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MULTIPLE ATTRIBUTE DECISION-MAKING MODEL OF GREY TARGET BASED ON POSITIVE AND NEGATIVE BULL'S-EYE

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Abstract- Aiming at complexity and uncertainty of actual decision-making environment, this study proposes a multiple attribute decision-making model of grey target based on positive and negative bull's-eye. Firstly, it defines that the optimal effect vector and the worst effect vector of grey target decision are respectively positive, negative bull's-eye of the grey target; secondly, comprehensively considering the space projection distance between various schemes and the positive and negative bull's-eye, it takes bull's-eye distance as the basis for space analysis and obtains a new integrated bull's-eye distance; then, in accordance with the comprehensive guidelines to minimize the bull's-eye distance, it constructs goal programming model for goal function, and thus solves the index weight. Finally, through case studies of selective purchase of information system, it verifies feasibility and effectiveness of the proposed grey target decision-making model.

Keywords- positive and negative bull's-eye, interval grey number, grey target decision-making, integrated bull's-eye distance, goal programming

1. INTRODUCTION

Grey target decision-making, as an important part of grey decision-making method, has been widely applied in many fields. A comprehensive review of literature at home and abroad reveals that, many experts and scholars have actively involved in such research, and have made some achievements. For example: 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&D projects by grey relational analysis model. William Ho *et al.* (2010) proposed the literature of the multi-criteria decision making approaches for supplier evaluation and selection. This study not only provides evidence that the multi-criteria decision making approaches are better than the traditional cost-based approach, but also aids the researchers and decision makers in applying the approaches effectively (Mohsen et al., 2011). Wann-Yih Wu *et al.* (2006) presented an alternative evaluation procedure to help retailers, especially hyper marketers, make a location decision by using the grey multi-objective decision method. Liu *et al.* (2013) proposed a novel multi-attribute grey target decision model and demonstrated with a practical case study. Dai and Li (2014), targeting at a class of group decision-making problems with property value, attribute weight and policymaker weights as interval grey number, introduced concept of group positive and negative bull's-eye and group deviation approaching degree and proposed group decision-making method for grey multiple attribute deviation approaching degree. Chen and Xie (2007) studied incompatibility problem of traditional grey target polarity reversal and proved probability of existence and occurrence of incompatibility problem by constructing a special sequence of moderate value indicator. Wang *et al.* (2009) considered the impact of the correlation between the various indicators, different dimensions and differences in importance on the effect of decision-making, improved traditional grey target decision-making method with weighted Mahalanobis distance and avoided the impact of the correlation between the various indicators, different dimensions and differences in importance on the effect of decision-making, as well as incompatibility problem of grey target transformation. Ma and Sun (2014), targeting at existing research results in multiple attribute grey target decision-making, extended the positive bull's-eye decided by policymakers' ideal preference and choice preference in index values of certain attributes to negative bull's-eye, analyzed different attribute value preference's impact on the decision-making scheme indicator, and dealt with policymakers' preference with generalized method of grey target decision-making. Fangeng and Zhang (2006) constructed an operator "rewarding good and punishing bad" which enlarges degree of indicator difference at undimensionalization transformation of indicators and established weighted grey target decision-making model on this basis. The above studies provide some ideas to solve grey target decision-making issues. However, it can also be seen that research on grey target decision-making issues with decision-making information as interval grey number and uncertain index weight is relatively small. Thus this paper proposes the corresponding grey target decision-making model to meet the needs of such decision-making.

2. MULTIPLE ATTRIBUTE DECISION-MAKING MODEL OF GREY TARGET

2.1 Description of the Problem

Suppose multiple attribute decision-making problem constitutes awaiting decision-making scheme set $A=\{A_1,A_2,\cdots,A_n\}$ with n prepared schemes, m evaluation indexes (attribute) constitute attribute set $C=\{C_1,C_2,\cdots,C_m\}$, scheme A_i 's attribute value against index C_j is $x_{ij}(\otimes)\in[\underline{x}_{ij},\bar{x}_{ij}]$, in which, $0\le \underline{x}_{ij}\le \bar{x}_{ij}$; $i=1,2,\cdots,n$; $j=1,2,\cdots,m$. Then, effect sample matrix X of scheme set A against property set C is:

	C_1	C_2	$\cdots$	C_m
A_1	$x_{11}(\otimes)$	$x_{12}(\otimes)$	$\cdots$	$x_{1m}(\otimes)$
A_2	$x_{21}(\otimes)$	$x_{22}(\otimes)$	$\cdots$	$x_{2m}(\otimes)$
$\vdots$	$\vdots$	$\vdots$	$\ddots$	$\vdots$
A_n	$x_{n1}(\otimes)$	$x_{n2}(\otimes)$	$\cdots$	$x_{nm}(\otimes)$

The above matrix can be converted to:

	C_1	C_2	$\cdots$	C_m
A_1	$[x_{11},\bar{x}_{11}]$	$[x_{12},\bar{x}_{12}]$	$\cdots$	$[x_{1m},\bar{x}_{1m}]$
A_2	$[x_{21},\bar{x}_{21}]$	$[x_{22},\bar{x}_{22}]$	$\cdots$	$[x_{2m},\bar{x}_{2m}]$
$\vdots$	$\vdots$	$\vdots$	$\ddots$	$\vdots$
A_n	$[x_{n1},\bar{x}_{n1}]$	$[x_{n2},\bar{x}_{n2}]$	$\cdots$	$[x_{nm},\bar{x}_{nm}]$

2.2 Distance and Possibility Degree Formula of Interval Grey Numbers

In the grey systems theory, the number with only likely range known but not the exact value is called grey number. Grey number is the basic unit of grey systems. Grey number with both lower bound $\underline{a}$ and upper bound $\bar{a}$ is called interval grey number, denoted by $a(\otimes)\in[\underline{a},\bar{a}]$ (B Zeng *et al.*, 2013).

Definition 1: Suppose two interval grey numbers $a(\otimes)\in[\underline{a},\bar{a}]$ and $b(\otimes)\in[\underline{b},\bar{b}]$, k is a positive real number, then:

1) $a(\otimes)+b(\otimes)\in[\underline{a}+\underline{b},\bar{a}+\bar{b}]$;

2) $a(\otimes)b(\otimes)\in[\min\{\underline{a}\underline{b},\underline{a}\bar{b},\bar{a}\underline{b},\bar{a}\bar{b}\},\max\{\underline{a}\underline{b},\underline{a}\bar{b},\bar{a}\underline{b},\bar{a}\bar{b}\}]$;

3) $ka(\otimes)\in[k\underline{a},k\bar{a}]$;

4) $k+a(\otimes)\in[k+\underline{a},k+\bar{a}]$.

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

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

Definition 3: For interval grey number $a(\otimes)\in[\underline{a},\bar{a}]$ and $b(\otimes)\in[\underline{b},\bar{b}]$, denote $l_a = \bar{a} - \underline{a}$, $l_b = \bar{b} - \underline{b}$, then

$$p(a(\otimes) \geq b(\otimes)) = \frac{\min\{l_a + l_b, \max(\bar{a} - \bar{b}, 0)\}}{l_a + l_b} \tag{2}$$

is possibility degree of $a(\otimes) \geq b(\otimes)$.

2.3 Establishment of Multiple Attribute Decision-Making Model of Grey Target

2.3.1 Normalized Process of Decision Matrix

In order to eliminate the effect of inter-property on decision-making result due to different dimensions, the following formula can be adopted to normalize the decision matrix and obtain normalized decision matrix. In multiple attribute decision-making problems, the common attribute types are efficiency model and cost model. For efficiency attribute, the bigger value, the better; but cost attribute is opposite. Suppose I_j respectively denotes subscript set of efficiency, cost type, $j = 1,2$.

For the efficiency attribute:

$$\underline{z}_{ij} = \frac{\underline{x}_{ij}}{\sqrt{\sum_{i=1}^{n} (\bar{x}_{ij})^2}}, \quad \bar{z}_{ij} = \frac{\bar{x}_{ij}}{\sqrt{\sum_{i=1}^{n} (\underline{x}_{ij})^2}} \tag{3}$$

Wherein, $i = 1,2,\cdots,n$; $j \in I_1$

For cost attribute:

$$\underline{z}_{ij} = \frac{(1/\bar{x}_{ij})}{\sqrt{\sum_{i=1}^{n} (1/\underline{x}_{ij})^2}}, \quad \bar{z}_{ij} = \frac{(1/\underline{x}_{ij})}{\sqrt{\sum_{i=1}^{n} (1/\bar{x}_{ij})^2}} \tag{4}$$

