Risk assessment of equipment maintenance cost supervision based on game theory cloud model

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Abstract. Equipment maintenance costs, as an important fund supporting equipment support, strengthening their risk management is of great significance for units to grasp the current situation of fund management and formulate corresponding measures. In response to the deficiencies in the theoretical and methodological research on risk management of equipment maintenance fee supervision, this article starts from the perspective of unit supervision and first uses the level holographic modeling method to identify risk factors in equipment maintenance fee supervision; Secondly, using game theory methods to find the optimal combination of indicator weights between subjective and objective weighting methods; Introducing the cloud model evaluation method again, using the three numerical features of expectation, entropy, and super entropy to describe and quantify the uncertainty of qualitative concepts, and presenting the results in a cloud map format; Finally, the model is applied to an example and compared and analyzed with the fuzzy comprehensive evaluation method. The case analysis shows that using this model to evaluate the supervision of unit equipment maintenance costs is feasible and the evaluation results are more accurate and intuitive than the fuzzy comprehensive evaluation method.

Keywords: Hierarchical holographic modeling; Game theory; Cloud model; Supervision of equipment maintenance costs; Risk assessment.

1 Introduction

With the deepening of national defense and military system reform, the regulatory requirements for military spending are also increasing. However, from recent inspections and audit reports, it can be seen that there are still many problems in the use of equipment maintenance fees in some units, such as false reporting, illegal cash out, duplicate expenses, and low execution rates, which pose significant risks to the management of equipment maintenance fee use. Therefore, a scientific and efficient risk assessment of equipment maintenance cost supervision is of great significance for military units to grasp the current situation of equipment maintenance cost management and use, and formulate targeted measures.

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Currently, there are many studies on risk issues, and mature theories and practical experiences have been formed from risk generation mechanisms, risk identification, risk analysis and evaluation, to risk response. Li Wenbo et al. [1]conducted quantitative analysis on the driving behavior of drivers under different emotions, constructed a mapping relationship between emotions and driving behavior risks, and further analyzed its influencing mechanism; Zhang Wenjun et al. [2] applied the HHM-RFRM theory to analyze ship navigation risks and accurately identified key risk factors in ship navigation; Yang Liu et al. [3] combined the grey relational analysis method and TOPSIS method to construct a risk analysis and evaluation model for online public opinion in higher education institutions. With the deepening of research, risk management has gradually developed from the engineering field to the economic, environmental and other fields, and risk management has also been gradually introduced into military mission activities[4-5]. However, from the current perspective, the risk management of military equipment maintenance cost supervision mainly relies on regulatory constraints and related financial inspection activities such as inspections and audits [6], and few risk assessment studies are limited to the risk management of equipment maintenance costs for individual projects [7], lacking research at the unit level. The relevant person in charge can only understand the risk management of individual equipment maintenance project funds, but cannot fully grasp the supervision of equipment maintenance costs in their unit, such as whether there are risks in fund allocation, system implementation, and other aspects. In addition, there are many factors involved in the supervision of equipment maintenance costs, and qualitative indicators often rely on subjective evaluations by experts, reflecting significant uncertainty. This uncertainty has not been well addressed in previous research.

The cloud model is an analytical method proposed by Professor Li Deyi to study uncertainty problems [8]. This model is based on fuzzy mathematics and random functions, reflecting the mathematical relationships between variables, and is used to effectively transform qualitative expressions into quantitative data [9]. It has been widely used in comprehensive evaluation in engineering, medicine, and other fields.

Based on this, this article proposes a risk assessment method for equipment maintenance cost supervision based on game theory cloud model. The G1 method and entropy method are used to determine the weights of each indicator in combination with game theory theory. The cloud model is used to reflect the fuzziness and uncertainty in the evaluation, making the evaluation results more accurate and intuitive.

