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RESEARCH **Open Access**

Evaluation of cabin energy consumption based on combination weighting and grey fuzzy comprehensive model

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Abstract

Painting is the largest energy consumption unit in ship repair enterprises, with annual electrical energy costs amounting to millions of dollars. The energy-saving model of painting business based on artificial intelligence, Internet of Vehicles (IoV) and big data technologies has become a current research hot spot. This paper takes a cargo ship of Youlian Shipyard as an example to improve the quality of special coating construction, reduce cost and increase efficiency. In the process of special coating construction, a comprehensive analysis of equipment usage in different compartments is carried out, and a compartment energy consumption analysis model based on combined weighting and Gray Fuzzy Comprehensive Evaluation is proposed. The model uses factors such as energy consumption, hours, and number of devices as evaluation indicators. Based on the fuzzy comprehensive evaluation, the gray correlation coefficients and comprehensive weights were weighted to obtain the final comprehensive evaluation results of each planning scheme, and then compare them to determine the optimal scheme. The results show that the grey fuzzy comprehensive evaluation model with combined weighting has better results than other models, and the evaluation results are scientific and reasonable. It has certain application value in multi-objective scheme optimization.

Keywords: Special painting, Cabin energy consumption, Combined weigh, Fuzzy comprehension evaluation method

1 Introduction

1.1 Research background

Due to the special nature of the cargo, ships carrying chemicals need to be regularly maintained with special coatings. The construction of these coatings needs to be carried out in special stages, special environment, special technology and process conditions to ensure the quality. Because the special coating process used in ship maintenance is similar to vehicle maintenance and road maintenance in Internet of Vehicles (IoV), optimizing and improving the special coating technology in ship maintenance is of great significance to the development of shipping industry and vehicle traffic in IoV. As an important direction of modern operation management and cost control of shipping enterprises, the management and control of ship repair and maintenance process had been paid more and more attention by enterprise managers. Good ship repair and maintenance work can not only ensure the safety of ship navigation and prolong the service life of ships, but also by shortening maintenance period and prolonging the repair interval of the ship to achieve the purpose of improving the operation rate of the ship, bringing more benefits to the enterprise. At the same time, strengthening control of ship maintenance and repair process can greatly reduce the operating cost of the ship and improve the economic benefits of the enterprise.

Shipping enterprises must strengthen ship maintenance management and carry out scientific maintenance of ships. It is in order to ensure the safety of ship navigation improve ship operation rate, improve ship operation rate, reduce ship operating costs and meet the requirements of domestic. Management, reasonable selection of ship maintenance location, arrangement of maintenance cycle, control of maintenance cost and capital investment, shipping enterprises can improve ship profitability, control and optimize ship maintenance process. The current research on ship maintenance was mostly focused on special coating technology and cost control, and there was relatively little research on cost control from the energy consumption control of ship equipment. Based on the above situation, taking a cargo ship of Youlian Shipyard as an example, this paper comprehensively evaluated the energy consumption of 22 compartments under the same special coating process by using four common evaluation methods, namely Analytic Hierarchy Process (AHP), Entropy Weight Method, Grey Relational Analysis and Fuzzy Comprehension Evaluation Method, and discussed the results of compartment energy consumption under different evaluation methods and weighting methods. The most reasonable scheme of cabin energy consumption is selected, and the use of equipment in these cabins is taken as the benchmark, which can reduce energy consumption as a whole.

1.2 Related work

At present, the research on ship special coating mainly focused on process technology, focusing on steel surface treatment, sandblasting abrasive selection, sandblasting process parameter optimization and paint spraying process optimization [1–3], exploring the temperature and humidity of special coating construction and other environmental conditions, analyzing the influence of the type, performance, and construction sequence of the coating on the project effect, studying the use of various methods to analyze the maintenance level of the ship [4–6], the cost of ship repair and maintenance, and determine the process of each stage of the special coating construction. However, few studies have paid attention to the energy consumption control of special coating projects.

Donghun Lee et al. invented an automatic sandblasting robot for the complex structure of coating construction cabin, the narrow space that is inconvenient for construction personnel to work, and the harsh sandblasting construction environment that caused great harm to the human body, which can effectively improve the coating cabin [7]. Celebi et al. studied the waste paint and paint containers generated during the coating construction process, and established a solvent recovery system to reduce VOC emissions, thereby improving the coating construction environment and avoiding pollution of the surrounding environment [8]. Mokashi et al. conducted a detailed study on the application of reliability-centered repair and maintenance on ships and the specific problems that may be encountered in the process [9, 10].

Effective control of maintenance cost is a problem that should be paid more attention from the perspective of the long-term development of ship repair shop. Cicek and Celik combined new ship technology with operation technology based on fault analysis mode, so as to reduce the probability of crankcase explosion, and put forward the concept of active maintenance to improve ship reliability [11]. Certa and Galante et al. suggested that the core of the maintenance management process was cost control. Cost control included not only the direct repair costs invested in maintenance operations, materials, spare parts, and wages, but also the costs associated with downtime, periodic overhauls, and preventive maintenance, and cost control also weighs the economic losses caused by downtime [12]. Based on the idea of modular design and production, Zhong et al. decomposed ship repair and maintenance into sub-modules with relatively independent functions, determined the repair scope and repaired cost standards of different sub-modules, identified cost risks, and applied Fuzzy Hierarchy Process to evaluates and analyzes the risk factors that affect the cost risk and adjusted and reduce the cost risk [13]. Ship maintenance needs to use a lot of resources, and the resource factor is an important reason for the long time and easy delay of ship maintenance projects. Liu et al. established a risk assessment model to effectively simulate the interaction and change process of various risk factors [14].