Wherein, $i = 1,2,\cdots,n$; $j \in I_2$

2.3.2 Grey Target Decision-Making of Positive and Negative Bull's-Eye

Definition 4: Suppose $z_j^+ = \max\{(\underline{z}_{ij} + \bar{z}_{ij})/2 \mid 1 \leq i \leq n\}, \{j = 1,2,\cdots,m\}$, and denote its corresponding decision value as $[\underline{z}_{ij}^+, \bar{z}_{ij}^+]$, then

$$z^+ = \{z_1^+, z_2^+, \cdots, z_m^+\} = \{[\underline{z}_{i1}^+, \bar{z}_{i1}^+], [\underline{z}_{i2}^+, \bar{z}_{i2}^+], \cdots, [\underline{z}_{im}^+, \bar{z}_{im}^+]\} \tag{5}$$

is optimal effect vector of grey target decision-making, known as positive bull's-eye (Luo and Wang, 2012).

Definition 5: Suppose $z_j^- = \min\{(\underline{z}_{ij} + \bar{z}_{ij})/2 \mid 1 \leq i \leq n\}, \{j = 1,2,\cdots,m\}$, and denote its corresponding decision value as $[\underline{z}_{ij}^{-}, \bar{z}_{ij}^{-}]$, then

$$z^{-} = \{z_1^{-}, z_2^{-}, \cdots, z_m^{-}\} = \{[\underline{z}_{i1}^{-}, \bar{z}_{i1}^{-}], [\underline{z}_{i2}^{-}, \bar{z}_{i2}^{-}], \cdots, [\underline{z}_{im}^{-}, \bar{z}_{im}^{-}]\} \tag{6}$$

is worst effect vector of grey target decision-making, known as negative bull's-eye.

Wherein, index weight $w = (w_1, w_2, \cdots, w_m)$, and $\sum_{j=1}^{m} w_j = 1$.

Definition 6: Refer to

$$\varepsilon_i^{+} = 2^{-\frac{1}{2}}[w_1(\underline{z}_{i1} - \underline{z}_{i1}^{+})^2 + w_1(\bar{z}_{i1} - \bar{z}_{i1}^{+})^2 + \cdots + w_m(\bar{z}_{im} - \bar{z}_{im}^{+})^2]^{\frac{1}{2}} \tag{7}$$

As positive bull's-eye distance of effect vector z_i.

Refer to

$$\varepsilon_i^{-} = 2^{-\frac{1}{2}}[w_1(\underline{z}_{i1} - \underline{z}_{i1}^{-})^2 + w_1(\bar{z}_{i1} - \bar{z}_{i1}^{-})^2 + \cdots + w_m(\bar{z}_{im} - \bar{z}_{im}^{-})^2]^{\frac{1}{2}} \tag{8}$$

As negative bull's-eye distance of effect vector z_i.

Definition 7: Refer to

$$\varepsilon_i^{0} = 2^{-\frac{1}{2}}[w_1(\underline{z}_{i1}^{+} - \underline{z}_{i1}^{-})^2 + w_1(\bar{z}_{i1}^{+} - \bar{z}_{i1}^{-})^2 + \cdots + w_m(\bar{z}_{im}^{+} - \bar{z}_{im}^{-})^2]^{\frac{1}{2}} \tag{9}$$

As positive and negative bull's-eye distance.

According to definition in literature (Luo, 2013), distance $\varepsilon_i^{+}, \varepsilon_i^{-}, \varepsilon_i^{0}$ fall on the same line or form a triangle. According to the law of cosines, it can be known that,

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

Since the positive bull's-eye distance ε_i^{+} and negative bull's-eye distance ε_i^{-} are vectors, consider projection of bull's-eye distance on the line between the positive and negative bull's-eye, then the integrated bull's-eye distance ε_i is:

$$\varepsilon_i = \varepsilon_i^{+}\cos\theta = \frac{(\varepsilon_i^{+})^2 + (\varepsilon_i^{0})^2 - (\varepsilon_i^{-})^2}{2\varepsilon_i^{0}} \tag{10}$$

Integrated bull's-eye distance comprehensively considers the positive and negative bull's-eye, and uses the bull's-eye distance as a vector for more scientific and rational decision-making information.