2 Risk Indicator System for Equipment Maintenance Cost Supervision

In order to adapt to the current situation of equipment maintenance supervision, when analyzing the risk factors of equipment maintenance cost supervision, this paper abandons the narrow idea of considering the risk problem only from the financial department, but starts from the overall perspective of the unit, and considers not only the risk factors at the financial level, but also the risk factors at the specific business level. The two are combined to analyze the risk problems existing in the supervision of equipment maintenance cost of military units. In terms of the specific methods of index system construction, the hierarchical holographic modeling (HHM) method [10] is adopted to construct the HHM sub-framework from two dimensions of project life cycle - risk factors and fund management process - risk factors, comprehensively analyze the risk factors existing in the supervision of equipment maintenance costs of military units, and then sort out and summarize these factors according to the fund operation process. Finally, an index system consisting of 5 first-level indicators (A1-A5), 14 second-level indicators (B1-B15) and 35 third-level indicators (C1-C35) was constructed.

3 Construction of Game Theory Cloud Model

The basic idea of game theory is to find an equilibrium point for game participants to resolve conflicts and maximize the interests of all parties involved. Introducing it into the indicator comprehensive weighting model can find the optimal solution among various weighting methods, with the minimum deviation between the optimal solution and each weight. This article places emphasis on the subjective weights determined by the G1 method and the objective weights determined by the entropy method for both parties in the game, in order to find the optimal combination weights that enable both parties to reach an equilibrium point.

3.1 G1 Method for Calculating Subjective Weights

The G1 method is an improved method for determining subjective weights based on the Analytic Hierarchy Process. This method is relatively simple to calculate and does not require complex consistency checks. When facing decision analysis with multiple evaluation indicators, it can better reflect the order relationship between indicators. The specific steps are as follows:

The first step is to determine the order of evaluation indicators. According to the importance of the indicators, evaluators rank them based on their level of importance.

The second step is to calculate the relative importance between two adjacent indicators.

$$r_k = \frac{w_{k-1}^*}{w_k^*} \tag{1}$$

In the formula, w_{k-1}^* and w_k^* are the weight coefficients corresponding to the two adjacent indicators after sorting.

Step three, calculate the weight w_n of a single indicator.

$$w_n = [1 + \sum_{k=2}^{n} (\prod_{i=k}^{n} r_k)]^{-1} \tag{2}$$

The weights of other indicators can be calculated step by step:

$$w'_{k-1} = r_k \times w'_k \tag{3}$$

3.2 Objective Weight Determination based on Entropy Method

The entropy method is a commonly used objective weighting method that is easy to operate and can determine the weight proportion based on the information contained in the evaluation indicators, without being affected by subjective factors of decision-makers. The steps for determining objective weights using the entropy method are as follows:

Step 1: Invite experts to use the traditional nine scale method to score the importance of indicators at each level and construct a judgment matrix;

$$Z = \left[z_{ij}\right]_{n\times n} \tag{4}$$

Step 2: Construct the normalized judgment matrix A.

$$A = \left[a_{ij}\right]_{n\times n} \tag{5}$$

$$a_{ij} = \frac{z_{ij}}{\sum_{i=1}^{n} z_{ij}} \quad (j = 1, 2, \ldots, n) \tag{6}$$

Step 3: Calculate the information entropy Ei of each indicator.

$$E_i = -\frac{1}{\ln n}\left(\sum_{j=1}^{n} p_{ij} \ln p_{ij}\right) \tag{7}$$

Among them, $p_{ij} = \frac{a_{ij}}{\sum_{j=1}^{n} a_{ij}}$

Step 4: Calculate objective weights.

$$w'' = \frac{1-E_i}{\sum_{i=1}^{n}(1-E_i)} \tag{8}$$

3.3 Combination Weighting based on Game Theory

The first step is to construct a linear combination.

