Reliability Analysis of Ship’S Power Supply Based on AHP Model

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Abstract. Ship supply system can be decomposed into a plurality of joints. This paper analyzed the influence of each link on the reliability of the whole ship power supply by taking equipments characteristics followed by marine engine managers as rule and each joint as object based on the AHP model. This paper also analyzed the application of the model in the implementation of task and declaration of spare parts.

1. Introduction
The reliability of power supply by the entire ship when the ship performs various tasks at sea is of great significance to the safety of the ship and the success of the mission. First of all, the loss of power to the entire ship will directly lead to host shutdown, servo-off, and pumping of the nacelle. The ship will lose its power, especially when it is sailing on big waves, sailing on a narrow waterway, and leaving the docks. The loss of power to the whole ship will seriously affect the ship. Safety; Secondly, during the mission, the loss of power to the entire ship will directly affect the successful completion of the mission. Therefore, it is of great practical significance to study and analyze the reliability of ship power supply and the influence of various links in the power supply system on the entire power supply system.

2. The Composition of the Ship's Power Supply System
The ship power supply system consists mainly of diesel generator sets, main switchboards, and district distribution boards. The power supply system can be divided into two major components: one is the prime mover part and the other is the power supply and distribution part. The prime mover part can be further subdivided into a diesel engine body and its safeguard system: a diesel engine body, a fuel supply system, an oil lubricating system, a cooling water system, and an air system. The power distribution section can be subdivided into generators, main switches, main switchboards, and PMS systems (power management systems). Taking a ship as an example, the diesel generator sets share the same fuel supply system, freshwater cooling system, seawater cooling system, and air system; the generators are connected to the busbars of the main switchboard through the main switch, and the control systems of each generator are mutually independent. The PMS system manages the operation, stopping, parallel decoupling, and power distribution of the five generators.

3. Establishment of Analytical Hierarchy Process Model
AHP-Analytic Hierarchy Process is a systematic, hierarchical analysis method. This paper uses the Analytic Hierarchy Process (AHP) model to solve the reliability analysis problem of the power supply system. The decision-making problem is divided into three levels: target level O, criterion level C, and...
target level P. Each level has several elements, and the relationship between elements in each level is used. Connected lines indicate. Through comparison with each other, the weight of each criterion on the target and the weight of each object on each criterion are determined. The above two sets of weights are integrated to determine the weight of each object on the target.

The assumptions for the model establishment are as follows: a single generator set supplies power to the entire ship. First determine the content of the target layer: reliable power supply for the entire ship. Secondly, the content of the criteria layer is determined. This article uses the five device performance \[1\] that the turbine management personnel pay attention to as the criterion layer: reliability, maintainability, detectability, urgency, and influence. The object layer is the nine main links in the power supply system: diesel engine block, fuel supply system, lubricating oil system, cooling water system, air system, generator, main switch, main switchboard, and PMS system. At this level, the analytical model is basically established.

4. Analysis and Calculation of Analytical Hierarchy Process Model

In the above section, a hierarchical analysis mathematical model of the ship power supply system was established. The following analysis and calculation was performed on the model to determine the influence of nine objects in the power supply system on the power supply system.

4.1. Paired Comparison Matrix of the Criterion Layer to the Target

The two elements are compared and the comparison is based on the relative scale. Let us compare the importance of the criteria \(C_1, C_2, \ldots, C_n\) to the goal. The element is the paired comparison matrix:

\[
A = \begin{bmatrix}
\frac{1}{5} & 1 & 1/2 & 1/3 & 1/5 \\
5 & 1/6 & 2 & 1/3 & 1/4 \\
6 & 1/7 & 3 & 3 & 1/2 \\
7 & 1/8 & 4 & 2 & 1
\end{bmatrix}
\]

The pairwise comparison matrix is obtained by the subjective pairwise comparison of experts. Any element in the matrix indicates the comparison of the importance between the two. This method of pairwise comparison enables the raters to focus on the two objects to be compared without the interference of other factors, making the pairwise comparison matrix relatively objective to a certain extent.
4.2. Verification of Consistency of Pairwise Comparison Matrices

