Fuzzy comprehensive evaluation of power suppliers based on combination weighting

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Abstract: In view of the deficiencies of power equipment supplier synthesis in evaluation index and evaluation method, a comprehensive evaluation model based on game theory is designed.Firstly, the model constructed an evaluation system including supply quality, operation quality and use range. The subjective and objective weights of each evaluation criterion were determined using the fuzzy analytic hierarchy process and factor analysis approach, respectively. The final weightage was obtained by employing the combined weighting method. Based on the principle of maximum membership, the supplier category was classified, and the final evaluation was completed accordingly. The proposed evaluation model was validated using a case study involving knife gate suppliers, and the results demonstrated its objectivity and rationality.

Keywords: power equipment supplier; evaluation model; combination weighting; comprehensive evaluation；

1 INTRODUCTION

Power grid material supply chain is a network chain structure formed by the life-cycle activities such as material procurement, circulation and recycling generated by power grid construction, operation and maintenance and emergency support, as well as the cooperation of enterprises of all links[1]. Conducting a performance evaluation of suppliers is an effective way to enhance the material supply support capacity and optimize the management of material resources. Analyzing supplier behavior and conducting a comprehensive evaluation of suppliers is of great practical significance for achieving these goals[2].

Currently, the evaluation of suppliers is primarily approached through two angles: the establishment of an index system for evaluation and the development of evaluation methods. For instance, in paper [3] and paper [4], the evaluation indexes were constructed based on social responsibility considerations, while literature sources such as literature [5, 6, 7, 8] employed various methods such as multiple discriminant analysis, grey clustering trigonometric approach, neural network, and support vector machine for conducting evaluations. In the above methods, the evaluation indexes are few, the weight is too one-sided, some of them are

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not closely related to the demand of the power grid, and the evaluation results are not consistent with the actual situation.

There are many kinds of suppliers in power enterprises, wide distribution of industries, and great differences among suppliers. The evaluation of power grid suppliers has strong fuzziness and uncertainty. Subjective evaluations rely too much on expert experience, objective evaluation to the idea of fuzzy comprehensive evaluation method of fuzzy mathematics was introduced to the comprehensive evaluation, which has the results clearly, systemic strong characteristic, better solve the problem of the fuzzy index quantification, and the index membership degree measurement problem, for the synthetic evaluation of power suppliers has good applicability to adopt the way of combination empowerment both subjective and objective two kinds of weights, it can make the index weighting more scientific and effectively improve the correctness and rationality of the performance evaluation of power equipment suppliers[9, 10, 11, 12].

This paper builds power equipment supplier comprehensive evaluation index system with the equipment defect data, and parameter data and the supplier data. The subjective fuzzy weights and objective weights for evaluation indexes were obtained through the fuzzy analytic hierarchy process and factor analysis, respectively. An optimization of the weights was then conducted through a game theory combination empowerment method to facilitate the selection of suppliers. Query related data records from material management system, equipment operational records, PMS system.

2 A COMPREHENSIVE EVALUATION INDEX SYSTEM FOR SUPPLIERS

The core goal of power grid material supply is to provide good quality, timely supply of materials, and ensure the power grid has fast and complete operation and emergency support. The evaluation index system is established from three aspects: supply quality, operation quality and production capacity.

1) Quality of supply. The frequencies of unqualified sampling inspection (A11) and The frequencies of untimely delivery (A12) were selected as evaluation indexes. The data can be queried through the material management system. Indicators evaluate the specific delivery conditions of suppliers in accordance with the contract, and measure the comprehensive production capacity and integrity level of suppliers.

2) Quality of operation. The number of defects (A21), nature of defects (A22), fault condition (A23) and accident condition (A24) of the equipment were selected as evaluation indexes. Defect rate is caused by design, process, production and other links of equipment defects; The defect property evaluates the condition that the defect belongs to familial defect. The failure rate is the probability of failure in operation, and the fault property is the consequence caused by the fault. The first three indicators are queried from the operating system, and A24 is given a comprehensive score by experts according to the records in the operating system.