$$w = aw' + bw'' \tag{9}$$

Among them, a and b are combination coefficients, a +b =1, a⩾0, b⩾0

The second step is to optimize the combination so that the optimal solution w* has the minimum deviation from w 'and w ", respectively, to achieve the objective function:

$$\min\left(\left\|w^* - w'\right\|_2 + \left\|w^* - w''\right\|_2\right) \tag{10}$$

$$w^* = a^* w' + b^* w'' \tag{11}$$

Step three, based on the properties, the optimal first derivative of equation (11) satisfies the following condition:

$$aw'(w')^T + bw''(w'')^T = w'(w')^T \tag{12}$$

$$aw''(w')^T + bw''(w'')^T = w''(w'')^T \tag{13}$$

Find a, b;

Step four, normalize a and b and calculate the combined weight.

3.4 Cloud Model Method

Cloud model definition: Assuming U={x} is a quantitative domain, A is a qualitative concept expression in domain U, and the membership degree μ (x) of A to any x is a random number with a stable tendency, where μ (x): U → [0,1], ∀ x ∈ U, x → μ (x), then x is called a cloud droplet on domain U, and the distribution of x on U forms a cloud.

The cloud model mainly expresses the overall characteristics of qualitative concepts using three numerical features: expected Ex, entropy E-n, and super entropy He. Among them, it is expected that the numerical features that best reflect qualitative concepts, represented in the cloud map, are the distribution center points of the domain U; Entropy E2 is an expression of uncertainty in qualitative concepts, directly reflecting the range of values for cloud droplets; Superentropy He is a measure of uncertainty in entropy En, which reflects the degree of aggregation of qualitative conceptual uncertainty, manifested as the thickness of cloud layers.

Cloud model construction steps:

The first step is to determine the standard cloud.

Based on the current situation of equipment maintenance cost management and expert opinions, the risk assessment level of equipment maintenance cost supervision is divided into five levels, namely low risk, low risk, medium risk, high risk, and high risk. The formula for calculating the digital features of standard cloud is as follows:

$$\begin{cases} E_{x-2} = V_{min} \\ E_{x-1} = E_{x0} - 0.328(E_{x0} - V_{min}) \\ E_{x0} = \frac{V_{min}+V_{max}}{2} \\ E_{x+1} = E_{x0} + 0.328(V_{max} - E_{x0}) \\ E_{x+2} = V_{max} \end{cases} \tag{14}$$

$$\begin{cases} E_{n-1} = E_{n+1} = \frac{0.328V_{max}-V_{min}}{6} \\ E_{n0} = 0.618E_{n-1} \\ E_{n-2} = E_{n+2} = \frac{E_{n-1}}{0.618} \end{cases} \tag{15}$$

$$\begin{cases} H_{e-1} = H_{e+1} = \frac{H_{e0}}{0.618} \\ H_{e-2} = H_{e+2} = \frac{H_{e-1}}{0.618} \end{cases} \tag{16}$$

In the equation, E (x-2), E (x-1), E (x0), E (x+1), E (x+2) are the expected values of the five standard clouds from left to right, and entropy and hyperentropic are the same. Vmin is the minimum value of the comment set, Vmax is the maximum value of the comment set, and He is a constant. The values are determined based on the actual situation of the research object, and this article takes 0.5.

Step 2: Calculate the evaluation cloud

Firstly, using a reverse cloud generator to convert expert ratings of indicators into numerical features of the cloud model, an indicator evaluation cloud is obtained. The specific calculation formula is as follows:

$$\begin{cases} E_x = \frac{1}{n}\sum_{i=1}^{n} x_i \\ E_n = \sqrt{\frac{\pi}{2}} \times \frac{1}{n}\sum_{i=1}^{n}|x_i - E_x| \\ H_e = \sqrt{\left|S^2 - {E_n}^2\right|} \end{cases} \tag{17}$$

Among them, S^2 is the variance of expert ratings for this indicator.

