underline{x}_{ij}}{|z_j|}\right] \quad (4)$$

The converted matrix is:

$$D=([\underline{y}_{ij},\overline{y}_{ij}])_{n\times m} \quad (5)$$

In this way, the $\underline{y}_{ij}$ obtained might be less than -1 and $\overline{y}_{ij}$ might be more than 1. Therefore, the following conversion matrix can be used for normalize treatment of matrix D, so as to obtain the normalized decision making matrix:

$$R=([\underline{r}_{ij},\overline{r}_{ij}])_{n\times m} \quad (6)$$

Where:

$$[\underline{r}_{ij},\overline{r}_{ij}]=\left[\frac{\underline{y}_{ij}}{\max\limits_{j}(|\underline{y}_{ij}|,|\overline{y}_{ij}|)},\frac{\overline{y}_{ij}}{\max\limits_{j}(|\underline{y}_{ij}|,|\overline{y}_{ij}|)}\right] \quad (7)$$

The conversion above is called the linear transformation operator of the interval number [-1, 1] (Liu *et al.,* 2013b).

In this way, $\underline{r}_{ij},\overline{r}_{ij}\in[-1,1]$ and each attribute can be subject to the above transformation to obtain the consistency effect measure matrix of plan A_i to the effect sample value of attribute C_j:

$$R=\begin{bmatrix}[\underline{r}_{11},\overline{r}_{11}] & [\underline{r}_{12},\overline{r}_{12}] & \cdots & [\underline{r}_{1m},\overline{r}_{1m}]\\ [\underline{r}_{21},\overline{r}_{21}] & [\underline{r}_{22},\overline{r}_{22}] & \cdots & [\underline{r}_{2m},\overline{r}_{2m}]\\ \vdots & \vdots & \ddots & \vdots\\ [\underline{r}_{n1},\overline{r}_{n1}] & [\underline{r}_{n2},\overline{r}_{n2}] & \cdots & [\underline{r}_{nm},\overline{r}_{nm}]\end{bmatrix} \quad (8)$$

Grey target decision making of positive and negative clouts

Definition 3:

$$\text{Let } r_j^+ = \max\left\{\frac{(\underline{r}_{ij} + \overline{r}_{ij})}{2} \mid 1 \le i \le n\right\}$$

$j = 1, 2, ..., m$ and the corresponding decision value is recorded as $[\underline{r}_{ij}^+, \overline{r}_{ij}^+]$ and:

$$r^+ = \{r_1^+, r_2^+, \cdots, r_m^+\} = \{[\underline{r}_{i1}^+, \overline{r}_{i1}^+], [\underline{r}_{i2}^+, \overline{r}_{i2}^+], \cdots, [\underline{r}_{im}^+, \overline{r}_{im}^+]\} \quad (9)$$

is called the optimal effect vector of the grey target decision making, called the positive clout of the interval number.

Definition 4:

$$\text{Let } r_j^- = \min\left\{\frac{(\underline{r}_{ij} + \overline{r}_{ij})}{2} \mid 1 \le i \le n\right\}$$

$j = 1, 2,...m$ and the corresponding decision making value is recorded as $[\underline{r}_{ij}^-, \overline{r}_{ij}^-]$ and:

$$r^- = \{r_1^-, r_2^-, \cdots, r_m^-\} = \{[\underline{r}_{i1}^-, \overline{r}_{i1}^-], [\underline{r}_{i2}^-, \overline{r}_{i2}^-], \cdots, [\underline{r}_{im}^-, \overline{r}_{im}^-]\} \quad (10)$$

is called the worst effect vector of grey target decision making, called the negative clout of the interval number.

