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ARTIFICIAL INTELLIGENCE BASED TUNING OF SVC CONTROLLER FOR CO-GENERATED POWER SYSTEM

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ABSTRACT

In view of multi-attribute decision-making problems with interval numbers in social economy and engineering system, this paper defines and analyzes the basic operational rule, normalized method, sequence comparison strategy, and the calculating formula for the distance of interval numbers and interval number sequence. It presents weighted TOPSIS decision-making model based on interval numbers operational rule, solves the key problems to calculate the standard matrix solution with the interval numbers decision-making system to select the positive ideal solution and negative ideal solution, and the distance calculation between DMUs with interval numbers and ideal solution. This model, which is simple and feasible, can solve optimal fire station location and improve the effectiveness, practicality and meeting surface. The problem of weighted TOPSIS suitable for real original property matrix is solved. In summary, the weighted TOPSIS decision-making model based on interval number operation rule offers scientific and practical ways and means for multi-attribute decision making problems with interval numbers.

Keywords: *Mathematical Model, Multi-Attribute Decision-Making, TOPSIS, Interval Numbers, Optimal Location.*

1. INTRODUCTION

There are lots of multiobjective decision-making problems in social economy and engineering system [1]. Because of the limitations of complexity, people's knowledge and cognitive ability on objective things, we will often meet uncertain and fuzzy decision information while solving the practical problems. It is difficult to determine the index with accurate or concrete primitive attribute value when we make decision to the system, but a evaluation or prediction interval can be often provided [2], sometimes part of the index attribute value are proposed, while the other part is used for interval number type data as attribute value.

Currently, the study on interval numbers data for decision-making system has been made in a considerable part of the results, and is widely used in decision-making, management, engineering and other fields [3-4]. In the existing literatures, decision matrix with interval numbers is mostly to be differentiated into upper decision matrix and lower decision matrix, and then employes a certain decision model to make system of decision on the two pieces of decision attribute matrix separately, such as the literature [5] is applied to TOPSIS, etc. In addition, while in dealing with the decision-making problem of real number type data and interval numbers type data, the real number is often transformed directly into both upper and lower bounds of the interval with the corresponding real operations. Thus the decision-making problem with interval numbers is almost solved by using this idea, but on the other hand, the interval numbers are dissevered artificially(and even a real number is dissevered too), which leads to lower goodness of fit between decision result and practice. For this reason, based on definition of operational and comparative rule, interval number is considered as a whole, this paper adopts the algorithm thought of TOPSIS, constructs the improvement TOPSIS based on interval numbers, and at last carry on positive research and analysis through optimal location in some urban fire station to realize and explain this model applicability and practicability in the multi-objective decision-making problems.

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2. TECHNIQUE FOR ORDER PREFERENCE BY SIMILARITY TO IDEAL SOLUTION

The Technique for Order Preference by Similarity to Ideal Solution nodel (TOPSIS) is a more effective multiple attribute decision-making method based on statistical analysis technique [1], and has been widely used in a lot of researches on social and economic fields in recent years. The basic idea of TOPSIS is to compare each system object with the positive and negative ideal solutions constructed by the decision-making system. In some sense, close to the ideal solution or away from the negative ideal solution is used as a basis for decision-making, then DMUs is sorted in the system and decisions are proposed. TOPSIS system in the application of decision-making will inevitably be subject to the preferences of decision makers or experts, and the influence degree to the system in decision making by each attribute is different, therefore, the weighted TOPSIS with decision-makers' preference is given below.

(Model 1)

Step1: The attribute system of decision-making system is constructed and its primitive attribute matrix is provided.