Secondly, based on the numerical characteristics of the cloud evaluated by the indicators, combined with the indicator weights obtained by comprehensive weighting, the numerical characteristics of the comprehensive evaluation cloud are calculated, as shown in equation (15).

$$\begin{cases} E_x = \frac{w_1 E_{x1} + w_2 E_{x2} + \cdots w_n E_{xn}}{\sum_{i=1}^{n} w_i} \\ E_n = \frac{{w_1}^2 E_{n1} + {w_2}^2 E_{n2} + \cdots {w_n}^2 E_{nn}}{\sum_{i=1}^{n} {w_i}^2} \\ H_e = \frac{{w_1}^2 H_{e1} + {w_2}^2 H_{e2} + \cdots {w_n}^2 H_{en}}{\sum_{i=1}^{n} {w_i}^2} \end{cases} \tag{18}$$

Step three, calculate similarity

In order to make more accurate judgments on the evaluation results, it is also necessary to calculate the similarity between the evaluation cloud and each standard cloud to determine the final evaluation level. This article uses the principle of normal cloud similarity to calculate the similarity between clouds. There are two evaluation clouds, V1 (E1, E1, H1) and V2 (E2, N2, H2), whose similarity V is calculated using the formula:

$$V = (V_1, V_2) = \frac{1}{2} + \frac{1}{2\mu} - \beta \tag{19}$$

$$\mu = \int_{-\infty}^{\beta} \frac{1}{\sqrt{2\pi}} e^{-\frac{t^2}{2}} dt \tag{20}$$

$$\beta = \frac{|E_{x2} - E_{x1}|}{\sqrt{{E_{n1}}^2 + {H_{e1}}^2} + \sqrt{{E_{n2}}^2 + {H_{e2}}^2}} \tag{21}$$

4 Example Analysis

To verify the feasibility of the model, this article takes the management and usage of equipment maintenance costs in a certain year of a naval unit as an example to evaluate the risk level of equipment maintenance cost supervision in that unit. By reviewing relevant materials related to the audit, inspection, and financial inspection of the unit, and conducting on-site inspections of the management and use of equipment maintenance costs in the unit, the necessary information for evaluation is obtained.

4.1 Weight of Risk Indicators for Equipment Maintenance Cost Supervision Based on Game Theory

Based on the G1 method, use equations (1) - (3) to calculate the subjective weights of the indicators; Based on the entropy method, use equations (4) - (8) to calculate the objective weights of the indicators; Based on game theory, use equations (9) - (12) to calculate the comprehensive weight of the indicators. The results are shown in table 1.

Table 1. Weights of regulatory risk indicators for equipment maintenance costs (partial)

First level indicator	Subjective weight	Objective weight	Comprehensive weight	Secondary indicators	Subjective weight	Objective weight	Comprehensive weight	Third level indicators	Subjective weight	Objective weight	Comprehensive weight
A1	0.075	0.102	0.096	B1	0.0422	0.0463	0.0526	C1	0.0357	0.0242	0.0284
				B2	0.0335	0.0558	0.0438	C3	0.0177	0.0282	0.0202
A2	0.302	0.283	0.297	B3	0.131	0.1009	0.1209	C5	0.0259	0.0399	0.0271
				B4	0.0481	0.0521	0.0504	C9	0.0302	0.0317	0.0311
				B5	0.0742	0.0801	0.0765	C11	0.0452	0.0395	0.0412
				B6	0.0495	0.0506	0.05	C13	0.0242	0.026	0.0242
A3	0.169	0.148	0.154	B7	0.1051	0.1001	0.1052	C15	0.0212	0.0229	0.022
				B8	0.0641	0.0481	0.0489	C19	0.0303	0.0212	0.0245
A4	0.274	0.300	0.285	B9	0.0764	0.0837	0.08	C21	0.0234	0.0256	0.0242
				B10	0.0832	0.0956	0.0913	C24	0.0251	0.0299	0.0281
				B11	0.0465	0.0625	0.0547	C27	0.0162	0.0245	0.0203
				B12	0.0681	0.0583	0.0594	C29	0.0199	0.0256	0.0212
A5	0.178	0.165	0.166	B13	0.0611	0.0582	0.0599	C31	0.0318	0.0295	0.0309
				B14	0.117	0.1077	0.1064	C33	0.0286	0.0352	0.0299

