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A Fuzzy Relative Ratio Method for Construction Safety Management Performance Evaluation

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Abstract

The construction safety management evaluation problem owns many evaluation indexes. Owing to the complexity and uncertainty of evaluation index and the ambiguity of human thinking, the crisp number cannot work well in construction safety management evaluation problem. Interval number can well depict the uncertain and fuzzy information. Thus, for the construction safety management evaluation problem, we construct a multi-attribute group decision making model and use the relative method to solve. Relative ratio method is a practical and useful technique in dealing with multi-attribute decision making problems. Combined with traditional relative ratio method and interval number theory, the article proposes a multi-attribute group decision making model under the condition of uncertain information in the construction safety performance evaluation problem. Firstly, interval number evaluation matrix is applied to describe the uncertain decision information by experts. Secondly, normalization formulas are adopted to construct the normalized interval number decision matrix. Besides, Euclidian distance function is further used in the original relative ratio technique. Finally, an application example shows that the proposed model is reasonable and efficient, and can easily extend to similar decision problems.

Keywords*: relative ratio method; multi-attribute group decision; interval number; safety performance*

1. Introduction

With the rapid economic development of China, construction companies are also boomed in recent years. Construction activities are increasing rapidly. But the construction safety management performance is still disappointingly poor in China. An effective measure of safety management is an important ingredient for improving safety management of construction companies [1]. It should help to assess site safety and provide guidance in prioritizing the safety management measures on construction sites [2]. A lot of research work has been made in the construction safety management [3-7]. Construction safety management field exists much uncertain information which can't be well depicted by crisp number [8]. Fuzzy set is recognized as an appropriate tool to deal with qualitatively as well as quantitatively for the uncertain decision making problems. Bellman and Zadeh [9] first used the fuzzy programming technique in decision making problems in 1970. After that, fuzzy numbers are studied by numerous research articles and fuzzy decision making methods also have been developed [10-13].

An assessment of construction safety management needs to be simultaneously considered [14]. Thus, the problem of safety performance evaluation is also a fuzzy multi-attribute decision making (MADM) problem. Due to the complexity of the uncertainty and fuzziness of human cognition, the MADM problem which the attribute

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values expressed with interval number has aroused great attention of people [15-17]. In order to make the decision-making process and the evaluation results are closer to the reality, and reduce the individual subjective factors of decision bias, group decision making methods are often used to make the decision making process more scientific and democratic [18]. Relative ratio method is an effective decision making method, and the study and application of this method received great attention by many scholars [19, 20]. In view of this, we combine the traditional relative ratio method with interval number theory, and propose a new group decision making method for multi-attribute group decision making (MAGDM) evaluation model. The new method can well deal with the uncertainty and deviation which often occur in safety performance evaluation problem.

The remainder of this paper is organized as follows. In Section 2, we establish a MAGDM model for the construction safety management performance evaluation model. In Section 3, the relative ratio method is developed for solving the construction safety management performance evaluation model. Section 4 gives a practical example to examine the feasibility and effectiveness of the proposed method. Finally, we conclude our paper in Section 5.

2. Preliminarily Knowledge

2.1. Model of Construction Safety Management Performance Evaluation

Construction enterprise safety performance evaluation problem contains many aspects. Determining the reasonable evaluation index is the key to safety performance evaluation. According to Chinese construction enterprise practice, the standard for the work safety assessment of construction company safety (JGJ/T77-2010) [21] is the mainly reference for construction enterprises safety management performance evaluation. Mainly evaluation indices are safety production management, safe technique management, equipments and facilities management, company operation, and the detail information is shown in Table 1.

Table 1. Evaluation Indices of Construction Safety Management Performance

Evaluation indices	Detail description of each index
Safety production management	Safety production management is for those safety problems in the process of safety production, using resources effectively, playing to people's wisdom through the efforts of the people, the decision-making, planning, organization and control activities, realizing the production process of human and machine equipment, material and environment harmony, etc.
Safe technique management	Safe technique management is to develop the basic knowledge and basic skills necessary for the management of safety technology, and be able to engage in the application of advanced technology in safety design, evaluation, supervision and technical management.
Equipments and facilities management	Equipments and facilities management is the management of the whole process of equipments and facilities’ life cycle, including the selection of equipment, the proper use of equipment, maintenance and repair equipment and the management of the whole process of updating the equipment.

Company operation	Company operation is refers to the enterprise in full consideration on the basis of market supply and demand conditions and other corporate relations, take a variety of decision-making behavior or to achieve its stated objectives taken adapt to requirements of market adjustment behavior.