Multi-index comprehensive evaluation method is a commonly used method in energy consumption evaluation, such as AHP [15–18], Entropy Weight Method [19], Grey Relational Analysis [20], Fuzzy Comprehension Evaluation Method [21], Artificial Neural Network [22] et al. Although the above methods have effectively promoted the development of the energy consumption evaluation problem to a certain extent, there were also some limitations. It was mainly reflected in the following aspects: First, there were relatively few studies on the evaluation of ship cabin energy consumption; Second, the evaluation method was relatively single, mostly using a single subjective or objective weighting method, which could not make full use of the known information of the index. In order to reduce the bias caused by single weighting in the evaluation scheme model and improve the accuracy of multi-attribute decision ranking, this paper adopts a gray fuzzy comprehensive evaluation model that can effectively solve the combination of multi-objective weighting and apply it to the multi-objective scheme selection of ship cabin energy consumption based on the summary of existing research methods, taking into account the subjective preference of decision makers and reflecting objective facts. This paper not only considers the subjective preferences of decision makers, but also reflects the objective facts, adopts a gray fuzzy comprehensive evaluation model that can effectively solve the combination weighting between multiple objectives, and applies it to the cabin energy consumption scheme preferred.

2 Method

2.1 Analytic hierarchy process (AHP)

Analytic Hierarchy Process can effectively quantify the qualitative problem, and use the maximum eigenvalue and feature vector of judgment matrix to calculate the weight value of the index or factor of a layer relative to each index or factor of the upper layer. Where the judgment matrix $B = (b_{ij})_{m \times m}$ is constructed using the Arabic numerals 1 to 9 and their reciprocals as scales.

The weight is calculated by the feature vector, and the calculation equation is:

$$BW = \lambda_{\max} W \tag{1}$$

where $\lambda_{\max}$ is the largest eigenvalue of the judgment matrix, B is hierarchical judgment matrix, W is weight vector.

The weight value of each level index relative to the previous level index or factor can be obtained by normalizing the weight vector. When establishing a judgment matrix, due to the complexity and diversity of objective things and the limitations of people's understanding of objective things, the maximum eigenvalue usually obtained is not unique. In order to avoid the deviation of the weight vector and ensure that the judgment matrix meets the requirements, it is necessary to perform a consistency check on the judgment matrix. Two consistency indexes are introduced: the measure judgment matrix deviation consistency index CI and the average random consistency index RI. Where the average random consistency index RI can be obtained by looking up the table.

CI is an indicator to measure the deviation consistency of the judgment matrix:

$$CI = \frac{\lambda_{\max} - m}{m - 1} \tag{2}$$

$$CR = \frac{CI}{RI} \tag{3}$$

CR is the proportion of consistency, which is the ratio of CI to RI. If $CR < 0.1$, the judgment matrix consistency check is qualified; Otherwise, the scale value of the judgment matrix needs to be corrected appropriately until the matrix consistency check meets the requirements.

2.2 Entropy weight method (EWM)

Entropy Weighting Method is used to determine the weights, which means that the weights of the indicators are determined based on the objective information contained in the data itself. Suppose the decision matrix is $Y = \left\{y_{ij}\right\}_{m \times n}$. In the equation, y_{ij} is the evaluation value of the jth index of the ith evaluation scheme. Then the entropy value of the jth index is calculated by the following equation:

$$e_j = -\frac{\sum_{i=1}^{m} p_{ij} \ln p_{ij}}{\ln m}. \tag{4}$$

$$p_{ij} = -\frac{y_{ij}}{\sum_{i=1}^{m} y_{ij}}. \tag{5}$$

where p_{ij} is the feature ratio of the jth index of the ith evaluation scheme, and the entropy weight of the jth index can be calculated by the following equation:

$$\beta_j = -\frac{1 - e_j}{\sum_{j=1}^{n} (1 - e_k)} \tag{6}$$

2.3 Comprehensive weight determination

The obtained subjective weight and objective weight are respectively weighted by Equal Weight method, Multiplication Weight Method, Difference Coefficient Method and Game theory to calculate the comprehensive weight W. Difference Coefficient Method (DCM) is shown in Eq. (7).

$$W = a\alpha + b\beta \tag{7}$$

where a, b are the undetermined coefficients of subjective and objective weighting; a + b = 1, which represents the importance of the evaluation model to the subjective and objective influences. Multiplicative Weighting (MW) is shown in Eq. (8).

$$W_j = \frac{\sqrt{\alpha_j \beta_j}}{\sum_{j=1}^{n} \sqrt{\alpha_j \beta_j}} \tag{8}$$

where α_j is the weight calculated by the analytic hierarchy process, β_j is the weight calculated by the entropy method.