Assume there are m decision-making units in some decision-making system M, denoted by $M_i(i=1,2,\cdots,m)$, and n decision attributes, denoted by $X_j(j=1,2,\cdots,n)$, sometimes decision attributes can be subdivided into s input attributes $X_j(j=1,2,\cdots,s)$ and $n-s$ output attributes $X_j(j=s+1,\cdots,n)$. Then we can get a primitive attribute matrix $M=(m_{ij})_{m\times n}$ of decision system M, in which m_{ij} express the primitive attribute of the ith decision-making unit M_i corresponding to the jth decision attribute X_j. The necessary normalization was completed according to requirement and finally we get the standardized attribute matrix $M'=(m'_{ij})_{m\times n}$ (Without loss of generality, let the attribute is maximal after normalization).

Step2: The positive ideal solution and negative ideal solution of decision-making system under TOPSIS are given. Let the positive ideal solution and negative ideal solution corresponding to the original attribute vectors of the virtual DMUs are $Z^+=\{z_1^+,z_2^+,\cdots,z_n^+\}$ 、 $Z^-=\{z_1^-,z_2^-,\cdots,z_n^-\}$, respectively, which the values of z_j^+ and z_j^- are

$$z_j^+=\max\{m'_{ij}\}, z_j^-=\min\{m'_{ij}\} \quad (1)$$

Step3: The distance between DMUs and the positive and negative ideal solution is calculating. We define the weighted distance D_i^+ and D_i^- between DMUs $M_i\ (i=1,2,\cdots,m)$ and the positive and negative ideal solution by using the Euclidean norm to calculate the Euclidean distance.

$$D_i^+=\sqrt{\sum_{j=1}^{n}[\omega_j(z_j^+-m'_{ij})]^2}, D_i^-=\sqrt{\sum_{j=1}^{n}[\omega_j(z_j^--m'_{ij})]^2} \quad (2)$$

Where ω_j is the preference weight of the jth decision-making attribute of the decision-making system M. The weights can be determined by subjective weighting method, such as AHP, Delphi analysis method or objective weighting method, including entropy weight coefficient method, variation coefficient method and etc..[6]

Step4：Relative closeness of every DMUs is confirmed, and sequence and decision are carried out hereby. By calculating we know the relative closeness of the ith decision-making unit Mi is

$$C_i=\frac{D_i^-}{D_i^++D_i^-}, i=1,2,\cdots,m \quad (3)$$

The DMU of a larger relative closeness, indicating that the program (decision- making unit) is close to the virtual optimal solution(the positive ideal solution) and is far from the virtual worst solution(the negative ideal solution), therefore the program has relatively dominant position in alternative.

In summary, we can see that, for decision-making system, including interval numbers, the main problems are basic operation rule, standardization of interval numbers, comparative sequence of interval numbers and the definition of distance between interval numbers and so on by using weighted TOPSIS decision-making model.

3. OPERATION AND ORDER COMPARATION OF INTERVAL NUMBERS

(Definition 1) Let $\tilde{a}=[\underline{a},\overline{a}]=\{x\,|\,\underline{a}\le x\le\overline{a}\}$ is a interval number. If $\tilde{a}=\{0\le x\,|\,\underline{a}\le x\le\overline{a}\}$, then $\tilde{a}$ is called positive interval number, interval number for short; If $\underline{a}=\overline{a}$, then $\tilde{a}$ degenerate for a real number

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[7], otherwise $\tilde{a}$ is called non-degenerate interval number.

To define the basic operations of interval numbers, we give the concept of two equal intervals at first.

(Definition 2) Let $\tilde{a}=[\underline{a},\overline{a}]$, $\tilde{b}=[\underline{b},\overline{b}]$ be two positive interval numbers, if $\underline{a}=\underline{b}$ and $\overline{a}=\overline{b}$, then we say $\tilde{a}=\tilde{b}$.