Suppose that $X=\{x_1,x_2,\cdots,x_m\}$ is a set of construction enterprises. Now the local government department wants to inspect these construction companies' safety performance. The evaluation index (attribute) set is $O=\{o_1,o_2,\cdots,o_n\}$. Considering the fuzziness and uncertainty of subjective judgment, and the expert assessment information for alternatives to a single attribute expressed with interval numbers. To evaluation these construction enterprises' safety management performance, many experts are need to work together and provide the evaluation values according to the designed indice set O. Supposed that $D=\{D_1,D_2,\cdots,D_s\}$ is the expert set. Suppose the rating of alternative x_i ($i=1,2,\cdots,m$) on index o_j ($j=1,2,\cdots,n$) given by expert D_k ($k=1,2,\cdots,s$) is an interval number, which can be described by $\tilde{a}_{ij}^k=[\underline{a}_{ij}^k,\bar{a}_{ij}^k]$. Hence, the construction enterprises safety performance model is a multi-attribute group decision making problem can be concisely expressed in matrix format as follows.

$$\tilde{D}^k=(\tilde{a}_{ij}^k)_{m\times n}=\begin{array}{c} \\ x_1 \\ x_2 \\ \vdots \\ x_m \end{array}\begin{array}{c} \begin{array}{cccc} o_1 & o_2 & \cdots & o_n \end{array} \\ \begin{pmatrix} \tilde{a}_{11}^k & \tilde{a}_{12}^k & \cdots & \tilde{a}_{1n}^k \\ \tilde{a}_{21}^k & \tilde{a}_{22}^k & \cdots & \tilde{a}_{2n}^k \\ \vdots & \vdots & \vdots & \vdots \\ \tilde{a}_{m1}^k & \tilde{a}_{m2}^k & \cdots & \tilde{a}_{mn}^k \end{pmatrix} \end{array} \tag{1}$$

where $k=1,2,\cdots,s$. In most actual situations, different index often owns different importance degree in the decision making process. Thus, we let w_j $(j=1,2,...,n)$ denotes the weight (importance degree) of the jth index o_j, and they satisfies the following conditions: $w_j\geq 0$ $(j=1,2,...,n)$, and $\sum_{j=1}^{n}w_j=1$. Then Eq. (2) will help us collect the index evaluation values of the fuzzy decision matrix $\tilde{D}^k=(\tilde{a}_{ij}^k)_{m\times n}$, $k=1,2,...,s$ into final decision matrix $\tilde{D}=(\tilde{a}_{ij})_{m\times n}$, where

$$\tilde{a}_{ij}=[a_{ij}^l,a_{ij}^u]=\frac{1}{s}(\tilde{a}_{ij}^1+\tilde{a}_{ij}^2+\cdots+\tilde{a}_{ij}^s) \tag{2}$$

2.2. Normalization Method

In general, indices can be classified into two types: benefit indices and cost indices. In other words, the index set can be divided into two subsets: I_1 and I_2, where $I_k(k=1,2)$ is the subset of benefit index set (*i.e.*, the-larger-the-better index) and cost index set (the-smaller-the-better index), respectively.

The normalization method is to preserve the property that the range of a normalized interval number $\tilde{r}_{ij}^k$ belongs to the closed interval [0, 1]. Hence, the fuzzy decision matrix $\tilde{D}=(\tilde{a}_{ij})_{m\times n}$ are transformed into the normalized fuzzy decision matrix $\tilde{R}=(\tilde{r}_{ij})_{m\times n}$, where $\tilde{r}_{ij}=[r_{ij}^l,r_{ij}^u]$ can be normalized by the following formula ([22]):

$$\begin{cases} r_{ij}^{l} = a_{ij}^{l} \Big/ \sqrt{\sum_{i=1}^{m} (a_{ij}^{u})^2} \\ r_{ij}^{u} = a_{ij}^{u} \Big/ \sqrt{\sum_{i=1}^{m} (a_{ij}^{l})^2} \end{cases}, i \in M, j \in I_1 \tag{3}$$

and

$$\begin{cases} r_{ij}^{l} = (1/a_{ij}^{u}) \Big/ \sqrt{\sum_{i=1}^{m} (1/a_{ij}^{l})^2} \\ r_{ij}^{u} = (1/a_{ij}^{l}) \Big/ \sqrt{\sum_{i=1}^{m} (1/a_{ij}^{u})^2} \end{cases}, i \in M, j \in I_2 \tag{4}$$

where $M=\{1,2,\ldots,m\}$.

8.3. Weighting Method

In decision making theory and practice, the weight is that the importance degree of each evaluation index (or evaluation project), indicating the different function of each evaluation index in the overall. Many weighting methods are developed and applied in various engineering fields [23].

In the evaluation index system, the greater the difference between the indicators, which is the more difficult to achieve indicators, such indicators can reflect the gap between the evaluation unit. The basic procedure of coefficient of variation method is that it is not suitable to directly compare the difference of each index in the evaluation index system. In order to eliminate the influence of the dimension of each evaluation index, the variation coefficient of each index is needed to measure the difference degree of each index value.