2.3.3 Determination of Index Weight

If the index weight sequence $w = (w_1, w_2, \cdots, w_m)$ is unknown, then the sequence is a sequence of grey connotation, and grey entropy can be defined as:

$$H_{\otimes}(w) = -\sum_{j=1}^{m} w_j \ln w_j \tag{11}$$

According to the principle of maximum entropy, $w_j(j = 1,2,\cdots,m)$ should be adjusted to reduce the uncertainty of sequence $w = (w_1, w_2, \cdots, w_m)$, namely to promote maximization of $H_{\otimes}(w)$. At the same time, adjust the weight $w_j(j = 1,2,\cdots,m)$ so that the overall integrated bull's-eye distance is minimal. For this end, a multi-objective optimization model as follows could be established:

$$\begin{cases} \min \sum_{i=1}^{n} \varepsilon_i = \sum_{i=1}^{n} \dfrac{(\varepsilon_i^{+})^2 + (\varepsilon_i^{0})^2 - (\varepsilon_i^{-})^2}{2\varepsilon_i^{0}} \\ \max H_{\otimes}(w) = -\sum_{j=1}^{m} w_j \ln w_j \\ s.t. \sum_{j=1}^{m} w_j = 1, w_j \geq 0, j = 1,2,\cdots,m \end{cases} \tag{12}$$

To solve the multi-objective optimization model, based on fair competition of various schemes, the above multi-objective optimization model can be converted into a single-objective optimization model.

$$\begin{cases} \min \left\{ \mu \sum_{i=1}^{n} \dfrac{(\varepsilon_i^{+})^2 + (\varepsilon_i^{0})^2 - (\varepsilon_i^{-})^2}{2\varepsilon_i^{0}} + (1-\mu) \sum_{j=1}^{m} w_j \ln w_j \right\} \\ s.t. \sum_{j=1}^{m} w_j = 1, w_j \geq 0, j = 1,2,\cdots,m \end{cases} \tag{13}$$

Wherein, $0 < \mu < 1$. Taking into account fair competition of optimized objective function, $\mu = 0.5$ is generally preferable. Solve the model by Visual C++ programming method, obtain the index weight sequence $w = (w_1, w_2, \cdots, w_m)$, substitute it into formula (8) and obtain integrated bull's-eye distance ε_i (Sahu et al., 2013). According to the size of ε_i value, sort the alternative scheme. The smaller ε_i is, the more excellent the corresponding scheme is.

2.4 Step of Multiple Attribute Grey Target Decision-Making

In summary, specific steps of multiple attribute grey target decision-making based on positive and negative bull's-eye are as follows:

Step 1 Use equation (3) and (4) for normalized process of decision matrix X and obtain normalized decision matrix Z;

Step 2 Use equation (5) and (6) to respectively determine the positive and negative bull's-eye of grey target decision-making;

Step 3 Use equation (7) and (8) to respectively determine the positive and negative bull's-eye distance of effect vector z_i;

Step 4 Solve the single objective optimization model shown in equation (13) with software programming method and obtain index weight sequence $w=(w_1,w_2,\cdots,w_m)$;

Step 5 Use equation (10) to determine integrated bull's-eye distance ε_i and sort the various alternative schemes according to the size of ε_i value.

3. APPLICATION EXAMPLE

Prove application of the aforementioned multiple attribute decision-making method with decision attribute value as interval grey number and uncertain attribute weight in information system selection problem by way of example. An enterprise plans five alternative information system selective purchase schemes (A_1, A_2, A_3, A_4, A_5) according to the need of information construction. There are three main evaluation indexes (attributes) (C_1, C_2, C_3). Wherein C_1 represents product performance, C_2 represents after-sale service, C_3 represents product price. Experts evaluate the five alternative schemes and organized data is shown in Table 1. Try to determine the optimal information system that policymakers should select.

Table 1. Decision Matrix X

	C_1	C_2	C_3
A_1	[6.47,6.49]	[7.36,7.56]	[1750,1840]
A_2	[8.23,8.92]	[7.28,7.64]	[2060,2250]
A_3	[8.19,8.83]	[8.85,9.24]	[1950,2040]
A_4	[8.04,8.49]	[7.65,7.89]	[1810,1900]
A_5	[7.53,8.74]	[8.04,8.44]	[2140,2200]

For the above attributes, C_1, C_2 are efficiency attributes, C_3 is cost attribute.

Weight information of each attribute is known: $w=(w_1,w_2,w_3)$. Under incomplete certain information, weight range of each attribute is: $0.25\le w_1\le 0.55, 0.17\le w_2\le 0.23, 0.3\le w_3\le 0.5$; and $\sum_{j=1}^{3} w_j=1$.

