Comprehensive Evaluation of Logistic Support Capability of Marine Control System Based on FAHP Method

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Abstract. The integrated control system of a certain type of ship was imported from abroad, and its independent maintenance support system has been established in China. However, due to the complex internal structure of the system, there are problems in actual use such as high failure rate and insufficient number of replacement spare parts. The application of a large number of advanced technologies and specific encryption measures makes the maintenance very difficult, and the existing logistics support capability is far from enough to ensure the execution of its normal tasks and seriously affects the performance of the entire ship warfare technology. To this end, comprehensively analyze the factors affecting the logistics support capability of the system, and use the analytic hierarchy process to construct an index system for evaluating factors of the logistics support capability. On this basis, the fuzzy comprehensive evaluation method is used to construct an evaluation model, combining the actual use and maintenance of the equipment. The validity of the model was verified. The results show that the lack of spare parts and the shortage of repair and debugging platforms are the main factors restricting the logistics support capability of the system. This comprehensive evaluation provides a reference for guiding the rational allocation and optimization of logistics support resources, improving the system's logistics support capabilities, and guiding the support construction of the same type of system, and has certain guiding significance for the later realization of the localization of the whole system.

1. Introduction

A certain type of ship motion control system (hereinafter referred to as the system) is a centralized motion control system that realizes the motion control of the hull together with the steering device, variable pitch propeller and navigation system. There are problems in the system such as poor stability and insufficient anti-interference ability [1]. The mission of the system is to receive the heel angle, trim angle, drift angle, speed and data from various sensors like the gyro compass, Doppler meter, and after it’s CPU’s control and calculate, we could get the hull motion control instructions. Finally, the system could monitor the boat motion data Form an automatic protection signal.

Due to the complex internal structure of the system, the application of a large number of advanced technologies and some encryption measures, the difficulty in purchasing spare parts, and the shortage
of maintenance support personnel, it is very difficult to maintain the system. To this end, this article conducts a comprehensive evaluation of the system's logistics support capabilities. The purpose is to accurately discover the problems of the equipment in the actual use and maintenance process of support, realize the scheduling optimization of logistics support resources, improve the level of support efficiency, improve logistics support capabilities, and achieving the upgrade of the entire maintenance support system. It is of great significance for maximizing the use of equipment and improving equipment’s reliability.

In recent years, scholars have increasingly studied the fuzzy analytic hierarchy process: for example, Zhao Wei and others have conducted in-depth studies on the basic principles and algorithm steps of multiple analytic hierarchy processes [2]; Aiming at the shortcomings of the current test allocation method, Li Jinlong and others applied the analytic hierarchy process to determine the weight of each factor, and realized the quantitative analysis of the influencing factors. [3]; Kong Jianguo combined the analytic hierarchy process and the triangular fuzzy comprehensive evaluation method to solve the ambiguity and variability of the judgment scale, and established the aviation alliance Partner selection model[4]; Zhang Hui and others applied the analytic hierarchy process to build a low-carbon supply chain performance evaluation index system, and used fuzzy comprehensive evaluation methods to build a performance evaluation model, which has certain guidance for the adjustment of low-carbon supply chain models[5]; Ge Yanyan and others used entropy theory to establish a fuzzy comprehensive evaluation model for the identification of combined drainage and extraction water sources, which solved the problem of fuzzy boundaries caused by uncertain factors[6]. The studies above are all faced with multi-attribute decision-making problems. There are many influencing factors in the support process of the system and the evaluation of logistics support capability can be regarded as a complex decision-making problem. Fuzzy-AHP has a wide range of applications, and the research on the logistics support capability of the control system is not sufficient. Therefore, the analytic hierarchy process is used to evaluate the logistics support capability of the system, obtain the weights of influencing factors at various levels, and accurately locate key factors. Through layer-by-layer comparison, experts are invited to score, data processing and analysis are used to complete the calculation of weights, and finally fuzzy evaluation is applied to evaluate the main object, which provides a reference for the evaluation of the logistics support capability of the same type of equipment.

