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Fusion Method for Decision-Making Bases with Heterogeneous Information Based on Evaluation Results

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Abstract: Aiming at the problem that the decision-making basis of heterogeneous information cannot be effectively integrated, this paper proposes a decision-making basis integration of heterogeneous information based on evaluation results. Firstly, the idea of maximizing the total deviation between the evaluation values of the evaluation objects by multiple single evaluation methods is used to construct the decision-making method fusion model based on the deviation maximization method. The decision-making basis fusion results of each evaluation object are calculated and sorted. Secondly, Spearman correlation coefficient is adopted to analyze the stability of the fused evaluation value. Finally, by combining the analysis in this study with a comparative analysis from previous paper, the results showed the scientific validity and effectiveness of the fusion method.

Keywords: Heterogeneous information; Decision-making basis fusion; Dispersion maximization; Spearman correlation rank coefficient

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1. Introduction

In recent years, local and foreign experts have proposed various single evaluation methods for mixed attributes, such as gray correlation method, Gini-Simpson index, and entropy value method. However, single evaluation methods often consider only one or several aspects, resulting in single evaluation results and the lack of comprehensiveness. Therefore, several experts and scholars have proposed the concept of "portfolio evaluation" to improve the accuracy of evaluation decision by integrating the decision basis [1]. Decision fusion methods are divided into two categories: (1) the combination of evaluation results, which includes the combination of ranking values and evaluation values; (2) the combination of evaluation methods, which includes parallel and nested combinations [2]. Using the idea of BU system analysis, Chen explored the multi-level and multi-perspective of the combined evaluation system and solved the issue of combining evaluation methods on the same level as well as the corresponding evaluation combinations between each level [3]. Guo proposed the idea of determining the validity of the combination method and verified the validity of several commonly used combination evaluation methods to solve the issue of inconsistent evaluation conclusions caused by different combination evaluation methods [4]. Li proposed the combination of each single evaluation method using the idea of deviation maximization; the combined evaluation results obtained not only integrated the characteristics of each single evaluation method, but also considered the distance between the values of each single evaluation method, so that the combination results were closer to actual situations [5]. Combining various evaluation methods is still flawed, thus requiring analysis of the validity of the combined evaluation results. Guo analyzed the validity of combination evaluation methods to solve the inconsistent evaluation conclusions caused by different combination evaluation methods [6]. Li measured the drift of different dynamic evaluation methods and established a dynamic combination evaluation model based on the drift degree, providing a solution to solving the issue of inconsistent evaluation conclusions of multiple dynamic evaluation methods; it is also a useful supplement to the research of comprehensive evaluation methods [7]. In 2019, Fan proposed an objective portfolio evaluation method based on Gini's criterion for the inconsistency of multi-method evaluation conclusions and made a comprehensive evaluation of the technological innovation capability of high technology industries [8]. Wang Xiao Li and Li Jing proposed a combined evaluation method that allows tied ranking; by studying the effect of the choice of a single evaluation method on the tied ranking method, when the choice of a single evaluation method does not provide adequate information about the advantages and disadvantages, there may be too many solutions given the same ranking; hence, for such cases the method needs to be further studied [9]. First, the combination of the three single-assignment results is demonstrated through a combined assignment model, integrating the dual constraints of similarity and difference, which reflects the differences between the evaluated enterprises and the characteristics of the three single-assignment methods to obtain a unique CSR ranking result. This solves the problem that the results of different single-assignment methods are too different and inconsistent. Second, the consistency test is conducted to verify the superiority of the model over the single-assignment method and the single-combination assignment method. Finally, the scientific and rationality of the method can be proven through the evaluation of the transportation industry [10]. In response to the inconsistent conclusions of multiple assessment methods in the application of single regional sustainable development assessment methods, Zhang's invention considers the special characteristics of regional sustainable development assessment, combines the connotation of sustainable development, proposes a regional sustainable development portfolio assessment model based on the CW operator incorporating sustainable characteristics, as well as conducts an empirical study using Jiangxi Province as an example, illustrating the scientific and rational nature of the method [11]. In order to reduce the risk of rock slope stability evaluation, Su proposed to use the set-pair coefficients to quantitatively characterize the deterministic and uncertainty relationships between single evaluation models as well as construct a combined evaluation model [12]. In order to solve the issue of inconsistent results of different single methods in evaluating comprehensive disaster risks, Xia proposed an evaluation method based on the dual combination of ranking values and evaluation values. The method is also used to rank the combined disaster risks of 31 provinces, autonomous regions, and municipalities directly under the central government of China (excluding Hong Kong, Macao, and Taiwan), in order to illustrate the scientific feasibility of the method [13]. In response to the shortcomings of current research on credit evaluation of micro and small enterprises, Zhang proposed an improved dynamic combination evaluation method based on fuzzy clustering analysis and SOM-K algorithm. The results were found to be consistent with the findings of the cross-checking by account managers, proving the feasibility and effectiveness of the method [14].