3) Scope of use: Equipment ownership A31, voltage level A32 and equipment model A33 were selected as evaluation indexes. The equipment ownership of the supplier in the ledger

data is defined as equipment ownership; Voltage level and device model Indicate the voltage level and type covered by the device.

3 COMPREHENSIVE EVALUATION MODEL

In the traditional fuzzy comprehensive evaluation method, the analytic hierarchy process (AHP) is used to calculate the index weight. The weighting process has strong subjectivity and does not reflect the information carried by the data itself. The objectivity weight of the index was computed by incorporating factor analysis (FA) into the AHP approach. Furthermore, game theory was applied to combine the weight, resulting in a comprehensive selection process.

3.1 Establish fuzzy relation matrix

1) Determine the evaluation factor set C. Suppose that there are n evaluation indexes, then the evaluation set C $=\{c_1,c_2,\ldots, c_n\}$, among them c_1, c_2, …c_n is the n evaluation factors involved in the evaluation,in this paper, 9 indicators are selected for evaluation,n=9。

2) In this study, a set of criteria for evaluating suppliers, denoted as $V=\{v_1, v_2, \ldots, v_m\}$, was developed. The standard set V comprises m evaluation levels, represented by v_1, v_2, …, v_m. The suppliers were categorized into three hierarchical levels, namely A, B, and C, with A being the highest and C being the lowest.

3) Establish fuzzy relation matrix.According to the standard set established in (2), let r_{ij} be the membership degree of the unit pair rank fuzzy factor, and the fuzzy relation matrix $R=(r_{ij})_{n\times m}$ .Membership degree r_{ij} is calculated by membership function as follows:

$$r_{ij}=\begin{cases} 1 & x_i \le s_i \\ (s_{j+1}-x_i)/(s_{j+1}-s_i) & s_i < x_i < s_{i+1} \\ 0 & x_i \ge s_{i+1} \end{cases} \tag{1}$$

3.2 Fuzzy analytic hierarchy process

The fuzzy analytic hierarchy process incorporates a fuzzy consistency matrix in AHP for subjective weighting. This approach retains the strengths of the traditional AHP method while simultaneously ensuring judgment matrix consistency.

1) The fuzzy complementary matrix is generated to conduct pairwise comparisons among the selected n evaluation indices. The extent of the fuzzy relationship between the indices is quantified based on the degree of membership within the range of 0.1-0.9, resulting in a fuzzy matrix. Undoubtedly, the matrix A represents a fuzzy complementary matrix.

$$A=\left[a_{ij}\right]_{n\times n},\quad a_{ij}+a_{ji}=1 \tag{2}$$

2) Once the fuzzy complementary matrix is obtained, it is transformed into a fuzzy consistent matrix. The consolidation of rows in the fuzzy complementary matrix A yields a resulting

matrix T that is converted into a fuzzy consistency matrix using a mathematical transformation formula.

$$t_{ij} = (t_i - t_j)/2n + 0.5 \tag{3}$$

3) The weight coefficient can be calculated by employing the fuzzy consensus matrix T in the analytic hierarchy process (AHP). By doing so, the weight of the fuzzy hierarchy, denoted as $\omega = (\omega_1, \omega_2, ..., \omega_n)$, can be determined.

$$\omega_i = \frac{2}{n(n-1)}(\sum_{j=1}^{n} t_{ij} - 1) \qquad i = 1,2,\cdots,n \tag{4}$$

3.3 Factor analysis

The index system mentioned earlier serves as a basis for standardizing and processing the collected sample data of power material suppliers. This standardized data is then used to form the initial set of index data.

1) By utilizing the covariance matrix, a common factor is extracted and its corresponding eigenvalue and eigenvector are determined. The principal factor is then derived based on the degree of variance contribution, typically requiring a cumulative contribution over 80% .