(**Definition 3)** Let $\tilde{a}=[\underline{a},\overline{a}]$, $\tilde{b}=[\underline{b},\overline{b}]$ be two positive interval numbers, $\alpha\in R$, then define addition, product, quotient, exponential operations of interval numbers by formulas (4)~(6) [8]

$$\alpha\tilde{a}=[\alpha\underline{a},\alpha\overline{a}],\ \tilde{a}\times\tilde{b}=[\underline{a}\times\underline{b},\overline{a}\times\overline{b}] \tag{4}$$

$$\frac{\tilde{a}}{\tilde{b}}=[\frac{\underline{a}}{\overline{b}},\frac{\overline{a}}{\underline{b}}],\ \tilde{b}\neq[0,0] \tag{5}$$

$$\alpha^{\tilde{a}}=[\alpha^{\underline{a}},\alpha^{\overline{a}}],\ \tilde{a}^{\alpha}=[\underline{a}^{\alpha},\overline{a}^{\alpha}],\ \alpha>0 \tag{6}$$

When the elements of decision-making matrix are real number, we transform cost index(minimal type) into benefit index(maximal type) through reciprocal. And then carry out standardized processing by mean method, difference method, standard difference method, efficacy coefficient method, etc. Usually, we can choose mean method, which is simple and convenient if it does not affect the results of decision-making. Hence, the standardized attribute matrix $M'=(m'_{ij})_{m\times n}$ of primitive attribute matrix $M=(m_{ij})_{m\times n}$. (***model 1***) can be given by the following formula: Let $S=\{X_j\}(j=1,2,\cdots,s)$ indicate minimal index and $T=\{X_j\}(j=s+1,\cdots,n)$ indicate maximal index, thus

$$m'_{ij}=\begin{cases}\dfrac{1/m_{ij}}{\sum_{i=1}^{m}(1/m_{ij})} & X_j\in S\\[2ex] \dfrac{m_{ij}}{\sum_{i=1}^{m}m_{ij}} & X_j\in T\end{cases} \tag{7}$$

According to the above mentioned, we can extend the standardized method of decision-making attribute matrix to the case whose element is interval number, that is, replace real numbers m_{ij}, m'_{ij} in formula (7) with interval numbers $\tilde{m}_{ij}=[\underline{m_{ij}},\overline{m_{ij}}]$ 、 $\tilde{m}_{ij}=[\underline{m'_{ij}},\overline{m'_{ij}}]$, respectively, hence

$$\tilde{m}'_{ij}=\begin{cases}\dfrac{1/\tilde{m}_{ij}}{\sum_{i=1}^{m}(1/\tilde{m}_{ij})} & X_j\in S\\[2ex] \dfrac{\tilde{m}_{ij}}{\sum_{i=1}^{m}\tilde{m}_{ij}} & X_j\in T\end{cases} \tag{8}$$

We can also know from definition 3 that the standardized attribute values are $\tilde{m}'_{ij}=[\underline{m'_{ij}},\overline{m'_{ij}}]$ for interval number-type elements $\tilde{m}_{ij}=[\underline{m_{ij}},\overline{m_{ij}}]$, in which, while $X_j\in S$, the minimal index, $\underline{m'_{ij}}=\dfrac{1/\overline{m_{ij}}}{\sum_{i=1}^{n}(1/\underline{m_{ij}})}$, $\overline{m'_{ij}}=\dfrac{1/\underline{m_{ij}}}{\sum_{i=1}^{n}(1/\overline{m_{ij}})}$; on the other hand, $X_j\in T$,the maximal index, $\underline{m'_{ij}}=\dfrac{\underline{m_{ij}}}{\sum_{i=1}^{n}(\overline{m_{ij}})}$,

$$\overline{m'_{ij}}=\frac{\overline{m_{ij}}}{\sum_{i=1}^{n}(\underline{m_{ij}})}.$$

Currently, there are many studies on order comparison of interval numbers at home and abroad. However, they concentrate on changing uncertain numbers into defining-numbers. In the literature [9], It summarized 11 kinds of representative comparison methods of interval numbers.

This paper plans to adopt the order relation method based on credibility that Zhang Xing-Fang proposed [10], and carries on appropriate adjustment to definition and explanation of this method.