In summary, a web search has revealed that portfolio evaluation methods have been widely researched on and applied to various fields, from credit evaluation of micro and small enterprises to the evaluation of comprehensive disaster risk. However, the boundaries of current conceptual research on portfolio evaluation methods are still unclear; thus, there is a possibility of conceptual confusion. Based on this, this paper analyzes the combination evaluation method of the above literature and summarizes its characteristics. It is found that there is a lack of fusion method for decision-making basis with heterogeneous information. In view of this, this study proposes a deviation maximization method to fuse the decision-making basis with heterogeneous information. The advantage of the deviation maximization method is that the fused evaluation results are as scattered as possible to achieve decision-making and ranking results. At the same time, this method can effectively fuse the evaluation information of various methods and increase the amount of information. Spearman correlation coefficient was used to analyze the stability of the fused evaluation results, which proved the effectiveness and rationality of the fusion method.

2. Deviation maximization-based decision fusion model

2.1. Basic principles of decision fusion

In this paper, the basic principles of the decision fusion method for heterogeneous information are as follows (**Figure 1**): (1) the evaluation value of each evaluation object (generalized bull's eye distance value) is calculated using the mixed attribute generalized gray target decision method, and the evaluation objects are ranked as superior or inferior; (2) since different evaluation methods are not comparable, it is necessary to process each single evaluation method dimensionless, so that various evaluation methods are comparable; (3) for different evaluation results, the idea of maximizing deviation to construct a decision fusion model based on different results is proposed, and the model is solved by using the Lagrange extreme value method to calculate the weight coefficient of each single evaluation method; after normalizing the weight coefficients, the combined evaluation value is calculated; (4) the ranking of advantages and disadvantages of each evaluation method may not be the same, so Spearman correlation coefficient is used to analyze the stability of the combined evaluation results, in which the larger the value, the higher the consistency and the better the stability.

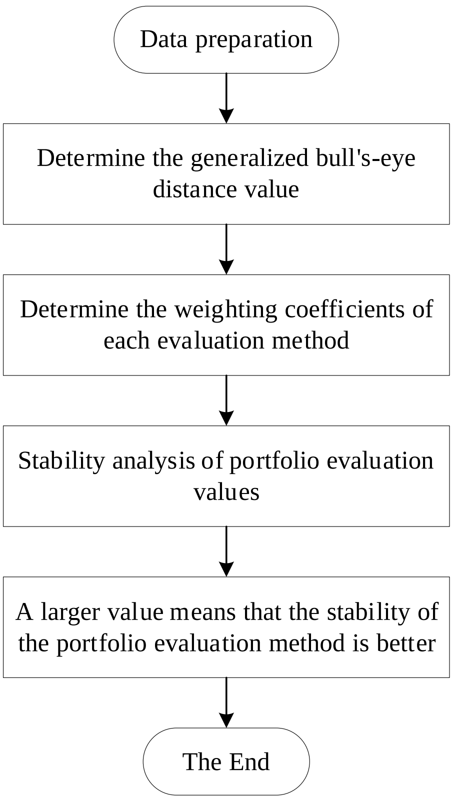

Figure 1. Basic principles of decision fusion

2.2. Basic element processing

Single evaluation methods are arranged into a set of evaluation methods, which are normalized because the indicators under different attributes are not comparable. $d = [d_1, \dots, d_m]$, denoting the evaluation value of s scheme under t evaluation method, which is normalized as shown below.