2. AHP and fuzzy comprehensive evaluation

2.1. Analytic Hierarchy Process (AHP)
Since Saaty proposed the analytic hierarchy process, AHP has been widely used in the optimization decision-making of solving complex multi-attribute problems [7]. As a way of thinking, AHP could determined the relative importance between the two by comparing and scoring different factors at the same level. Finally, the judgments of the decision maker are comprehensively calculated to determine the overall ranking of the relative importance of each factor. This method uses a quantitative way to express people's subjective decisions, and it is widely used in complex decision-making issues such as resource allocation, performance evaluation, priority evaluation, etc [8]. When using the AHP method to make decisions, we generally follow the following four steps: ① Analyze the relationship between the various factors of the system, and establish the hierarchical relationship of the system; ② The factors of the same level follow a certain criterion in the previous level to pairwise comparison and score, then construct a pairwise judgment matrix; ③ Calculate the relative weight of the comparison element to the criterion from the judgment matrix; ④ Calculate the composite weight of each layer element to the system target, and sort it[9].

2.1.1. Hierarchical decomposition of influencing factors. Combining with the preliminary investigation and research, the hierarchical decomposition of the factors affecting the logistics support capability of the system was initially realized. Starting from the overall support requirements of the system and referring to the relevant requirements of GJB2547A-2012[10], we can divide the system into Criterion-
level factors: technical support materials $B_1$, spare parts $B_2$, repair and debugging conditions $B_3$, maintenance support team construction $B_4$ and cost factors $B_5$. Then analyze the sub-criteria level factors that affect the criteria level separately, including $C_{11}$ software and hardware debugging technology, $C_{12}$ supporting documents, $C_{13}$ functional module composition and functional principle, $C_{14}$ overall structure composition, $C_{15}$ technical specifications, $C_{21}$ parts procurement capability, $C_{22}$ independent development capability, $C_{23}$ performance index control, $C_{24}$ use and management records, $C_{25}$ storage, transportation environment, $C_{31}$ repair and debugging platform, $C_{32}$ land training platform, $C_{33}$ repair and debugging equipment, $C_{34}$ supporting measures, $C_{41}$ personnel ability, $C_{42}$ personnel scale, $C_{43}$ personnel training, $C_{44}$ support base construction, $C_{51}$ design and research costs, $C_{52}$ transportation costs, $C_{53}$ accessories costs, $C_{54}$ repairs, testing costs, $C_{55}$ personnel training costs, a total of 23 sub-index level indicators. The details are shown in Fig 1.

![Hierarchical decomposition of influencing factors](image)

**Fig 1. Hierarchical decomposition of influencing factors**

2.1.2. **Reconstruction of the judgment matrix.** In 1.1.1, the hierarchical structure shows the degree of membership relationship between the layer and sub-layer elements. By comparing the influencing factors at the same level, a judgment matrix $A$ is generated. This method can overlap and compare different objective factors and can improve the degree of difficulty of the accuracy of the evaluation results[11]. Use the comparison scale proposed by Satty (see Table 1) to assign the elements’ specific values in $A$.

| Scaling | Description                                      |
|---------|--------------------------------------------------|
| 1       | Both have the same importance                    |
| 3       | The former is slightly more important than the latter |
| 5       | The former is obviously more important than the latter |
| 7       | The former is more important than the latter      |
| 9       | The former is extremely important than the latter |
| 2,4,6,8 | Represents the middle value of the above scale    |

Matrix $A$ is a reciprocal matrix and the elements $a_{ij}$ in the matrix have the following three characteristics:

$$a_{ij} > 0, \quad a_{ij} = \frac{1}{a_{ji}}, \quad a_{ii} = 1$$

(1)