(**Definition 4)** Given two non-degenerate positive interval numbers $\tilde{a}=[\underline{a},\overline{a}]$ and $\tilde{b}=[\underline{b},\overline{b}]$, let $\tilde{a}\neq\tilde{b}$, if one of the following conditions is satisfied, then say $\tilde{a}$ more than $\tilde{b}$ (or $\tilde{b}$ less than $\tilde{a}$), denoted by $\tilde{a}>\tilde{b}$.

① $\underline{a}\geq\overline{b}$, also called $\tilde{a}$ strong more than $\tilde{b}$ ($\tilde{b}$ strong less than $\tilde{a}$), denoted by $\tilde{a}>>\tilde{b}$;

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② $(\underline{a}+\overline{a})/2>(\underline{b}+\overline{b})/2$, also called $\tilde{a}$ weak more than $\tilde{b}$ ($\tilde{b}$ weak less than $\tilde{a}$), denoted by $\tilde{a}\succ\succ\tilde{b}$;

③ $\overline{a}>\overline{b}$, and $(\underline{a}+\overline{a})/2=(\underline{b}+\overline{b})/2$,also called $\tilde{a}$ optimistic more than $\tilde{b}$ ($\tilde{b}$ optimistic less than $\tilde{a}$) or called $\tilde{b}$ pessimistic more than $\tilde{a}$ ($\tilde{a}$ pessimistic less than $\tilde{b}$),denoted by $\tilde{a}\succ\succ\tilde{b}$, specific judgments determined according to the mentality of decision makers.

Thus, we can use the comparative method which is given in definition 3 to solve the positive and negative ideal solutions.

The distance between each DMU and the positive ideal solution and negative ideal solution is the key to solving problems when we carry out system decision through TOPSIS, so we can define the distance between interval numbers from real numbers corresponding.

(**Definition 5)** Give two positive interval numbers $\tilde{a}=[\underline{a},\overline{a}]$ and $\tilde{b}=[\underline{b},\overline{b}]$, then $l_p(\tilde{a},\tilde{b})$ in formula (9) is named p^th order distance between $\tilde{a}$ and $\tilde{b}$:

$$l_p(\tilde{a},\tilde{b})=\left(\frac{(\underline{a}-\underline{b})^p+(\overline{a}-\overline{b})^p}{2}\right)^{\frac{1}{p}} \qquad (9)$$

If $p=1$, $l_1(\tilde{a},\tilde{b})=\frac{1}{2}[|\underline{a}-\underline{b}|+|\overline{a}-\overline{b}|]$ is named Hamming-distance; And if $p=2$, $l_2(\tilde{a},\tilde{b})=\frac{1}{\sqrt{2}}[(\underline{a}-\underline{b})^2+(\overline{a}-\overline{b})^2]^{\frac{1}{2}}$ is named Euclidean distance. When $\tilde{a}$ and $\tilde{b}$ degenerate into real number a and b , $l_2(a,b)=\frac{1}{\sqrt{2}}[(a-b)^2+(a-b)^2]^{\frac{1}{2}}$ $=|a-b|=d(a,b)$.

Obviously, the distance between interval numbers can be seen the generalization from the distance of real numbers. Moreover, it can be extended to the form of order, perhaps we can define the weighted distance.

(**Definition 6**) Let $\tilde{A}=(\tilde{a}_1,\tilde{a}_2,\cdots,\tilde{a}_n)$ and $\tilde{B}=(\tilde{b}_1,\tilde{b}_2,\cdots,\tilde{b}_n)$ are interval number sequence who have the same dimension(*n* dimensional), $\tilde{a}_i=[\underline{a}_i,\overline{a}_i]$, $\tilde{b}_i=[\underline{b}_i,\overline{b}_i]$, $i=1,2,\cdots,n$, then $L_p(\tilde{A},\tilde{B})$ in formula (10) is named *p*-th distance between interval number sequence $\tilde{A}$ and $\tilde{B}$.

$$L_p(\tilde{A},\tilde{B})=\left(\sum_{i=1}^{n}((\underline{a}_i-\underline{b}_i)^p+(\overline{a}_i-\overline{b}_i)^p)\right)^{\frac{1}{p}} \qquad (10)$$