2) Estimation of factor scores and calculation of index scores was performed using both the maximum likelihood and least square methods.

$$\omega_j^2 = \frac{\beta_j}{\sum_{j=1}^{n} \beta_j} \tag{5}$$

3.4 Game theory combinatorial weighting

The combined weighting method of game theory enables the comprehensive integration of subjective perspectives and the internal distribution of objective data, thereby enhancing the scientific and rational determination of weights[12]. Specifically, this approach is utilized for optimizing both subjective and objective weights.

1) The evaluation indexes of suppliers are weighted using both the analytic hierarchy process (AHP) and factor analysis method, resulting in a comprehensive weight vector $\omega = \{\omega_1, \omega_2\}$. The subjective weight vector ω_1 is determined by AHP, while the objective weight vector ω_2 is obtained through factor analysis, and the comprehensive weight vector is：

$$\omega = \alpha_1 \omega_1^T + \alpha_2 \omega_2^T \tag{6}$$

2) In accordance with the principles of game aggregation modeling, the two linear combination coefficients (α_1 and α_2) in the aforementioned equation are optimized to achieve

the objective of minimizing deviation. Through this process, the optimal weight of ω can be determined.

$$f = \min\|\omega - \omega_k\|_2, \quad k = 1,2 \tag{7}$$

3) The optimal first-order derivative conditions in the form of a linear system, which is equivalent to Equation (6), can be derived based on the principles of matrix differentiation.

$$\begin{bmatrix} \omega_1\omega_1^T & \omega_1\omega_2^T \\ \omega_2\omega_1^T & \omega_2\omega_2^T \end{bmatrix} \begin{bmatrix} \alpha_1 \\ \alpha_2 \end{bmatrix} = \begin{bmatrix} \omega_1\omega_1^T \\ \omega_2\omega_2^T \end{bmatrix} \tag{8}$$

4) The above formula yields the optimal linear combination coefficient, which is then normalized to obtain the comprehensive weight ω using game theory-based combination weights.

$$\omega = \alpha_1^* \omega_1^T + \alpha_2^* \omega_2^T \tag{9}$$

Among them, $$\begin{cases} \alpha_1^* = \alpha_1 / (\alpha_1 + \alpha_2) \\ \alpha_2^* = \alpha_2 / (\alpha_1 + \alpha_2) \end{cases} \tag{10}$$

3.5 Comprehensive evaluation model

The comprehensive evaluation model is constructed, and based on it, the fuzzy comprehensive evaluation vector is computed. The highest membership principle $\max\{p_j\}$ is utilized to select the supplier's grade.

$$P = \omega \cdot R \tag{11}$$

4 THE EXAMPLE ANALYSIS

In order to verify the feasibility of the proposed method and the scientific nature, is an object with isolating switch, the power grid company provide 16 the operation of the power equipment supplier data and parameter record data to carry on the comprehensive analysis, voltage grade, supplier name, equipment type, date of commissioning, nature of the defect, defect parts, defective parts, defect description, classification based on content, defects, etc., A total of 76893 pieces of data, the data of some manufacturers are shown in the table 1.

Three indexes A, B and C were established, as shown in the table 1.

In this paper, five experts are selected to give their respective index layer weights according to the above steps, determine the prior weights of each expert, calculate subjective weights and objective weights respectively, and get the comprehensive weight by combining weights. The weights of comprehensive weights are 0.93 and 0.07 respectively.