4.2 Equipment Maintenance Cost Supervision Risk Assessment Standard Cloud

For ease of calculation, the range of values for the risk assessment rating of equipment maintenance fee supervision is specified as [0,100]. Among them, [80,100) represents high risk, [60,80) represents high risk, [40,60) represents medium risk, [20,40) represents low risk, and [0,20) represents low risk. According to equations (13) - (15), the standard cloud digital characteristics of the five levels of equipment maintenance cost supervision and evaluation are calculated in table 2.

Table 2. The digital characteristics of standard clouds

Evaluation level	Ex	En	He
high-risk	100	10.303	1.309
Higher risk	69.1	6.367	0.809
Medium risk	50	3.394	0.5
Lower risk	30.9	6.367	0.809
Low risk	0	10.303	1.309

Input the above standard cloud digital features as parameters into MATLAB software to generate five standard cloud maps, from left to right, as low-risk, low-risk, medium risk, high-risk, and high-risk standard cloud maps, as shown in Figure 1.

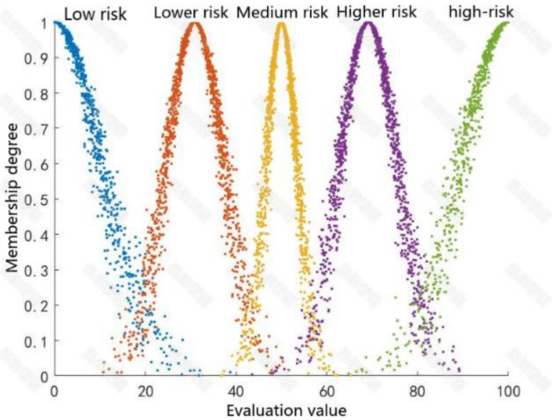

Fig. 1. Standard cloud map

4.3 Equipment Maintenance Cost Supervision Index Evaluation Cloud

Based on the expert scoring results and the comprehensive weight of indicators, equations (16) and (17) were used to calculate the cloud digital characteristics of each level of indicator evaluation. The results are shown in Table 3:

Table 3. Indicator numerical characteristics (partial)

First level indicator	*Ex*	*En*	*He*	Secondary indicators	*Ex*	*En*	*He*	Third level indicators	*Ex*	*En*	*He*
A1	23.1353	2.9632	1.4923	B1	24.7574	3.0979	1.5332	C1	16.2	3.3087	1.3237
				B2	21.1872	2.7691	1.4334	C3	17.2	2.3061	0.7862
A2	31.2316	3.6211	1.5597	B3	35.2299	3.6721	1.8766	C5	22.6	2.1056	0.9309
				B4	20.6175	3.6374	1.1479	C9	24.6	3.6095	1.1085
				B5	44.3867	4.0831	1.4247	C11	53.8	5.3141	1.5687
				B6	15.2584	2.2251	0.4411	C13	16.6	1.9050	0.4133
A3	29.5597	3.3166	0.8039	B7	35.6508	3.3616	0.8264	C15	28	2.5066	0.8850

				B8	25.5836	3.1082	0.6997	C19	17.6	3.1082	0.6009
A4	26.1788	2.4217	0.6949	B9	19.0550	1.9985	0.5275	C21	15.4	2.9077	0.3933
				B10	31.3452	2.6571	0.4029	C24	33.2	2.8074	0.5642
				B11	29.5857	2.2994	0.5756	C27	23.8	1.7045	0.8914
				B12	19.7589	2.7366	1.7896	C29	15	2.5066	2.0535
A5	35.8192	2.9662	1.1797	B13	23.6474	2.4572	0.5625	C31	31.2	3.2085	0.3072
				B14	46.6440	3.1275	1.3753	C33	33.4	4.1109	2.3240