2.4 Game theory combinatorial empowerment (GTCE)

Combining the game theory idea with the AHP and Entropy method for optimization, the game theory combination weighting is to take the conflict between different weights as the coordination goal, compare and coordinate, so as to find the optimal result that takes both subjective and objective weights into consideration. The weighting steps for merging are as follows:

$$W = \sum_{i=1}^{m} \alpha_i w_i^T \tag{9}$$

$$\begin{pmatrix} w_1 \cdot w_1^T & \cdots & w_1 \cdot w_m^T \\ \cdots & \cdots & \cdots \\ w_m \cdot w_1^T & \cdots & w_m \cdot w_m^T \end{pmatrix} \begin{pmatrix} \alpha_1 \\ \alpha_2 \\ \alpha_3 \end{pmatrix} = \begin{pmatrix} w_1 \cdot w_1^T \\ \cdots \\ w_m \cdot w_m^T \end{pmatrix} \tag{10}$$

where w_i is the weight vector determined by the ith method, $w_i = \{w_{i1}, w_{i2}, \ldots, w_{im}\} (i = 1, 2, \ldots, m)$, α_i is the linear combination coefficient, ($\alpha_i > 0$).

Since α_i and W in Eq. (9) are assumed values, the sum of α_i calculated by Eq. (10) may not be 1. According to the idea of game theory, the goal is to minimize the dispersion to find the similarities and differences of different weights. The values need to be normalized to obtain α_i^*, and the weight W^* obtained by α_i^* is:

$$W_3 = \sum_{i=1}^{n} \alpha_i^* w_i^T \tag{11}$$

2.5 Grey relational analysis (GRA)

Grey relational analysis is a method to quantitatively describe and compare the development and change of the system. The basic idea is to judge whether they are closely connected by constructing the reference data column and the comparison data column, and calculating the geometric similarity of the two. It reflects the degree of association between variables. The specific calculation steps are as follows:

2.5.1 Construct a reference sequence

Suppose the evaluation value of the index j of the kth group of data is $h_j(k)$, and its value is calculated according to the following equation:

$$h_j(0) = \begin{cases} \min\limits_{1\le k\le n} \{h_j(k)\}, j \in \text{cost index} \\ \max\limits_{1\le k\le n} \{h_j(k)\}, j \in \text{benefit index}. \\ h(0), \text{j} \in \text{moderate indicator} \end{cases} \tag{12}$$

The final constructed optimal index set is:$H(0) = [h_1(0), h_2(0), ..., h_n(0)]$. Where $h_j(0)$ represents the optimal value of the jth index, $j = 1, 2, ..., n$.

2.5.2 Construct a comparison sequence

Since the dimensions of different indicators will be different and cannot be directly calculated, the indicators should be normalized, and the normalized indicator value $h_j^{'}$ is obtained by using the efficacy coefficient method. The calculation equation is as follows:

$$h_j^{'}(k) = c + \frac{h_j(k) - \min\{h_j(1), \cdots, h_j(k)\}}{\max\{h_j(1), \cdots, h_j(k)\} - \min\{h_j(1), \cdots, h_j(k)\}} \times d \tag{13}$$

where $k = 1, 2, ..., m; j = 1, 2, ..., n$ and c, d are constants DETERMINED by the requirements of the data gap, c represents the amount of translation, and d represents the amount of zoom; This paper takes c = 0.85, d = 0.15.

2.5.3 Calculate the gray correlation coefficient matrix

After normalizing the indicators, the optimal indicator set $H^{'}(0) = [h_1^{'}(0), h_2^{'}(0), ..., h_n^{'}(0)]$ is used as the reference sequence. According to the grey relational analysis, the grey relational coefficient δ_{kj} of the jth index of the kth scheme is calculated respectively. The equation is as follows:

$$\delta_{kj} = \frac{\min_k \min_j \left| h_j^{'}(0) - h_j^{'}(k) \right| + \rho \max_k \max_j \left| h_j^{'}(0) - h_j^{'}(k) \right|}{\left| h_j^{'}(0) - h_j^{'}(k) \right| + \rho \max_k \max_j \left| h_j^{'}(0) - h_j^{'}(k) \right|} \tag{14}$$

where ρ is the resolution coefficient. The smaller the ρ is, the greater the resolution. Generally, the value range of ρ is (0, 1). When $\rho \le 0.5463$, the resolution is the best, usually $\rho = 0.5$.

After all the gray correlation coefficients are calculated, the gray correlation coefficient matrix G is further obtained:

$$G = \begin{pmatrix} \delta_{11} & \cdots & \delta_{1n} \\ \vdots & \ddots & \vdots \\ \delta_{m1} & \cdots & \delta_{mn} \end{pmatrix} \tag{15}$$

2.5.4 Calculate relevance

The correlation degree r_k of each scheme is calculated, which is the score of each scheme. The higher the score, the closer the evaluation plan is to ideal optimal plan, and the one with the highest score is recorded as optimal plan. The specific equation is as follows:

$$r_k = \frac{1}{n}\sum_{j=1}^{n}\delta_{kj} \tag{16}$$

2.6 Fuzzy comprehension evaluation method (FCEM)

Fuzzy comprehensive evaluation is a method to comprehensively evaluate the subordinate level of evaluation objects by using fuzzy mathematical tools. Based on the comprehensive weight vector W and the correlation coefficient evaluation matrix G calculated above, the comprehensive evaluation mathematical model is constructed as follows:

$$C = W^0 G. \tag{17}$$

where C is the final decision vector of the m evaluation schemes, $C = [c(1), c(2), ...c(m)]$ and $c(i)$ are the gray correlation degree of the ith scheme; G is the evaluation matrix of each index, there is $G = \{g_i(j)\}$; W is the vector weight of the n evaluation indicators, there is $W = [w_1, w_2, ...w_n]$; "0" indicates a fuzzy operator, and here the weighted average type synthetic operator is chosen, which is $C = W^0 G = W \times G$.