Table 1: data statistics of some switches

Name of supplier	***A***	***B***	***C***
Random inspection of unqualified quantity	12	8	1
Times of untimely delivery	6	4	3
Number of defects	48	27	6
Number of familial defects	37	20	2
The fault number	533	67	17
Number of accidents	372	92	19
Equipment ownership	22718	6971	458
Number of voltage levels	5	3	2
Model number	159	65	13

Table 2: three-level indicators

Name of supplier	**Table Column Head**		
	A	***B***	***C***
Random inspection of unqualified quantity	<2	<5	≥5
Times of untimely delivery	<2	<5	≥5
Number of defects	<8	<30	≥30
Number of familial defects	<5	<20	≥20
The fault number	<10	<100	≥100
Number of accidents	<10	<100	≥100
Equipment ownership	≥10000	≥1000	<1000
Number of voltage levels	≥4	≥2	<2
Model number	≥100	≥20	<20

Based on the evaluation criteria outlined in Table 2 and the comprehensive weight values presented in Table 3, the ultimate evaluation outcome can be obtained, which is consistent with the real-world scenario. For instance, consider supplier k-04, whose equipment model number is 65 belonging to the second level. The membership degrees of A, B and C are 0.658, 0.296 and 0.046, respectively, and the supplier is evaluated as A level.

Table 4 shows the statistical table of rating results of all suppliers. Among them, there are 7 suppliers with grade A, 4 suppliers with grade B, and 5 suppliers with grade C. The evaluation results are shown in the table.

A comparison is made between the findings of the conventional fuzzy analytic hierarchy process and the suggested approach, and the corresponding results are exhibited in Table 5. The evaluation of K-06 and K-09 by the traditional method is A, and the evaluation of K-12 is B, while the evaluation of this method is B, B and C, respectively. The above observation reveals that the conventional technique tends to overlook the inherent connections within the data, leading to a disparity between the assessment outcomes and the practical scenario.

Table 3: final layer weight

Index layer	***Subjective weight***	***objective weight***	***comprehensive weight***
Random inspection of unqualified quantity	0.040	0.072	0.04224
Times of untimely delivery	0.064	0.049	0.06295
Number of defects	0.093	0.068	0.09125
Number of familial defects	0.083	0.134	0.08657
The fault number	0.054	0.147	0.06051
Number of accidents	0.103	0.093	0.1023
Equipment ownership	0.295	0.17	0.28625
Number of voltage levels	0.169	0.124	0.16585
Model number	0.098	0.143	0.10115

Table 4: supplier scoring statistical results table

Supplier	**A**	**B**	**C**	**Level**
K-01	0.743	0.230	0.027	A
K-02	0.563	0.380	0.057	A
K-03	0.682	0.315	0.003	A
K-04	0.658	0.296	0.046	A
K-05	0.719	0.225	0.056	A
K-06	0.331	0.661	0.008	B
K-07	0.709	0.225	0.066	A
K-08	0.231	0.661	0.108	B
K-09	0.743	0.230	0.027	A
K-10	0.353	0.597	0.050	B
K-11	0.261	0.738	0.001	B
K-12	0.045	0.294	0.661	C
K-13	0.012	0.348	0.640	C
K-14	0.029	0.294	0.677	C
K-15	0.713	0.264	0.023	A
K-16	0.035	0.204	0.761	C

Table 5: comparison results of supplier evaluation methods

Supplier	**Evaluation result**	
	The traditional AHP	**The Present Paper**
K-01	A	A
K-02	A	A
K-03	A	A
K-04	A	A
K-05	A	A
K-06	A	B
K-07	A	A
K-08	B	B
K-09	A	B
K-10	B	B
K-11	C	C
K-12	B	C
K-13	C	C
K-14	A	A

Supplier	Evaluation result	
	The traditional AHP	The Present Paper
K-15	C	C
K-16	C	C

5 CONCLUSION

This paper designs a comprehensive evaluation model for power equipment suppliers. Firstly, a reasonable supplier evaluation system was constructed by considering the supply quality, operation quality and use range of the equipment. Subsequently, the subjective weight and objective weight of the evaluation criteria were derived through AHP and factor analysis, respectively. The combined weighting scheme based on game theory was then employed to compute the comprehensive weight of each criterion. Finally, a comprehensive evaluation was conducted to rank the suppliers. The effectiveness and feasibility of the proposed model were confirmed via illustrative instances.

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