Wherein, the attribute weight is $w = (w_1, w_2,...,w_m)$ and

$$\sum_{j=1}^{m} w_j = 1$$

Definition 5:

$$\varepsilon_i^+ = 2^{-\frac{1}{2}}[w_1(\underline{z}_{i1} - \underline{z}_{i1}^+)^2] + w_1(\overline{z}_{i1} - \overline{z}_{i1}^+)^2 + \cdots + w_m(\overline{z}_{im} - \overline{z}_{im}^+)^2]^{\frac{1}{2}} \quad (11)$$

is called the positive off-target distance of effect vector z_i.

$$\varepsilon_i^- = 2^{-\frac{1}{2}}[w_1(\underline{z}_{i1} - \underline{z}_{i1}^-)^2] + w_1(\overline{z}_{i1} - \overline{z}_{i1}^-)^2 + \cdots + w_m(\overline{z}_{im} - \overline{z}_{im}^-)^2]^{\frac{1}{2}} \quad (12)$$

is called the negative off-target distance of effect vector z_i.

Definition 6:

$$\varepsilon_i^0 = 2^{-\frac{1}{2}}[w_1(\underline{z}_{i1}^+ - \underline{z}_{i1}^-)^2] + w_1(\overline{z}_{i1}^+ - \overline{z}_{i1}^-)^2 + \cdots + w_m(\overline{z}_{im}^+ - \overline{z}_{im}^-)^2]^{\frac{1}{2}} \quad (13)$$

is called the spacing of positive and negative clouts.

As defined in literature (Luo, 2013), the distances ε_i^+, ε_i^-, ε_i^0 fall on the same straight line or form a triangle. Therefore, it is possible to obtain the optimal decision making of the event by using size of projection of the positive off-target distance on the connection between the positive and negative clouts, i.e., the larger the projection is, the more excellent the corresponding decision making will be. Let that the included angle between the positive off-target distance and positive and negative connection is θ, according to the cosine law:

$$(\varepsilon_i^+)^2 + (\varepsilon_i^0)^2 - 2\varepsilon_i^+\varepsilon_i^0\cos\theta = (\varepsilon_i^-)^2$$

Both the positive off-target distance ε_i^+ and negative off-target distance ε_i^- are vectors, in consideration of the projection of off-target distance on the connection between positive and negative clouts, the comprehensive off-target distance ε_i is:

$$\varepsilon_i = \varepsilon_i^+\cos\theta = \frac{(\varepsilon_i^+)^2 + (\varepsilon_i^0)^2 - (\varepsilon_i^-)^2}{2\varepsilon_i^0} \quad (14)$$

The comprehensive off-target distance comprehensively considers the positive and negative clouts, the off-target distance is used as a vector, so that the decision-making information is more scientific and reasonable.

Determination of attribute weight: If the attribute weight sequence $w = w_1, w_2,...,w_m$ is unknown, the sequence is grey connotation sequence and the grey entropy can be defined:

$$H_{\otimes}(w) = -\sum_{j=1}^{m} w_j \ln w_j \quad (15)$$

According to the principle of maximum entropy, it is required to adjust w_j (j = 1, 2, ..., m) to reduce the uncertainty of $w = w_1, w_2,...,w_m$, i.e., to promote the maximization of $H_{\otimes}(w)$. At the same time, the weight w_j (j = 1, 2, ..., m) is adjusted to minimize the overall comprehensive off-target distance and in this way, the following multi-objective optimal model can be established:

$$\begin{cases} \min\sum_{i=1}^{n}\varepsilon_i = \sum_{i=1}^{n}\frac{(\varepsilon_i^+)^2 + (\varepsilon_i^0)^2 - (\varepsilon_i^-)^2}{2\varepsilon_i^0} \\ \max H_{\otimes}(w) = -\sum_{j=1}^{m} w_j \ln w_j \\ \text{s.t.}\sum_{j=1}^{m} w_j = 1, w_j \ge 0, j = 1, 2, \cdots, m \end{cases} \quad (16)$$