Therefore, the grey relational degree is finally expressed as:

$$c(i) = \sum\nolimits_{j=1}^{n} w_j g_i(j). \tag{18}$$

The final calculated correlation degree is sorted by size. If the evaluation scheme is close to the ideal optimal scheme, the higher the correlation degree is. The solution with the greatest correlation is the optimal solution for comparison.

3 Results and discussion

3.1 Experimental environment

The cargo ship in Youlian Shipyard is a chemical tanker, and the special coating project is 100% sand washing, rust removal and old paint. There are 22 special coating projects for cabins with a total area of 27,600 square meters. The special coating construction procedures are in sequence: erection, pre-sanding, sand-absorbing, structural treatment, rinsing and cleaning, drying, main sanding, sand-absorbing, first-degree painting, second-degree painting, dismantling, bottom repair and finishing cleaning.

The construction period of cabin special coating is long and the process is complex. A large number of equipment need to be used to ensure the normal progress of special coating construction. In the process of special coating construction, the special coating equipment that needs to be used are: dehumidifier, industrial air conditioner, sand suction machine, sand blasting machine, paint sprayer, air compressor, etc. Blowers, industrial air conditioners, and dehumidifiers are required for processes such as frame erection, pre-washing, structural treatment, and cleaning. The pre-flushing process requires a sand suction machine to suck sand; After cleaning, drying, main sand washing and other processes need to use a dehumidifier to reduce the air humidity in the cabin, and use a sand suction machine to absorb sand; The process of painting, dismantling, repairing and cleaning the floor needs to control the temperature and humidity in the cabin, and must use a dehumidifier and a sand suction machine for cleaning. The construction time of the special coating project was from September 19 to November 12, 2021, and it took a total of 55 days. The total energy consumption of the special coating equipment during this period was 1.17×10^6 kWh.

3.2 Experimental results

In this paper, four evaluation methods are used to count and analyze the actual energy consumption of each process of each compartment special coating project, which are analytic hierarchy process, entropy weight method, grey correlation analysis and improved fuzzy comprehensive evaluation methods. The applicability of energy consumption of cabin equipment is discussed through the above four evaluation methods. By comparing the four methods, this paper finded out the reasonable energy consumption of special coating project, reduced the energy consumption per unit area, realized real-time energy consumption monitoring and early warning, and took corrective measures for unreasonable energy consumption in time. The whole process involves a lot of calculation data tables, so it is not listed one by one in the abbreviated text.

3.2.1 Evaluation indicators

The cargo ship has a total of 22 cabin special coating projects. Under the 10 special coating construction processes, the total energy consumption, total time consumption, energy consumption per unit area and the number of equipment used in each cabin are different. As shown in Fig. 1, the energy consumption of each compartment under each process is regarded as a scheme, so as to build the energy consumption evaluation index system of cabin equipment. Based on the original data and comprehensive consideration of the energy consumption of ship cabin equipment, the following four indicators are screened out: total energy consumption Ei (total electrical energy consumed by equipment used to complete a process), total time ti (the time it takes to complete a certain process, unit: days), energy consumption per unit area pEi (total electric energy consumed by a certain cabin to complete a certain process/area of the cabin, which can represent the consumption rate of electric energy), use the number of equipment Qi (the number of equipment required to complete a process, measured by the number of air ducts, 1 air duct means 1/4 of the equipment). The evaluation index values of each scheme are shown in Fig. 2**.**

3.2.2 Based on combined weighting and grey fuzzy comprehensive evaluation model

The fuzzy comprehensive evaluation method needs to assign weights to each evaluation index. In this paper, the AHP and the entropy weight method are used to determine the subjective weight and objective weight of the index respectively, and then combine the subjective and objective weights to obtain the comprehensive weight. At present, there are many combined weighting methods. There are many combination assignment methods, this paper uses equal weight method, multiplicative addition,