The criterion-level index judgment matrix is shown in Table 2, and the sub-criteria-level index judgment matrix is shown in Tables 3-7.
2.1.3. Weight calculation and consistency check. After constructing the reciprocal matrix $A$, it is necessary to calculate the maximum eigenvalue and eigenvector to obtain the relative weight for comparative analysis. There are two common methods for calculating weight coefficients, namely the square root method and the sum product method[8], specifically, geometric average method, arithmetic average method, eigenvector method and least square method[12]. Considering the actual situation and computational complexity, this paper uses the geometric average method to calculate the weight vector. The specific steps are as follows:

(1) Calculate the product $M_i$ of each row element of the judgment matrix $A$:

$$M_i = \prod_{j=1}^{m} a_{ij}$$  \hspace{1cm} (2)

$a_{ij}$— the element of the i-th row and the j-th column of the judgment matrix;
$m$—— the number of elements

(2) After obtaining the product $M_i$ of each row element, find the geometric mean $w_i$ of $M_i$:

$$w_i = \sqrt[n]{M_i}$$ \hspace{1cm} (3)

(3) Obtain the relative weight value after normalization;
Check the consistency of the weights of the required matrix, and find the consistency index CI;

\[ CI = \frac{\lambda_{\text{max}} - n}{n - 1} \]  

where \( \lambda_{\text{max}} \) is the largest characteristic root and \( n \) is the order of the judgment matrix.

In order to better test whether the judgment matrix has satisfactory consistency, it is necessary to introduce the average random consistency index CR.

\[ CR = \frac{CI}{RI} \]

The specific values of the random consistency index coefficient value RI are shown in Table 8.

### Table 8. Average random consistency index

| Matrix order | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|--------------|---|---|---|---|---|---|---|---|
| RI           | 0 | 0 | 0.52 | 0.89 | 1.12 | 1.26 | 1.36 | 1.41 |

When CR < 0.10, pass the consistency check, and the eigenvector \( V \) corresponding to the calculated \( \lambda_{\text{max}} \) is the weight of the corresponding; When CR ≥ 0.10, the scores in matrix A need to be adjusted. The weight value and total weight of each level indicator are shown in Table 9.

### Table 9. Detailed data of index weights at all levels of the system

| Target level          | Criterion level | Weight | Sub-criteria level | The weight of Sub-criteria level index relative to criterion level index |
|-----------------------|-----------------|--------|-------------------|--------------------------------------------------|
| Logistic support      | B1              | 0.1239 | C11               | 0.5064                                           |
|                       |                 |        | C12               | 0.2429                                           |
|                       |                 |        | C13               | 0.1395                                           |
|                       |                 |        | C14               | 0.0593                                           |
|                       |                 |        | C15               | 0.0519                                           |
|                       |                 |        | C21               | 0.2751                                           |
|                       |                 |        | C22               | 0.4729                                           |
|                       | B2              | 0.4078 | C23               | 0.1104                                           |
|                       |                 |        | C24               | 0.0919                                           |
|                       |                 |        | C25               | 0.0497                                           |
|                       |                 |        | C31               | 0.4499                                           |
|                       |                 |        | C32               | 0.2680                                           |
|                       |                 |        | C33               | 0.1873                                           |
|                       |                 |        | C34               | 0.0949                                           |
|                       |                 |        | C35               | 0.4740                                           |
|                       | B3              | 0.3274 | C41               | 0.6868                                           |
|                       |                 |        | C42               | 0.2547                                           |
|                       |                 |        | C43               | 0.2025                                           |
|                       |                 |        | C44               | 0.5040                                           |
|                       |                 |        | C51               | 0.0352                                           |
|                       |                 |        | C51               | 0.2669                                           |
|                       |                 |        | C51               | 0.1311                                           |
|                       |                 |        | C51               | 0.0627                                           |
2.2. Fuzzy Comprehensive Evaluation (FCE)

In this study, the fuzzy comprehensive evaluation method was used to evaluate the system. This method is based on fuzzy mathematics and it takes the fuzzy object under study and the fuzzy concept reflecting the object as a fuzzy set, and then establishes an appropriate membership relationship to describe the fuzzy boundary, quantitatively analyzes the fuzzy object, and finally evaluates the comprehensive evaluation of things affected by various factors [13]. This method has the advantages of simple model, easy to master and apply [14]. It consists of the following steps:

(1) Construct a set of evaluation factors.