To calculate the multi-objective optimal model, according to the fair competitiveness of each plan, the multi-objective optimal model above can be transformed into a single-objective optimal model:

$$\begin{cases} \min\left\{\mu\sum_{i=1}^{n}\frac{(\varepsilon_i^+)^2+(\varepsilon_i^0)^2-(\varepsilon_i^-)^2}{2\varepsilon_i^0}+(1-\mu)\sum_{j=1}^{m}w_j\ln w_j\right\} \\ \text{s.t.}\sum_{j=1}^{m}w_j=1, w_j\geq 0, j=1,2,\cdots,m \end{cases} \quad (17)$$

where, $0<\mu<1$. In consideration of the fair competitiveness of the optimal objective function, generally $\mu = 0.5$. The model is calculated through Visual C++ programming and the attribute weight sequence $w = (w_1, w_2,..., w_m)$ is obtained. Finally, substituting it into formula 14, it is possible to get the comprehensive off-target distance ε_i. The alternative plans are sequenced according to the size of ε_i value, the smaller ε_i is and the more excellent the corresponding plan will be.

Steps of multi-attribute grey target decision making: As stated above, the specific steps of the interval number multi-attribute grey target decision making based on positive and negative clouts are as follows:

Step 1 : Construct the effect sample matrix according to the multi-attribute decision making problem and [-1, 1] interval number linear transformation operator is used to convert the effect sample matrix into a normalized decision making matrix

Step 2 : Use formulas 9 and 10 to respectively determine the positive and negative clouts of interval of grey target decision making

Step 3 : Use formulas 11 and 12 to respectively determine the positive and negative off-target distances of the effect vector z_i and get the spacing of positive and negative targets according to formula 13

Step 4 : Through the single-objective optimization model displayed in formula 17, apply software programming method to calculate this model and obtain the attribute weight sequence $w = (w_1, w_2,..., w_m)$

Step 5 : Use formula 14 to determine the comprehensive off-target distance ε_i and rank each alternative plan according to the size of ε_i value

RESULTS AND DISCUSSION

Application example: A sophisticated product manufacturing enterprise decides to have technical transformation to the original leading products, now there are 4 transformation plan (A_1, A_2, A_3, A_4), with 4 major assessment attributes, cost C_1, reliability C_2, product life C_3 and risk loss value C_4, where C_1 and C_4 belong to cost attributes, C_2 and C_3 belongs to efficiency attribute. The decision maker gives the criteria weight space of incompletely certain information form: $0.2\leq w_1\leq 0.4$, $0.25\leq w_2\leq 0.3$, $0.15\leq w_3\leq 0.25$, $0.3\leq w_4\leq 0.4$ and

$$\sum_{j=1}^{4}w_j=1$$

The optimal transformation plan is determined.

Upon investigation statistics, the relevant parameter assessment of this enterprise in a year is obtained and the data obtained are as shown in Table 1 after sorting.

According to the [-1, 1] interval number linear transformation operator, the interval number effect sample matrix is converted into the dimensionless decision making matrix i.e., the normalized decision making matrix, as shown in Table 2.

Respectively calculate the interval number positive and negative clouts of grey target decision making with formulas 9 and 10:

$$r^+ = \{[0.379, 0.695], [0.620, 0.851], [0.345, 1.000], [0.431, 0.756]\}$$

$$r^- = \{[-1.000, -0.291], [-1.000,-0.802], [-0.309, -0.164], [-1.000, -0.480]\}$$

Determine the positive and negative off-target distances of the effect vector z_i with formulas 11 and 12.

The positive off-target distance is:

$$\begin{cases} \varepsilon_1^+ = 2^{-\frac{1}{2}}[0.1646w_1+1.6578w_2+4.5117w_3]^{\frac{1}{2}} \\ \varepsilon_2^+ = 2^{-\frac{1}{2}}[0.1692w_4]^{\frac{1}{2}} \\ \varepsilon_3^+ = 2^{-\frac{1}{2}}[2.8732w_1+0.3235w_2+1.7825w_3+1.3537w_4]^{\frac{1}{2}} \\ \varepsilon_4^+ = 2^{-\frac{1}{2}}[0.9582w_1+5.3559w_2+0.2116w_3+3.5746w_4]^{\frac{1}{2}} \end{cases}$$