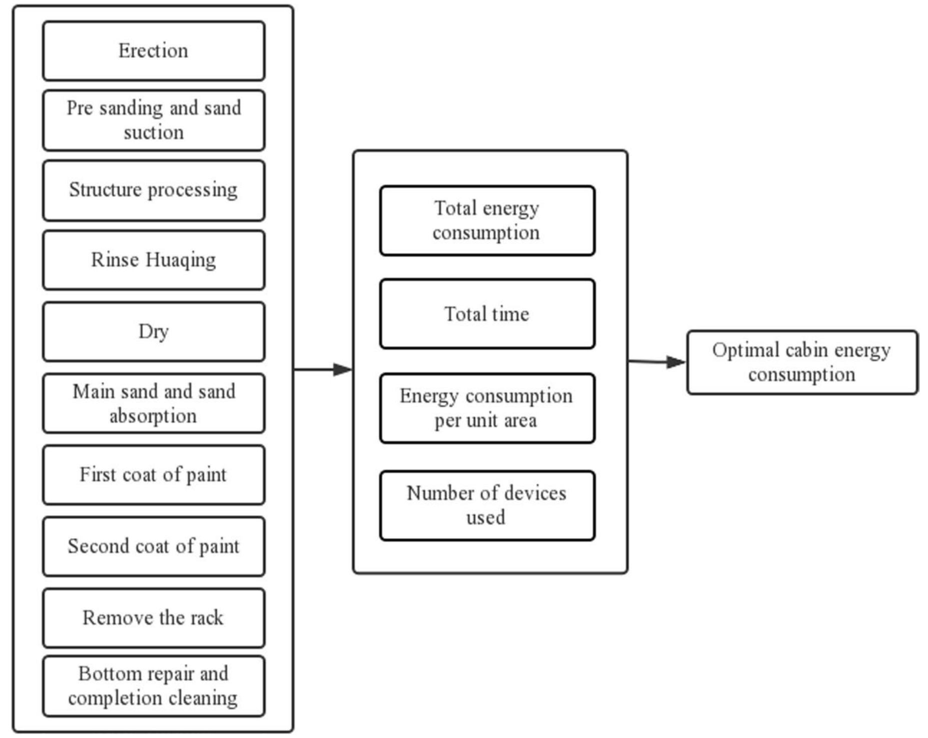

Fig. 1 Evaluation index system of cabin energy consumption

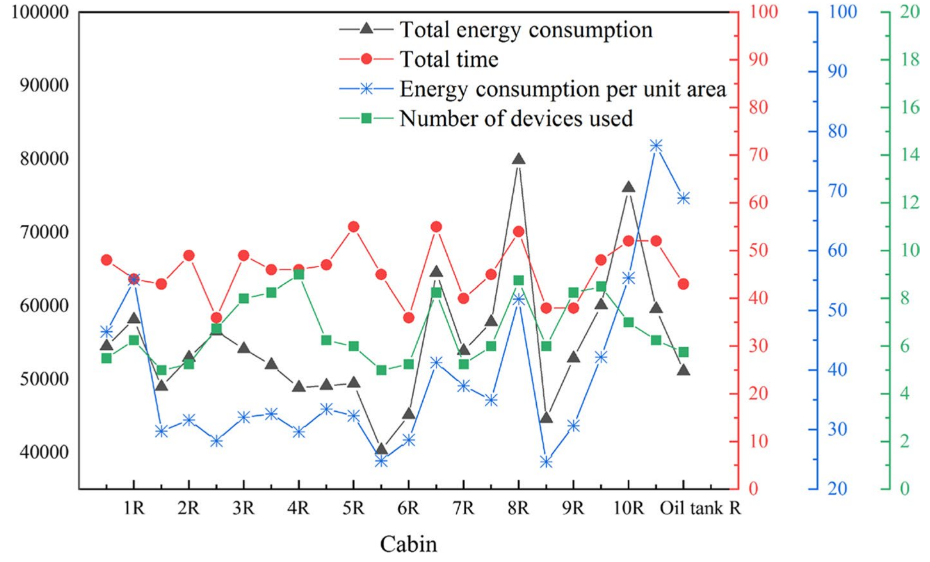

Fig. 2 Evaluation index values of each scheme

difference coefficient method and game theory combination assignment method to combine the subjective and objective weights and compare them. The results of some comprehensive weights are shown in Table 1.

Table 1 Comprehensive weight of each evaluation index

Ei	Comprehensive weight of evaluation indicators			
	EW	MW	DCM	GTCE
E1	0.0161	0.0203	0.016	0.016
E2	0.0496	0.0429	0.0519	0.0513
E3	0.0265	0.0322	0.027	0.0269
t1	0.0135	0.0163	0.0132	0.0133
t2	0.0413	0.0489	0.0423	0.042
t3	0.0178	0.0217	0.0181	0.018
pE1	0.01	0.0099	0.0096	0.0097
pE2	0.0154	0.0175	0.0158	0.0157
pE3	0.015	0.0174	0.0146	0.0147
Q1	0.0191	0.0105	0.018	0.0183
Q2	0.0259	0.0271	0.0249	0.0252
Q3	0.0399	0.0233	0.0376	0.0382

The weight calculation is carried out according to the equal weight method, the multiplication addition method, the difference coefficient method and the game theory combined weighting method. From the above table, we can see the importance of the main sanding and sand suction process under the total energy consumption, the first degree of paint under the total consumption time and the first degree of paint under the use of equipment indicators is more prominent. It shows that the energy consumption of these processes has a greater impact on the total energy consumption of cabin than other processes.