$$d'_{st} = d_{st} / \sum_{s=1}^{n} d_{st} \tag{1}$$

2.3. Establishing a fusion model

Suppose r_{ijt} is the value of the deviation between programs F_i and F_t under a single evaluation method d_j. The expression for the deviation is as follows:

$$r_{ijt} = \left| d_{ij} - d_{tj} \right| \tag{2}$$

Let the weight vector of each single evaluation method be $\alpha = (\alpha_1, \ldots \alpha_j, \ldots, \alpha_m)^T (j = 1, \ldots, m)$. The deviation after the fusion of scheme F_i, F_t evaluations is shown in equation (3), while the total deviation under all scheme fusion methods is shown in equation (4).

$$r_{it} = \sum_{j=1}^{m} \alpha_j \left| r_{ij} - r_{tj} \right| \tag{3}$$

$$R = \sum_{i=1}^{n} \sum_{t=1}^{n} \sum_{j=1}^{m} \alpha_j \left| r_{ij} - r_{tj} \right| \tag{4}$$

The evaluation fusion model based on deviation maximization is established based on equation (4).

$$\max R = \sum_{i=1}^{n} \sum_{t=1}^{n} \sum_{j=1}^{m} \alpha_j \left| r_{ij} - r_{tj} \right|$$
$$s.t \begin{cases} \sum_{j=1}^{m} \alpha_j^2 = 1 \\ \alpha_j > 0 \end{cases} \tag{5}$$

2.4. Solving the evaluation fusion model

This model is solved for α_j of the above model using the Lagrange extreme value method, and α_j' is obtained after normalizing α_j using equation (7).

$$\alpha_j = \sum_{i=1}^{n} \sum_{t=1}^{n} \left| r_{ij} - r_{tj} \right| / \sqrt{\sum_{j=1}^{m} \left(\sum_{i=1}^{n} \sum_{t=1}^{n} \left| r_{ij} - r_{tj} \right| \right)^2} \tag{6}$$

$$\alpha'_j = \sum_{i=1}^{n} \sum_{t=1}^{n} \left| r_{ij} - r_{tj} \right| / \sum_{j=1}^{m} \sum_{i=1}^{n} \sum_{t=1}^{n} \left| r_{ij} - r_{tj} \right| \tag{7}$$

The weights of each evaluation method can be obtained using equation (7), and the expression of the combined evaluation value of scheme F_i can be obtained as shown in equation (8).

$$H_i = \alpha_1' d_{i1} + \alpha_2' d_{i2} + \ldots + \alpha_m' d_{im} \tag{8}$$

2.5. Stability analysis of evaluation results after decision basis fusion

In statistics, the Spearman rank correlation coefficient is used to estimate the correlation between two variables [15]. Let two variables be X and Y, with n elements; having the two variables assume the value i ($1 < i < n$), express them as X_i, Y_i, X, and Y, with ascend or descend sorting, to obtain two rearranged elements of the new set x, y, where x_i is the sorting of X_i in X, while y_i is the sorting of Y_i in Y. The elements in x, y will be subtracted from each other to obtain a sequential difference set d; the Spielman's correlation coefficient between the random variables X, Y can then be defined as follows [16]:

$$d_i = x_i - y_i, 1 \leq i \leq n \tag{9}$$

$$\rho = 1 - [6\sum_{i}^{n} d_i^2 / n(n^2 - 1)] \tag{10}$$

The value range in equation (10) is $\rho = [-1,1]$; if $\rho = 1$, then the variables X and Y change in the same direction and show a completely positive correlation; if $\rho = -1$, then the variables X and Y show a completely negative correlation; if $\rho = 0$, then the variables X and Y show a completely irrelevant correlation. In short, the larger the value, the better correlation between the two variables and the higher the consistency. This study introduces Spearman rank correlation coefficient as a measure of consistency, in which the larger its p value, the closer to the optimal decision it belongs to.

3. Calculation steps

(1) **Step 1:** Since the evaluation methods are not comparable, equation (1) is used to normalize each evaluation method.

(2) **Step 2:** Equations (2) to (3) are used to calculate the deviations between the evaluation values of each evaluation object. The evaluation fusion model based on the maximization of the deviation is constructed using equations (5) to (7), and the weight coefficients of each evaluation method are solved.

(3) **Step 3:** The weight coefficients of each evaluation method are calculated using the above formulas, and the combination of each evaluation method is evaluated using equation (8).