Table 1: Interval number effect sample matrix

	C_1	C_2	C_3	C_4
A_1	[5.5, 5.9]	[3.8, 4.2]	[2.4, 2.8]	[0.46, 0.51]
A_2	[4.6, 5.4]	[6.4, 7.1]	[4.2, 5.1]	[0.52, 0.53]
A_3	[7.1, 8.9]	[5.0, 6.1]	[3.3, 3.5]	[0.54, 0.67]
A_4	[6.5, 7.0]	[1.5, 2.1]	[3.6, 4.9]	[0.65, 0.73]

Table 2: Normalized decision making matrix

	C_1	C_2	C_3	C_4
A1	[0.182, 0.340]	[-0.240, -0.107]	[-0.964, -0.673]	[0.431, 0.756]
A2	[0.379, 0.695]	[0.620, 0.851]	[0.345, 1.000]	[0.301, 0.366]
A3	[-1.000, -0.291]	[0.157, 0.521]	[-0.309, -0.164]	[-0.610, 0.236]
A4	[-0.251, -0.054]	[-1.000, -0.802]	[-0.091, 0.855]	[-1.000, -0.480]

The negative off-target distance is:

$$\begin{cases} \varepsilon_1^- = 2^{-\frac{1}{2}}[1.7953w_1 + 1.0600w_2 + 0.6876w_3 + 3.5746w_4]^{\frac{1}{2}} \\ \varepsilon_2^- = 2^{-\frac{1}{2}}[2.8732w_1 + 5.3559w_2 + 1.7825w_3 + 2.4070w_4]^{\frac{1}{2}} \\ \varepsilon_3^- = 2^{-\frac{1}{2}}[3.0872w_2 + 0.6642w_4]^{\frac{1}{2}} \\ \varepsilon_4^- = 2^{-\frac{1}{2}}[0.6166w_1 + 1.0843w_3]^{\frac{1}{2}} \end{cases}$$

The spacing between positive and negative clouts is:

$$\varepsilon^0 = 2^{-\frac{1}{2}}[2.8732w_1 + 5.3559w_2 + 1.7825w_3 + 3.5746w_4]^{\frac{1}{2}}$$

Through the single-objective optimization model determined in formula 17, apply the software programming to calculate this model and get the attribute weight.

$$w_1 = 0.265,\ w_2 = 0.25,\ w_3 = 0.184,\ w_4 = 0.30$$

Use formula 14 to determine the comprehensive off-target distance ε_i and rank each alternative plan according to the ε_i value.

$$\varepsilon_1 = 0.538,\ \varepsilon_2 = 0.076,\ \varepsilon_3 = 0.776,\ \varepsilon_4 = 1.104$$

In this way, $\varepsilon_1<\varepsilon_2<\varepsilon_3<\varepsilon_4$, so the ranking result of each plan is $\varepsilon_1, \succ \varepsilon_2 \succ \varepsilon_3 \succ \varepsilon_4$. Upon calculation and analysis, this result is consistent with the conclusion in literature (Liu *et al*., 2013a) proving that this method is feasible and effective.

CONCLUSION

The grey target decision making is one of the important methods to solve the multi-attribute decision making problem. Aimed at the complexity and uncertainty of the actual decision making environment, an interval number multi-attribute grey target decision making method based on positive and negative clouts is proposed in this study. In this method, the interval number linear transformation operator is used for normalized treatment of multi-attribute grey target decision making value and the concepts of positive and negative clouts and positive and negative off-target distances of grey target decision making are introduced and on this basis, in combination with the spatial analysis, the calculation method of the comprehensive off-target distance is proposed; at the same time, each plan is ranked according to the comprehensive off-target distance. A practical decision making method is proposed to solve the grey target decision making problem in which the decision making information is an interval grey number and the feasibility and effectiveness of the model constructed are verified through example analysis.

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