The average value of the four cabins with the smallest energy consumption under each process is the energy consumption baseline under each process, and the baseline is called optimal index set. The optimal set of indicators is shown below.

$$\begin{aligned}&[749.47, 5675.8, 448.075, 787.1, 741.32, 7034.32, 988.25, 4053.9,\\&692.31, 2896.79, 3, 3, 1, 0.5, 0.5, 2, 2, 2, 2, 3, 0.67, 6.44, 0.43, 0.605, 0.54,\\&6.36, 0.72, 1.69, 0.24, 1.02, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1]\end{aligned} \tag{19}$$

Calculate the gray correlation coefficient matrix G with python, and some of the results are as follows:

$$\begin{pmatrix} 0.9869 & 0.8541 & 0.8755 & 0.7312 & 0.7571 & 0.7777 & 0.7760 & 0.4991 \\ 0.9674 & 0.8406 & 0.7540 & 0.8811 & 0.8072 & 0.8331 & 0.3375 & 0.8409 \\ 0.8101 & 0.8758 & 0.9620 & 0.7871 & 0.7417 & 0.5913 & 0.8618 & 0.6780 \\ 0.8162 & 0.8143 & 0.9620 & 0.8496 & 0.6073 & 0.7004 & 0.7522 & 0.6852 \end{pmatrix} \tag{20}$$

Combined with the evaluation matrix G (grey correlation coefficient matrix) and the weight vector W calculated above, the fuzzy comprehensive evaluation models of different weighting methods are used to comprehensively evaluate the cabin energy consumption scheme. The evaluation results are shown in Fig. 3.

As shown in Fig. 3, the fuzzy comprehensive evaluation results under the combined weights obtained by different combinations of methods are different but roughly the same. Among the four results, the cabins in the top 3 are 3 left, 9 left and 6 left, and the cabins in the bottom 3 are 7 left, 10 right and 8 right. Then it can be determined that the

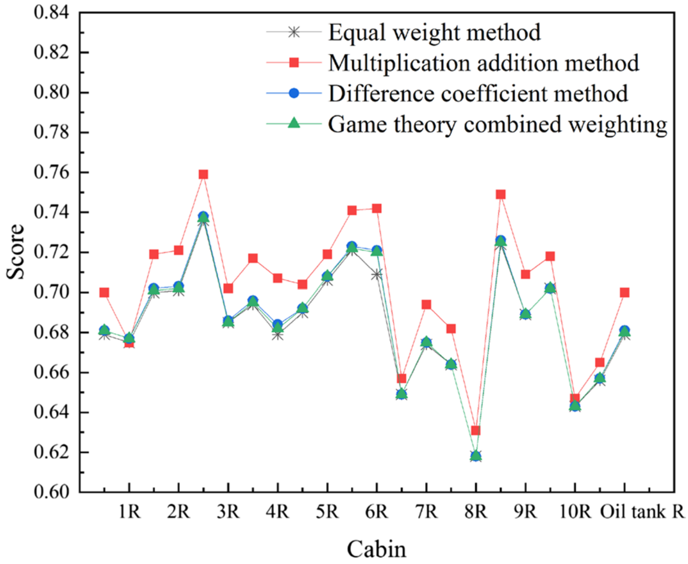

Fig. 3 Fuzzy comprehensive evaluation results

energy consumption of the process equipment in the three cabins 3 left, 9 left, and 6 left is closest to the optimal reference sequence. The process flow and equipment scheduling usage of these cabins can be used as a reference for subsequent ship-related operations to save energy; The energy consumption of sequence equipment in the 7 left, 10 right and 8 right compartments is too different from the energy consumption baseline. The process flow and equipment scheduling and usage of these cabins need to be adjusted to achieve lower energy consumption.

3.2.3 Comparison of evaluation results of different models

Analytic hierarchy process and entropy weight method both analyze from the data level. The final calculation is related to the size of the value. It means that the higher the energy consumption, the higher the calculation score. Energy consumption increases the score will be higher, and the purpose of this paper is to save energy. The smaller the energy consumption, the better the result. Therefore, the ranking standard of these two methods is that the smaller the score, the higher the ranking. The grey relational method and the fuzzy comprehensive evaluation method both use the score to measure the closeness of the energy consumption of each cabin to the energy consumption baseline. If the method has a higher score, it will be closer to the baseline and ranked higher. The evaluation results of different models are shown in Fig. 4.

As shown in Fig. 5, among the ranking results of the four methods, there is no significant difference in the evaluation results of the cabins with poor energy consumption. The selection of the top 3 cabins with excellent performance in energy consumption is slightly different. The results of expert scoring and sorting are to consider the total energy consumption, total time consumption, energy consumption per unit area and the number of equipment used for the 22 schemes. In order to better measure the rationality and accuracy of several evaluation methods, we compare the ranking results of the