Specifically,

$L_2(\tilde{A},\tilde{B})=\sqrt{\sum_{i=1}^{n}((\underline{a}_i-\underline{b}_i)^2+(\overline{a}_i-\overline{b}_i)^2)}$ (when $p=2$) is named Euclidean distance. If $\tilde{A}$ and $\tilde{B}$ are attribute vectors with *n* index corresponding to two DMUs, we can get the weighted Euclidean distance between DMUs $\tilde{A}$ and $\tilde{B}$ after weight vector of index system $\omega=(\omega_1,\omega_2,\cdots,\omega_n)$ is given:

$$L_2(\tilde{A},\tilde{B};\omega)=\sqrt{\sum_{i=1}^{n}\omega_i((\underline{a}_i-\underline{b}_i)^2+(\overline{a}_i-\overline{b}_i)^2)} \qquad (11)$$

4. IMPROVED TOPSIS DECISION-MAKIN-G MODEL BASED ON INTERVAL NUMBE-RS OPERATION

In summary, we can give the algorithm of improved TOPSIS decision-making model based on interval numbers as follows.

(*Model 2*)

Step1: We construct decision-making program sets M and decision-making attribute sets X of decision-making system and give its original attribute matrix. According to the attribute values that indexes correspond are real number or interval numbers, we can standardize the original attribute values by formula (7) and formula (11), respectively, and get the standardized decision-making matrix of decision-making system.

Step2: According to the attribute values that indexes correspond are real number or interval numbers, we can standardize the original attribute values by formula (1) and formula (4), respectively, and select the positive and negative ideal solutions of decision-making system with TOPSIS.

***Step*3**: Determining weight coefficient vector of decision-making system by some method. First, we converts index with real attribute to interval numbers with upper and lower bounds are the real number, after that, uses formula (11) method to solve the distance between decision-making units and the positive and negative ideal solution.

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Step4: we determine the relative approach degree for all decision-making units by using formula (3), and then sort and make decision accordingly.

In this paper, the optimal location of fire stations, a pratical problem which one city plans to increase the fire stations in order to improving the fire defence capability, is solved by using improved TOPSIS decision-making model based on interval numbers. Literature [11] gives a simple integrated decision-making index system for the city fire station, and then selects number of staff(X_1) and fire funds(X_2) as input index, the standard-reaching rate of 15 minutes fire time(X_3) and the number of fires (X_4) as output index, Sample data shown in table 1.

Tab1. Original Attribute Values Of 10 Alternative Fire Station

DMU	X_1	X_2	X_3	X_4
1	70	8.55	[0.76,0.83]	[513,567]
2	34	5.16	[0.70,0.79]	[238,286]
3	54	6.14	[0.80,0.89]	[395,436]
4	23	2.55	[0.75,0.84]	[289,324]
5	50	7.38	[0.60,0.68]	[501,542]
6	26	3.34	[0.80,0.88]	[230,281]
7	52	6.25	[0.74,0.84]	[398,437]
8	35	4.50	[0.88,0.93]	[309,363]
9	23	3.01	[0.70,0.81]	[287,326]
10	32	3.46	[0.87,0.92]	[269,319]

Then we can get the standardized attribute values corresponding indicator system of DMU according to formula (7) and (8), such as table 2.

Tab2. Standardized Attribute Values Of 10 Alternative Fire Station

DMU	X_1	X_2	X_3	X_4
1	0.0498	0.0508	[0.0904,0.1092]	[0.1322,0.1654]
2	0.1026	0.0841	[0.0832,0.1039]	[0.0613,0.0834]
3	0.0646	0.0707	[0.0951,0.1171]	[0.1018,0.1272]
4	0.1517	0.1702	[0.0892,0.1105]	[0.0754,0.0945]
5	0.0698	0.0588	[0.0713,0.0895]	[0.1291,0.1581]
6	0.1342	0.1299	[0.0951,0.1158]	[0.0593,0.0819]
7	0.0671	0.0694	[0.0880,0.1105]	[0.1026,0.1274]
8	0.0997	0.0964	[0.1046,0.1224]	[0.0796,0.1059]
9	0.1517	0.1442	[0.0832,0.1066]	[0.0740,0.0951]
10	0.1090	0.1254	[0.1034,0.1211]	[0.0693,0.0930]