(4) **Step 4:** Stability analysis of the combined evaluation results using Spearman correlation coefficient. Equations (9) to (10) were used to calculate the ρ values of the evaluation fused results with each evaluation method.

4. Example analysis

In this paper, the effectiveness of the method is illustrated using examples from the *Research on Hybrid Multi-Indicator Gray Target Decision Model* [17]. Six decision attributes are used to evaluate the four missiles, which are denoted by A1 to A6 for hit accuracy, warhead load, mobility, price, reliability, and maintainability, respectively [17]. The data are shown in **Table 1**.

Table 1. Raw data

F_i	A_1	A_2	A_3	A_4	A_5	A_6
F_1	2	500	[55,56]	[4.7,5.7]	[0.4,0.5,0.6]	[0.8,0.9,1]
F_2	2.5	540	[30,40]	[4.2,5.2]	[0.2,0.3,0.4]	[0.4,0.5,0.6]
F_3	1.8	480	[50,60]	[5,6]	[0.6,0.7,0.8]	[0.6,0.7,0.8]
F_4	2.2	520	[35,45]	[4.5,5.5]	[0.4,0.5,0.6]	[0.4,0.5,0.6]

(1) **Step 1:** Single evaluation method selection.

In this paper, the proximity [18], Gini-Simpson index [19], and Kullback-Leibler distance [20,21] of the mixed-attribute generalized gray target decision method are used to evaluate the total utility of the four missiles. m=3, and the set of evaluation methods $d = \{d_1, d_2, d_3\}$, where d_1 represents the proximity method, d_2 the K-L distance method, and d_3 the G-S index method. The calculation results are normalized by using equation (1), and the results are shown in **Table 2**.

Table 2. Evaluation values of each single evaluation method

F_i	Proximity	Ranking	K-L	Ranking	G-S	Ranking
F_1	0.2986	3	0.0175	1	0.0174	3
F_2	0.0678	1	0.0362	3	0.0106	1
F_3	0.4386	4	0.0373	4	0.0267	4
F_4	0.1949	2	0.036	2	0.017	2

(2) **Step 2:** The weight values of each evaluation method are calculated.

Based on the data in **Table 2**, the weight value α_j of the evaluation fusion of each evaluation method is calculated by using equations (5) to (6), and the normalization process is performed by using equation (7) to obtain $\alpha_1' = 0.666$, $\alpha_2' = 0.01$, and $\alpha_3' = 0.324$. The combined evaluation values of various missiles are obtained by bringing the weight values into equation (8), which are $H_1 = 0.2047$, $H_2 = 0.049$, $H_3 = 0.3011$, and $H_4 = 0.1357$; using equation (4), the total deviation of all evaluation objects is obtained, $R = 16.14$.

(3) **Step 3:** Stability analysis.

Based on the data in **Table 2**, stability analysis is performed assuming that the most standard comparison quantity of its fused evaluation value is compared with the other three single evaluation methods. Referring to the ranking of Person's coefficient, Spearman correlation coefficient can be ranked when $0.9 < |\rho| < 1$, highly correlated; $0.7 < |\rho| < 0.9$, strongly correlated; $0.4 < |\rho| < 0.7$, moderately correlated; $0.2 < |\rho| < 0.4$, weakly correlated; $0 < |\rho| < 0.2$, very weakly correlated or not want to be correlated. The mean Spearman value of the three evaluation methods calculated by using equations (9) and (10) is 0.7333. This indicates that the stability of this decision fusion method is strong.

5. Conclusion

In this paper, the decision-making basis for the existence of heterogeneous information is integrated by introducing the idea of maximizing deviation. This method not only considers the characteristics of each single evaluation, but also avoids the deviation of the results caused by the combination of weights, and increases the amount of information in the results. In addition, the deviation maximization theory makes the final combination evaluation results as dispersed as possible, which is convenient for ranking and decision-making, as well as prevents issues relating to fairness in the evaluation method selection arising from the evaluation values being close to each other. Meanwhile, in order to analyze the stability of the evaluation results after decision fusion, the Spearman value is used to analyze the consistency between the combination evaluation and each single evaluation method. The results showed that the stability of the evaluation results after decision fusion is better. The entire decision fusion process is clear in concept and organization as well as simple in calculation. Therefore, this decision fusion method can be universally applied and promoted in the practical evaluation of various fields, such as nature, economy, and society.

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