In this study, the influencing factors are divided into secondary indicators. There are 5 corresponding criterion-level indicators, denoted as \( B=\{B_i\}=\{B_1,B_2,B_3,B_4,B_5\} \). The corresponding next-level indicators can be Denoted as \( C_i=\{c_{i1},c_{i2},...,c_{ik}\} \), \( k \) is the number of single factors at the same level.

(2) Determine the evaluation result set.

Too many grades of the comment set will lead to complex calculations, and it is not conducive to the scoring staff to grade, so this article divides the comment set into 5 grades: \( V=\{\text{tiptop, good, fair, poor, bad}\} \), corresponding to the assignment matrix \( P \):

\[
P = \begin{pmatrix} p_1 \end{pmatrix} = \begin{pmatrix} 9 & 7 & 5 & 3 & 1 \end{pmatrix}
\] (7)

(3) Construct a fuzzy evaluation matrix.

Invite professionals to score and evaluate each factor in factor sets \( B \) and \( C \) in combination with the comment set \( R \), and map the final result into a fuzzy evaluation matrix \( R_i \):

\[
R_{ij} = \{r_{ijk}\}
\] (8)

In the formula, \( r_{ijk} \) is the number of professionals who have made the k-th evaluation on a certain index factor in the total number of experts.

(4) Calculate the comprehensive evaluation vector.

After determining the weighting factor set \( A \) and the comprehensive evaluation matrix \( R \), a fuzzy operator can be used to perform fuzzy comprehensive evaluation according to its fuzzy operation rules.

At present, there are four commonly used fuzzy operators: main factor determination type, main factor prominent type, unbalanced average type and weighted average type [15]. According to the weight distribution of each factor in the evaluation target, the quantitative solution value of the evaluation is obtained through the synthetic operation of the fuzzy matrix. Based on the above process, the fuzzy comprehensive evaluation method is used to calculate the comprehensive evaluation value [16, 17]. In this paper, the weighted average fuzzy operator is used to calculate, and the comprehensive evaluation vector \( M \) for single factor is obtained, as shown in the following formula.

\[
M = V \bigtriangleup R = \left( v_1, v_2, ..., v_j \right) \begin{pmatrix} r_{11} & \cdots & r_{1k} \\ \vdots & \ddots & \vdots \\ r_{ll} & \cdots & r_{lk} \end{pmatrix}
\] (9)

(5) Conduct comprehensive evaluation

Multiply the comprehensive evaluation matrix \( M \) and the assignment matrix \( P \) to obtain the comprehensive evaluation value \( N \) of the system.

\[
N = MP
\] (10)
3. Case analysis
The fuzzy-analytic hierarchy process is now used to comprehensively evaluate the system's logistics support capabilities. The specific steps are as follows.

(1) Solve the fuzzy matrix
First, the technical support data is evaluated, and the evaluation results are shown in Table 10.

| Evaluation index | tiptop | good | fair | poor | bad |
|------------------|-------|------|------|------|-----|
| B11              | 2     | 3    | 3    | 1    | 1   |
| B12              | 3     | 2    | 2    | 2    | 1   |
| B13              | 3     | 3    | 2    | 1    | 1   |
| B14              | 2     | 4    | 2    | 1    | 1   |
| B15              | 2     | 4    | 2    | 1    | 1   |

From this, the fuzzy evaluation matrix under the evaluation factor "technical support materials" can be obtained:

\[ R_{B1} = \begin{pmatrix}
0.2 & 0.3 & 0.3 & 0.1 & 0.1 \\
0.3 & 0.2 & 0.2 & 0.2 & 0.1 \\
0.3 & 0.3 & 0.2 & 0.1 & 0.1 \\
0.2 & 0.2 & 0.4 & 0.2 & 0 \\
0.2 & 0.4 & 0.2 & 0.1 & 0.1
\end{pmatrix} \quad (11) \]