Step 1 Use equation (3) and (4) for normalized process of decision matrix *X* and obtain normalized decision matrix *Z*, as shown in Table 2;

Table 2. Normalized Decision Matrix Z

	C_1	C_2	C_3
A_1	[0.347,0.376]	[0.402,0.430]	[0.468,0.518]
A_2	[0.441,0.517]	[0.398,0.435]	[0.383,0.440]
A_3	[0.439,0.511]	[0.484,0.526]	[0.422,0.465]
A_4	[0.431,0.492]	[0.418,0.449]	[0.453,0.501]
A_5	[0.404,0.506]	[0.440,0.480]	[0.391,0.424]

Step 2 Use equation (5) and (6) to respectively calculate the positive and negative bull's-eye of grey target decision-making.

$z^+ = \{ [0.441,0.517], [0.484,0.526], [0.468,0.518] \}$

$z^- = \{ [0.347,0.376], [0.398,0.430], [0.383,0.424] \}$

Step 3 Use equation (7) and (8) to respectively determine the positive and negative bull's-eye distance of effect vector z_i;

The positive bull's-eye distance:

$$\varepsilon_1^+ = 2^{-\frac{1}{2}}[0.0287 w_1 + 0.0158 w_2]^{\frac{1}{2}}$$

$$\varepsilon_2^+ = 2^{-\frac{1}{2}}[0.0157 w_2 + 0.0133 w_3]^{\frac{1}{2}}$$

$$\varepsilon_3^+ = 2^{-\frac{1}{2}}[0.0049 w_3]^{\frac{1}{2}}$$

$$\varepsilon_4^+ = 2^{-\frac{1}{2}}[0.0007 w_1 + 0.0102 w_2 + 0.0005 w_3]^{\frac{1}{2}}$$

$$\varepsilon_5^+ = 2^{-\frac{1}{2}}[0.0015 w_1 + 0.004 w_2 + 0.0148 w_3]^{\frac{1}{2}}$$

The negative bull's-eye distance:

$$\varepsilon_1^- = 2^{-\frac{1}{2}}[0.0162 w_3]^{\frac{1}{2}}$$

$$\varepsilon_2^- = 2^{-\frac{1}{2}}[0.0287 w_1 + 0.0003 w_3]^{\frac{1}{2}}$$

$$\varepsilon_3^- = 2^{-\frac{1}{2}}[0.0269\,w_1 + 0.0165\,w_2 + 0.0033\,w_3]^{\frac{1}{2}}$$

$$\varepsilon_4^- = 2^{-\frac{1}{2}}[0.0205\,w_1 + 0.0008\,w_2 + 0.0109\,w_3]^{\frac{1}{2}}$$

$$\varepsilon_5^- = 2^{-\frac{1}{2}}[0.0202\,w_1 + 0.0042\,w_2 + 0.0001\,w_3]^{\frac{1}{2}}$$

Space between positive and negative bull's-eye:

$$\varepsilon^0 = 2^{-\frac{1}{2}}[0.0287\,w_1 + 0.0165\,w_2 + 0.0162\,w_3]^{\frac{1}{2}}$$

Step 4 Solve the single objective optimization model determined by equation (13) with software programming and obtain index weight.

$$w_1 = 0.4, \quad w_2 = 0.229, \quad w_3 = 0.37$$

Step 5 Use equation (10) to determine integrated bull's-eye distance ε_i and sort the various alternative schemes according to the size of ε_i value.

$$\varepsilon_1 = 0.0736, \quad \varepsilon_2 = 0.0441, \quad \varepsilon_3 = 0.0177, \quad \varepsilon_4 = 0.0282, \quad \varepsilon_5 = 0.0465$$

Thus, $\varepsilon_3 < \varepsilon_4 < \varepsilon_2 < \varepsilon_5 < \varepsilon_1$. So sorting results of the various schemes are as follows: $\varepsilon_3 \succ \varepsilon_4 \succ \varepsilon_2 \succ \varepsilon_5 \succ \varepsilon_1$. Through computational analysis, the result obtained in this study is consistent with literature (Sun and Zhang, 2011), 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.

4. CONCLUSION

Grey target decision-making is one important way to solve multiple attribute decision-making problems. This study constructs a multiple attribute grey target decision-making model based on positive and negative bull's-eye, and introduces the concepts of positive and negative bull's eye and positive and negative bull's eye distance of grey target. Based on this, it combines spatial analysis and proposes calculation method of integrated bull's-eye distance, and sorts the pros and cons of each scheme by the size of integrated bull's-eye distance. It provides a scientific, practical decision-making method to solve grey target decision-making problem with decision-making information as interval grey number and verifies feasibility and effectiveness of the constructed model by example analysis.

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