Calculating the index weight vector by the following step:

(i) The final construction safety management performance decision $\tilde{R} = (\tilde{r}_{ij})_{m\times n}$ is firstly defused into a crisp number decision matrix $G = (g_{ij})_{m\times n}$ by the expectation method given as follows [24]:

$$g_{ij} = \frac{1}{2}(r_{ij}^{l} + r_{ij}^{u}) . \tag{5}$$

(ii) The variation coefficient formula of each index is as follows:

$$\delta_j = \frac{s_j}{\overline{x}_j} \tag{6}$$

Where $\overline{x}_j = \frac{1}{m}\sum_{i=1}^{m} x_{ij}$ is the mean of the i-th index and $s_j = \sqrt{\frac{1}{m}\sum_{i=1}^{m}(x_{ij} - \overline{x}_j)^2}$ is the standard deviation of the i-th index.

(iii) The coefficient of variation method proposed by Men and Liang [25], and the calculation formula is

$$w_j = \frac{\delta_j}{\sum_{j=1}^{n} \delta_j}, j = 1,2,...,n , \tag{7}$$

3. Relative Ratio Method for Construction Safety Management Performance Evaluation

In this section, we will give the calculation steps of the relative ratio method for the construction safety management performance as follows:

Step1. Calculate the normal construction safety management performance decision matrix $\tilde{R} = (\tilde{r}_{ij})_{m\times n}$;

Step2. Calculate the positive and negative ideal solution:

The positive ideal solution is defined as:

$$x^* = (x_1^*, x_2^*, \ldots, x_n^*),$$

And the negative ideal solution is defined as:

$$x^- = (x_1^-, x_2^-, \ldots, x_n^-),$$

Here $x_j^* = [1,1]$ and $x_j^- = [0,0]$.

Step3. Calculating the index weight vector by coefficient of variation method.

Step4. Calculate the distance measure of alternative x_i with the positive and negative ideal solution, as

$$d(x_i, x^*) = \sqrt{\sum_{j=1}^{n} w_j^2 d^2(\tilde{r}_{ij}, r_j^*)}, \tag{8}$$

And

$$d(x_i, x^-) = \sqrt{\sum_{j=1}^{n} w_j^2 d^2(r_{ij}, r_j^-)} \tag{9}$$

where the distance measures are

$$d(\tilde{r}_{ij}, r_j^*) = \sqrt{(1-r_{ij}^L)^2 + (1-r_{ij}^U)^2},$$
$$d(\tilde{r}_{ij}, r_j^-) = \sqrt{(r_{ij}^L - 0)^2 + (r_{ij}^U - 0)^2}.$$

Step 5. Calculate the relative ratio of the alternative:

Set

$$d(x^-) = \max_{1\le i\le m}\{d(x_i, x^-), d(x^+) = \min_{1\le i\le m}\{d(x_i, x^*) \tag{10}$$

The relative ratio of the i-th alternative defined as:

$$\xi_i = \frac{d(x_i, x^-)}{d(x^-)} - \frac{d(x_i, x^*)}{d(x^+)}, i = 1, 2, \ldots, m. \tag{11}$$

It is easily to prove that the relative ratio $\xi_i \le 0$, and ξ_i reflects the i-th object close to being the positive ideal solution and away from negative ideal solution, indicating that the alternative i and the positive ideal vector objects relative distance is smaller, while the negative ideal vector larger relative distance.

Step6. Rank all the alternatives according to ξ_i. The larger of ξ_i, the better of the alternative x_i.

4. A Practical Example

Suppose that the local government department wants to inspect four construction companies' safety performance. These four construction companies are denoted by x_1, x_2, x_3, x_4, and the evaluation indexes are determined as the following four indices: o_1 (safety production management), o_2 (safe technique management), o_3 (equipments and facilities management) and o_4 (company operation). These four indices are all the larger the better indices (*i.e.*, benefit indices). To assessment the four construction companies safety management performance, the government department hires three experts (decision makers) D_1, D_2 and D_3 to evaluate these four companies, and the index evaluation values provided by the experts are shown in Table 2.

Table 2. The Index Evaluation Values of the Four Companies by Experts

Evaluation Index	Company	Expert		
		D_1	D_2	D_3
o_1	x_1	[65,75]	[70,80]	[70,75]
	x_2	[70,80]	[65,75]	[80,85]
	x_3	[70,75]	[70,75]	[70,80]
	x_4	[65.70]	[65.70]	[65.70]
o_2	x_1	[70,75]	[75,80]	[80,85]
	x_2	[75,80]	[70,80]	[65,75]
	x_3	[65,75]	[70,75]	[75,80]
	x_4	[70,75]	[65,70]	[70,80]
o_3	x_1	[70,80]	[70,75]	[65,70]
	x_2	[65,70]	[65,70]	[75,80]
	x_3	[70,75]	[65,75]	[70,75]
	x_4	[80,85]	[65,75]	[75,80]
o_4	x_1	[75,80]	[65,70]	[75,80]
	x_2	[70,75]	[70,75]	[65,75]
	x_3	[75,80]	[75,85]	[70,80]
	x_4	[75,85]	[70,80]	[65,70]