Similarly, spare parts, repair and debugging conditions, maintenance support team construction and cost factors are scored and evaluated in turn, and the fuzzy evaluation matrix obtained is as follows:

\[ R_{B2} = \begin{pmatrix}
0 & 0.1 & 0.3 & 0.3 & 0.3 \\
0.1 & 0.2 & 0.2 & 0.4 & 0.1 \\
0.3 & 0.3 & 0.3 & 0.1 & 0 \\
0.3 & 0.2 & 0.3 & 0.2 & 0 \\
0.2 & 0.3 & 0.3 & 0.2 & 0
\end{pmatrix} \quad (12) \]

\[ R_{B3} = \begin{pmatrix}
0.1 & 0.1 & 0.2 & 0.4 & 0.2 \\
0 & 0.2 & 0.4 & 0.3 & 0.1 \\
0.3 & 0.2 & 0.4 & 0.1 & 0 \\
0.3 & 0.3 & 0.2 & 0.1 & 0.1
\end{pmatrix} \quad (13) \]

\[ R_{B4} = \begin{pmatrix}
0.2 & 0.3 & 0.4 & 0.1 & 0 \\
0.1 & 0.2 & 0.4 & 0.2 & 0.1 \\
0.4 & 0.3 & 0.2 & 0.1 & 0 \\
0.1 & 0.1 & 0.4 & 0.3 & 0.1
\end{pmatrix} \quad (14) \]
(2) Conduct single factor evaluation
Combine the obtained fuzzy evaluation matrix with the corresponding weight vector to realize the evaluation of single factor. The weighted average fuzzy operator is used here, which takes into account the weight of each element, and the evaluation result reflects the overall characteristics of the evaluation object. The evaluation weight vector of each criterion layer of the system is solved as follows:

\[ R_{s6} = \begin{pmatrix} 0.1 & 0.1 & 0.2 & 0.2 & 0.4 \\ 0.1 & 0.3 & 0.3 & 0.2 & 0.1 \\ 0.1 & 0.2 & 0.2 & 0.2 & 0.3 \\ 0 & 0.1 & 0.4 & 0.3 & 0.2 \\ 0.1 & 0.1 & 0.3 & 0.3 & 0.2 \end{pmatrix} \] (15)

\[ S_{s6} = R_{s6} \times \mathbf{w}_6 = \begin{pmatrix} 0.1 & 0.1 & 0.2 & 0.2 & 0.4 \\ 0.1 & 0.3 & 0.3 & 0.2 & 0.1 \\ 0.1 & 0.2 & 0.2 & 0.2 & 0.3 \\ 0 & 0.1 & 0.4 & 0.3 & 0.2 \\ 0.1 & 0.1 & 0.3 & 0.3 & 0.2 \end{pmatrix} \times \begin{pmatrix} 0.564 & 0.2429 & 0.1395 & 0.0593 & 0.0519 \\ 0.2 & 0.3 & 0.1 & 0.1 \\ 0.3 & 0.2 & 0.2 & 0.1 \\ 0.3 & 0.2 & 0.1 & 0.1 \\ 0.2 & 0.4 & 0.2 & 0 \end{pmatrix} = \begin{pmatrix} 0.2382 & 0.2750 & 0.2625 & 0.1302 & 0.0941 \end{pmatrix} \] (16)

\[ S_{s5} = R_{s5} \times \mathbf{w}_5 = \begin{pmatrix} 0.4999 & 0.2650 & 0.1873 & 0.0949 \\ 0.1 & 0.1 & 0.2 & 0.4 & 0.2 \\ 0.2 & 0.3 & 0.3 & 0.2 & 0.1 \\ 0.1 & 0.2 & 0.4 & 0.1 \\ 0.3 & 0.3 & 0.3 & 0.1 & 0.1 \end{pmatrix} \times \begin{pmatrix} 0.4499 & 0.2680 & 0.1873 & 0.0949 \end{pmatrix} = \begin{pmatrix} 0.1179 & 0.1885 & 0.2527 & 0.3110 & 0.1298 \end{pmatrix} \] (17)