Input the numerical characteristic parameters of the above evaluation indicators into MATLAB software to generate a comparison chart between the evaluation cloud and the standard cloud for each indicator, as shown in Figure 2-4. From the figure, it can be clearly seen that the position relationship between the evaluation cloud and the standard cloud for each indicator. For example, the evaluation cloud for plan management indicator A1 is located between the low-risk standard cloud and the lower risk standard cloud, closer to the lower risk standard cloud.

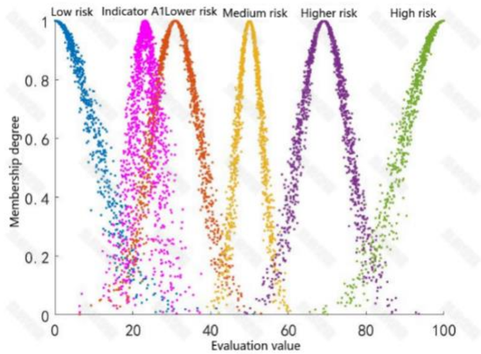

Fig. 2. Comparison between Budget Execution Indicator Cloud and Standard Cloud

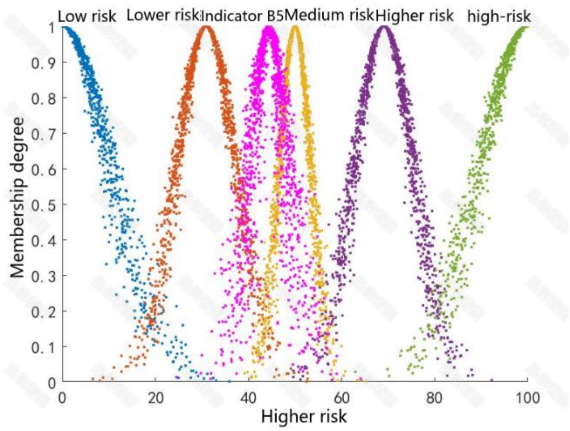

Fig. 3. Comparison between Budget Execution Indicator Cloud and Standard Cloud

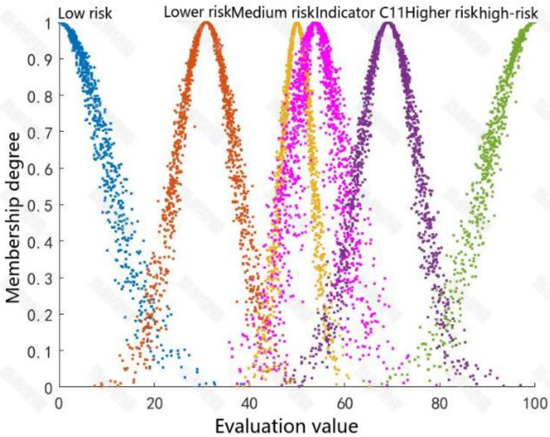

Fig. 4. Comparison between expenditure range indicator cloud and standard cloud

Although the above comparison cloud map can intuitively reflect the location of the evaluation index risk, it is easy to make misjudgments based solely on visual observation. To more accurately assess the risk level of each indicator, it is necessary to calculate the similarity between the indicator evaluation cloud and the five standard clouds according to equation (18-20), and determine the evaluation level based on the principle of maximum similarity, as shown in Table 4.

Table 4. The similarity between primary indicators and standard clouds

Risk level	Low risk	Lower ris	Medium risk	Higher risk	high-ris
A1	0.0696	**0.3475**	0.0001	0.0000	0.0000
A2	0.0221	**0.9623**	0.0082	0.0002	0.0000
A3	0.0243	**0.8479**	0.0021	0.0000	0.0000
A4	0.0321	**0.5115**	0.0000	0.0000	0.0000
A5	0.0063	**0.5231**	0.0243	0.0004	0.0000

Due to space limitations, only the final evaluation levels for secondary and tertiary indicators are listed in Table 5.