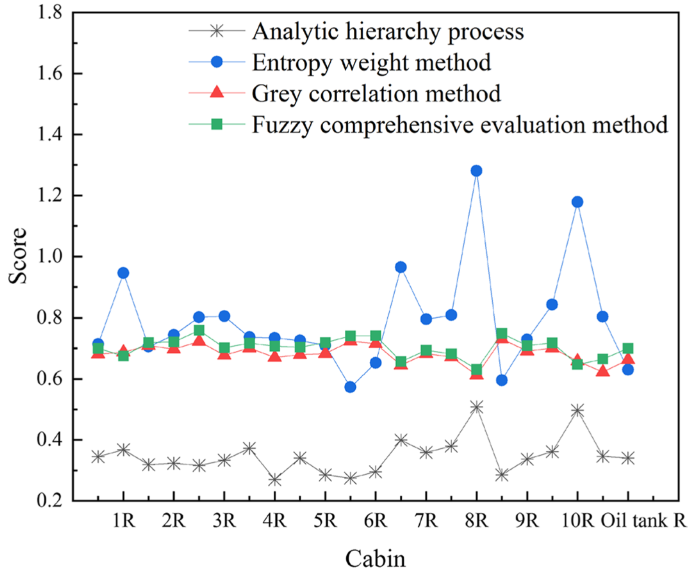

Fig. 4 Comparison of evaluation results of different models

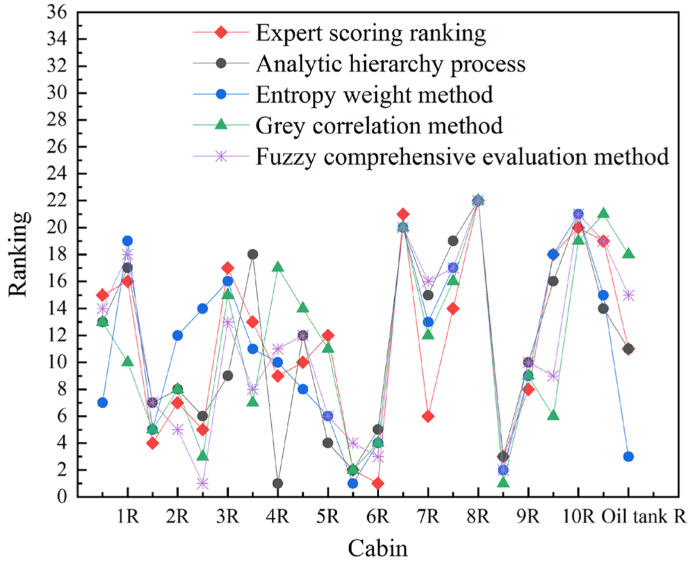

Fig. 5 Comparison of ranking results of different evaluation models

energy consumption of each cabin obtained by the four evaluation methods with the ranking results scored by experts. The mean square error (MSE), the root mean square error (RMSE), the mean absolute error (MAE), and the mean absolute percentage error (MAPE) are used as measurement indicators, and the comparison results are shown in Table 2.

As shown in Fig. 6, the fuzzy comprehensive evaluation ranking result using multiplicative weighting to calculate the comprehensive weight has the smallest error compared with the expert ranking result(MSE is 15.45, RMSE is 3.93, MAE is 3.0, MAPE is 0.45). The evaluation results of AHP and entropy weight method in Fig. 7 are quite different

Table 2 Error comparison of each algorithm

Error	AHP	EW	GRA	FCEM			
				EW	MW	DCM	GTCE
MSE	17.91	17.18	19.09	21.36	15.45	19.82	20.82
RMSE	4.23	4.15	4.37	4.62	3.93	4.45	4.56
MAE	3.09	3.09	3.18	3.27	3.00	3.18	3.18
MAPE	0.48	0.50	0.44	0.51	0.45	0.50	0.50