(3) Conduct comprehensive evaluation
Combine the above single factor evaluation results to obtain a comprehensive evaluation matrix $R$.

$$R = \begin{bmatrix} S_{a1} \\ S_{a2} \\ S_{a3} \\ S_{a4} \end{bmatrix}$$  \hspace{1cm} (21)$$

The criterion layer weight obtained by the analytic hierarchy process is $V_B$, $V_B=(0.1242 \ 0.5417 \ 0.2215 \ 0.0610 \ 0.0516)$, then the comprehensive evaluation result of the target layer is

$$W = V_B \cdot R = \begin{bmatrix} 0.1239 & 0.4078 & 0.3274 & 0.1046 & 0.0363 \\ 0.2382 & 0.2750 & 0.2625 & 0.1302 & 0.0941 \\ 0.1579 & 0.1985 & 0.3257 & 0.3110 & 0.1298 \\ 0.1296 & 0.1456 & 0.1645 & 0.2911 & 0.2886 \\ 0.2238 & 0.2526 & 0.3491 & 0.1474 & 0.0271 \end{bmatrix} \cdot \begin{bmatrix} 0.1242 & 0.5417 & 0.2215 & 0.0610 & 0.0516 \end{bmatrix} \hspace{1cm} (22)$$

Finally, the fuzzy comprehensive evaluation result and the grade evaluation index are combined numerically to obtain the final evaluation result.

$$\hat{X} = WP \begin{bmatrix} 0.1466 & 0.1961 & 0.2760 & 0.2608 & 0.1285 \end{bmatrix} = \begin{bmatrix} 9 \\ 7 \\ 5 \\ 3 \\ 1 \end{bmatrix} \cdot 4.9750$$  \hspace{1cm} (23)$$

Comparing the grade scoring standard of formula (7), the scoring result is located in the "normal" position, slightly biased to "poor", which indicates that the system's logistics support capability is generally at a general level and the support capability can basically meet the needs of use. The following key issues exist in logistics support:

1) Insufficient spare parts: There are many types and quantities of system configuration, long-term external procurement and ordering cycles, and weak procurement capabilities, and the autonomy of spare parts production needs to be strengthened;

2) Shortage of repair and debugging equipment: a professional repair and debugging platform helps to achieve sufficient testing, and can provide effective testing for imported spare parts and domestic parts, achieve laboratory effects, and effectively avoid test risks. Besides, it can also improve the level of personnel control and management, and is safe and controllable. The existing platform resources are relatively scarce.

Among all the first-level indicators of the standard level, the weights of spare parts, the repair and debugging equipment are respectively 0.4078 and 0.3274, which are significantly higher than other indicators. Among all the indicators of the spare parts, independent development capabilities and components The weight of procurement capacity is significantly higher than the others, which are 0.4729 and 0.2751 respectively; in the secondary indicators of repair and debugging equipment, the weights of repair and debugging platforms and onshore training platforms are 0.4499 and 0.2680 respectively.

This result is consistent with the actual situation of the current maintenance support, which verifies the validity of the model and shows that the comprehensive evaluation of the system's logistics support capability is reasonable.
4. Conclusion
This study uses the analytic hierarchy process and fuzzy comprehensive evaluation method to evaluate the logistics support capability of a certain type of control system, which has the advantages of both methods.

This research evaluates a variety of factors that affect maintenance support, and can coordinate and find shortcomings in the logistics support process. This has a guiding role for targeted project research and project establishment in the future, and is useful for similar systems. Design, development, and improvement of domestic equipment support capabilities are of great significance.

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