Similarly, we construct positive ideal solution and negative ideal solution of decision-making systerm under TOPSIS based on formula (1) and definition (4).

$$Z^+ = \{0.1517, 0.1702, [0.1046, 0.1224], [0.1332, 0.1654]\}$$

,

$$Z^- = \{0.0498, 0.0508, [0.0713, 0.0895], [0.0593, 0.0819]\}$$

In order to not only give an objective weight index, but also take full account of the preferences of decision makers, this paper adopts the weighted average method according to fuzzy AHP and entropy weight coefficient method [12], and gets weight vector $\omega = (0.32, 0.12, 0.35, 0.21)$, then converts index with real attribute to interval numbers with the real upper and lower bounds, after that, uses formula (11) method to solve the distance between DMUs and the positive and negative ideal solution, and sorts accordingly. The results are shown in Table 3.

Tab3. Distance, Approach Degree And Order Of Each One Dmu

DMU	D^+	D^-	C	ORDER
1	0.1010	0.0533	0.3454	8
2	0.0779	0.0466	0.3745	6
3	0.0882	0.0388	0.3058	9
4	0.0434	0.1021	0.7014	1
5	0.0897	0.0501	0.3584	7
6	0.0567	0.0806	0.5873	3
7	0.0875	0.0368	0.2962	10
8	0.0660	0.0554	0.4561	5
9	0.0465	0.0947	0.6709	2
10	0.0598	0.0658	0.5240	4

From above, we can see that relative approach degree of DMU_4 is maximum, which shows the plan has the best approach degree to virtual optimal solution, and the maximum degree away from the virtual worst solution. Therefore, if we only choose one new fire station, DMU_4 is the preferred program because of its comparative advantage position in all alternative programs. In addition, DMU_9 has the better approach degree too and the smaller gap with DMU_4, so this plan can be used as second choice in alternative program. At last, the approach degree of DMU_6 and DMU_{10} are more than 50%, so they should belong to the third choice in alternate program.

5. CONCLUSION

In social economy and engineering systems, there are a large number of research demands of multi-attribute decision-making with finite alternatives. This paper first analyzed the current research situation of decision-making analysis with interval numbers, in particular pointed out the deficiency of the mostly adopted method of dividing decision-making matrix into upper decision-making matrix and lower decision-making matrix. Then this paper defined and analyzed the basic operation rules of interval numbers, standardized methods, order comparison strategy, interval numbers distance and

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calculation formula of the distance of interval numbers sequence, presented the weighted TOPSIS decision-making model, and analyzed the key problems of decision-making system with interval numbers solved by TOPSIS decision-making model. Using the above definitions and some operations of interval numbers analyzed, this paper proposed the weighted TOPSIS decision-making model based on interval numbers operation, and solved some key problems, such as the standardized method of decision-making matrix with interval numbers, selecting the positive and negative ideal solutions of TOPSIS with interval numbers, and calculating the distance between decision-making units with interval numbers and the positive and negative ideal solutions, etc. Furthermore, this paper improved the existing TOPSIS apply only to decision-making system of real number type of original attribute matrix greatly, expanded its adaptation and practicability, while the realization of the algorithm has not increased its difficulty at the same time and the algorithm is simple and easy to do. Finally, in order to solve the practical problem of increase the fire stations for improving the fire defence capability, an application example for optimal location of emergency system was given, and solved well by simulation, which further showed the weighted TOPSIS decision-making model based on interval numbers operations given in this paper was a science, practical method and ways for solving the multi-attribute decision-making problem with interval numbers.

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