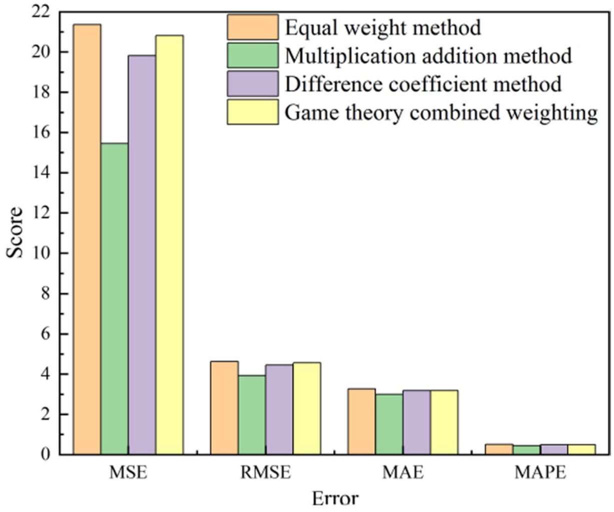

Fig. 6 Comparison of errors of different combination weighting methods

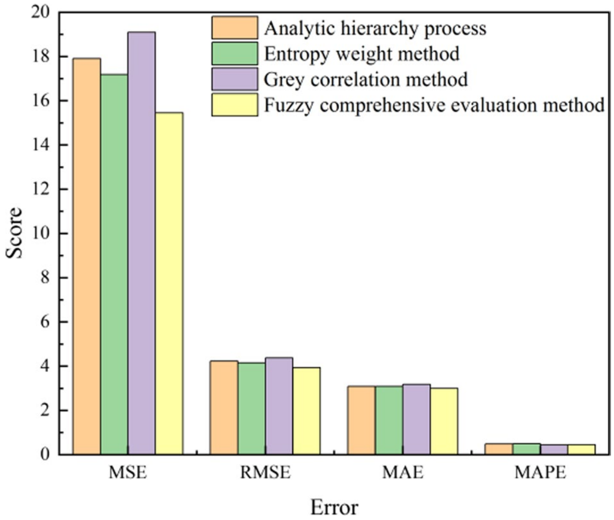

Fig. 7 Error comparison of different evaluation models

from the evaluation results of experts (MSE are 17.91, 17.18; RMSE are 4.23, 4.15). The evaluation index under the AHP and entropy weight method adopts a single subjective or objective weighting method, which cannot make full use of the known information of the index. Therefore, the credibility of evaluation results is low. The evaluation result of grey relational analysis has the largest deviation from the expert ranking result (MSE is 19.09, RMSE is 4.37). Grey correlation analysis is based on the correlation coefficient to measure the degree of correlation between two series, usually the dimensions between the series are consistent. The problem studied in this paper involves different indicators. However, the dimensions of each indicator are not consistent and different indicators have different impacts on energy consumption. Therefore, weights are needed to distinguish them. The grey relational analysis does not consider the weight of the indicators, which makes the evaluation results deviate greatly from the expert results. The Fuzzy Comprehensive Evaluation can reduce the bias caused by a single assignment in the scheme and improve the accuracy of decision ranking. It also introduces weights to reduce the influence of different indicators on the evaluation results and constructs a combined weighting evaluation model. It can be determined that the results of the grey fuzzy comprehensive evaluation model based on the multiplication and addition method are better than other models. The optimal scheme of the grey fuzzy comprehensive evaluation model based on the multiplication and addition method is shown in Fig. 8.

4 Conclusion

In this paper, a grey fuzzy comprehensive evaluation model based on combined assignment was proposed to evaluate the equipment usage in ship cabins during maintenance. The results of cabin energy consumption evaluation were influenced by different evaluation methods and weights, and the variability of the results was large. We compared four

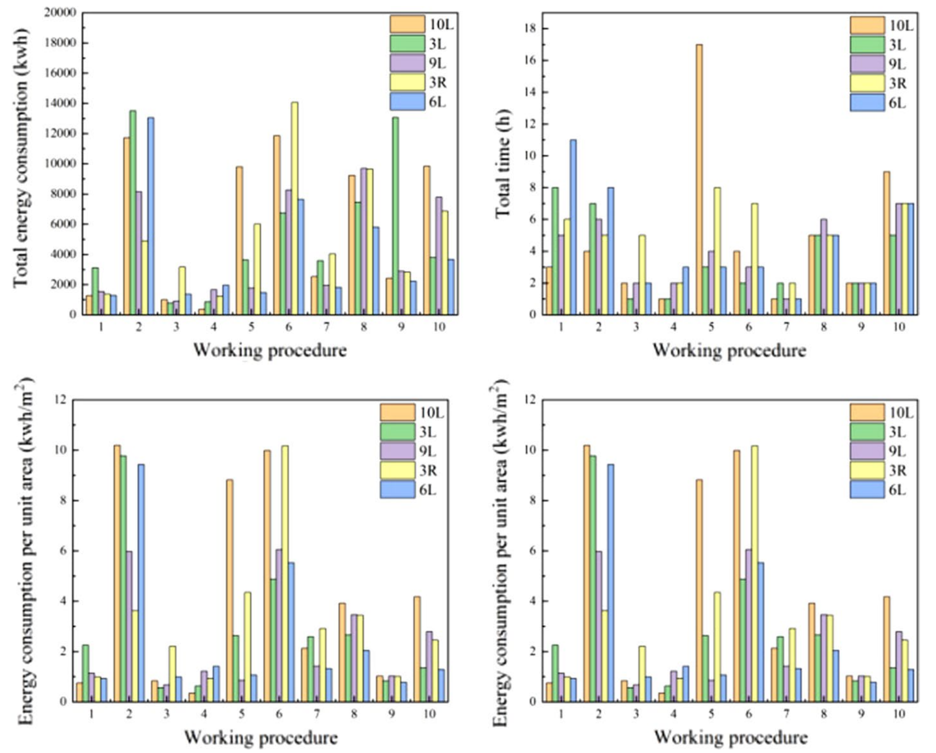

Fig. 8 The optimal scheme under the improved fuzzy comprehensive evaluation method (the first five)

evaluation methods, namely hierarchical analysis method, entropy weight method, gray correlation method and improved fuzzy comprehensive evaluation method, as well as the effects of equal weight method, multiplicative addition method, difference coefficient method and game theory combination assignment method on the evaluation results of shipboard energy consumption. The results showed that the gray fuzzy comprehensive evaluation model based on combined weights proposed in this paper had the best results and the highest consistency with the ranking results scored by experts.

Abbreviations

IoV: Internet of vehicles; AHP: Analytic hierarchy process; EW: Entropy weight; DCM: Difference coefficient method; MW: Multiplicative weighting; GTCE: Game theory combinatorial empowerment; GRA: Grey relational analysis; FCEM: Fuzzy comprehension evaluation method; Ei: Evaluation indicators.

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Authors' contributions

XR and QJ designed the research. ZH and BO performed the numerical calculations and derived the formulae in the paper. BP contributed to the literature review, discussion of the results and edited the manuscript. All authors read and approved the final manuscript.

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Availability of data and materials

The datasets used and analysed during the current study are available from the corresponding author on reasonable request.

Declarations

Competing interests

The authors declare that they have no competing interests.

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