To sort the four construction companies' safety performance, we use the proposed fuzzy ratio values method, and the detail steps are illustrated as follows:

Step1. According to the Eq.(1) and Eq.(2), we can get the following fuzzy decision matrix $\tilde{D} = (\tilde{a}_{ij})_{m\times n}$.

$$\tilde{D} = \begin{bmatrix} [68.33,76.67] & [75.00,80.00] & [68.33,75.00] & [71.67,76.67] \\ [71.67,80.00] & [70.00,78.33] & [68.33.73.33] & [68.33,75.00 \\ [70.00,76.67] & [70.00,76.67] & [68.33,75.00] & [73.33,81.67] \\ [65.00,70.00] & [68.33,75.00] & [73.33,80.00] & [70.00,78.33] \end{bmatrix}$$

Step2. The normal construction companies' safety performance decision matrix $\tilde{R} = (\tilde{r}_{ij})_{m\times n}$ is calculated as:

$$\tilde{R}=\begin{bmatrix} [0.4500,0.5572] & [0.4837,0.5644] & [0.4503,0.5387] & [0.4597,0.5410] \\ [0.4720,0.5814] & [0.4515,0.5526] & [0.4503,0.5267] & [0.4383,0.5292] \\ [0.4610,0.5572] & [0.4515,0.5408] & [0.4503,0.5387] & [0.4704,0.5763] \\ [0.4281,0.5088] & [0.4407,0.5291] & [0.4833,0.5746] & [0.4490,0.5527] \end{bmatrix}$$

Step3. The ideal solution and negative ideal solution are respectively given as:

$$x^{*}=(x_1^{*},x_2^{*},x_3^{*},x_4^{*})=([1,1],[1,1],[1,1],[1,1])$$

$$x^{-}=(x_1^{-},x_2^{-},x_3^{-},x_4^{-})=([0,0],[0,0],[0,0],[0,0])$$

Step4. Calculate the index weight vector:

(i) Calculate the crisp number decision matrix $G=(g_{ij})_{m\times n}$:

$$G=\begin{bmatrix} 0.5036 & 0.5240 & 0.4945 & 0.5003 \\ 0.5267 & 0.5020 & 0.4885 & 0.4838 \\ 0.5091 & 0.4962 & 0.4945 & 0.5233 \\ 0.4684 & 0.4849 & 0.5289 & 0.5009 \end{bmatrix}$$

(ii) Then the weights of these four indices can be obtained by coefficient of variation method respectively as follows:

$$w_1=0.3234, w_2=0.2178, w_3=0.2440, w_4=0.2148.$$

Step5. The distance measure of alternative x_i with the positive and negative ideal solution are obtained as follows:

$$d(x_1,x^{*})=0.7030, d(x_2,x^{*})=0.7069,$$
$$d(x_3,x^{*})=0.7023, d(x_4,x^{*})=0.7195$$

and

$$d(x_1,x^{-})=0.7175, d(x_2,x^{-})=0.7147,$$
$$d(x_3,x^{-})=0.7186, d(x_4,x^{-})=0.7019$$

Then we have

$$d(x^{-})=0.7186, d(x^{*})=0.7023.$$

Step6. The relative ratio of the i-th alternative employee defined as:

$$\xi_1=-0.0025, \xi_2=-0.0119, \xi_3=0, \ \xi_4=-0.0477.$$

Step7. Obviously, $\xi_4<\xi_2<\xi_1<\xi_3$, then the four construction companies' safety performance order is $x_4<x_2<x_1<x_3$, and the construction company x_3 owns the best safety management level .

5. Conclusion

This article is focused on solving the construction companies' safety performance problem. To better model the vague information of decision makers, interval numbers are used to establish the evaluation model, and then we proposed a fuzzy multi-attribute group decision-making method for this evaluation problem on the basis of a relative ratio method. In this paper, the coefficient variation method is adopted to determine the weight of each evaluation index, the use of number information itself reflects the index weight, which can overcome the artificial and uncertainty of subjective weight. In this paper, the proposed method is simple, in line with the actual situation, the algorithm is easy to finish by using Matlab and Excel software as modular operation, and each department can use the method in the construction companies' safety performance problem and other multi-attribute decision-making models, such as teaching performance evaluation, machine selection.

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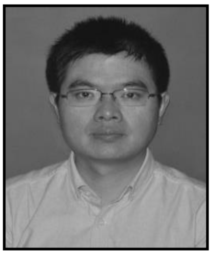

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