Table 5. The final evaluation level of secondary and tertiary indicators

Risk level	evaluating indicator
high-risk	
Higher risk	C35
Medium risk	B5, B14, C8, C11, C17
Lower risk	A1, A2, A3, A4, A5, B1, B2, B3, B4, B7, B8, B9, B10, B11, B12, B13, C2, C4, C5, C6, C7, C9, C12, C15, C16, C18, C20, C22, C24, C25, C26, C27, C28, C30, C31, C33, C34
Low risk	B6, C1, C3, C10, C13, C14, C19, C21, C23, C29, C32

4.4 Comprehensive evaluation cloud for equipment maintenance fee supervision risks

According to Table 3, calculate the cloud digital characteristics of the comprehensive evaluation of equipment maintenance cost supervision risk for this unit: (29.7674, 3.0912, 1.1343). Generate a comparison cloud map between the comprehensive evaluation cloud and the standard cloud using MATLAB software, as shown in Figure 5.

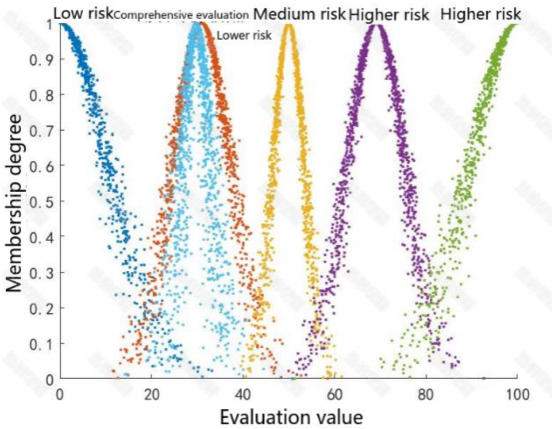

Fig. 5. Comprehensive evaluation cloud map

Similarly, the similarity between the comprehensive evaluation cloud and the standard cloud can be calculated, as shown in Table 6.

Table 6. Comprehensive evaluation of cloud and standard cloud similarity

Grade	Low risk	Lower risk	Medium risk	Higher risk	High risk
Similarity	0.0223	**0.8686**	0.0020	0	0

From Figure 5, it can be seen that the risk assessment cloud map of equipment maintenance cost supervision in this unit is located between low risk and medium risk, closer to low risk; According to Table 6, the comprehensive evaluation cloud map has the highest similarity with the lower risk standard cloud map, which is 0.8686. According to the principle of maximum similarity, the risk assessment level of equipment maintenance cost supervision in this unit is relatively low.

5 Conclusion

In response to the shortcomings in the current research on risk management of equipment maintenance fee supervision, this article starts from the perspective of unit equipment maintenance fee supervision, establishes an evaluation index system using the HHM method, and constructs an equipment maintenance fee supervision risk evaluation model based on game theory cloud model. Using game theory to determine the comprehensive weights of indicators, and by comparing the similarity between the evaluation cloud and the standard cloud of each indicator, a comprehensive evaluation of the regulatory risks of each indicator and equipment maintenance costs can be achieved. This method not only combines the advantages of subjective and objective weighting, but also effectively solves the problem of effective conversion between quantitative data and qualitative tables in the risk assessment of equipment maintenance cost supervision. The evaluation results are presented in the form of cloud maps, making the evaluation results more accurate and intuitive. The evaluation model was applied to the risk assessment of equipment maintenance cost supervision in a certain military unit, and compared and analyzed with the evaluation results of the fuzzy comprehensive evaluation method. It was found that the equipment maintenance cost supervision risk assessment model based on game theory cloud model was superior to the fuzzy comprehensive evaluation method in processing qualitative data, and had good feasibility and applicability.

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