In an ideal case where pairs are completely identical. Any element in A satisfies this time is called the identity matrix. In most practical situations, it is not a consistent matrix. It is necessary to determine the range of inconsistency and the consistency check is required. Set the maximum eigenvalue of the matrix and define the consistency indicator:

$$CI = \frac{\lambda - n}{n-1}$$  \hspace{1cm} (1)

The larger CI in the formula is, the more serious the inconsistency is. In order to measure the size of the equation CI, a random consistency index RI is introduced, the value of which is shown in the following table [3]

| n  | 1   | 2   | 3   | 4   | 5   | 6   | 7   | 8   | 9   | 10  | 11  |
|----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| RI | 0   | 0   | 0.58| 0.9 | 1.12| 1.24| 1.32| 1.41| 1.45| 1.49| 1.51|

Define the consistency ratio as $$CR = CI / RI$$. At that time of $$CR < 0.1$$, the paired comparison matrix passed the consistency check and the inconsistency was within the allowable range.

4.3. Weight Vector of Target at Criterion Level

The corresponding Eigenvectors are obtained from the maximum characteristic Root $$\lambda = 5.29$$ \(w = (0.45, 0.05, 0.07, 0.13, 0.30)^T\). Put $$\lambda = 5.29$$ into the formula (1), $$CI = (5.29 - 5) / (5 - 1) = 0.07$$. We get $$RI = 1.12$$ from table 2, with available consistency ratio of $$CR = 0.07 / 1.12 = 0.06 < 0.1$$ If a pairwise comparison matrix passes the consistency test, then the weight vector is a feature vector. \(w = (0.45, 0.05, 0.07, 0.13, 0.30)^T\)

4.4. Combination Weight Vector of Object Layer to Criterion Layer

By using the method mentioned above, it is determined that the pair comparison matrices of each object layer for each criterion are represented by a pair matrix, and they are all 9-order positive reciprocal matrices.

$$B_1 = \begin{bmatrix}1 & 1/2 & 1/4 & 1 & 1/6 & 1/8 & 1/8 & 1/9 & 1/8 \\2 & 1 & 1/5 & 3 & 1/4 & 1/6 & 1/7 & 1/8 & 1/8 \\4 & 5 & 1 & 4 & 2 & 1/2 & 1 & 1/3 & 1/3 \\1 & 1/3 & 1/4 & 1 & 1/3 & 1/5 & 1/5 & 1/7 & 1/7 \\6 & 4 & 1/2 & 3 & 1 & 1/2 & 1/2 & 1/3 & 1/3 \\8 & 6 & 2 & 5 & 2 & 1 & 2 & 1 & 2 \\8 & 7 & 1 & 5 & 2 & 1/2 & 1 & 1/2 & 1/2 \\9 & 8 & 3 & 7 & 3 & 1 & 2 & 1 & 2 \\8 & 8 & 3 & 7 & 3 & 1/2 & 2 & 1/2 & 1/2 \end{bmatrix}$$

$$B_2 = \begin{bmatrix}1 & 1/7 & 1/5 & 1/5 & 1/5 & 5 & 6 & 1/2 & 8 \\2 & 1/5 & 1/5 & 1/5 & 1/5 & 5 & 6 & 1/2 & 8 \\4 & 5 & 1/3 & 1 & 1/2 & 1/3 & 1/3 & 1/3 & 1/3 \\5 & 1/3 & 1 & 1/2 & 1/3 & 1/3 & 1/3 & 1/3 & 1/3 \\6 & 5 & 1/4 & 2 & 3 & 1 & 6 & 7 & 6 \\8 & 1/5 & 1/5 & 1/4 & 1/6 & 1 & 2 & 1/3 & 3 \\1/6 & 1/8 & 1/5 & 1/5 & 1/7 & 1/2 & 1 & 1/4 & 3 \\2 & 1/7 & 1/5 & 1/5 & 1/5 & 1/7 & 1/2 & 1 & 1/4 & 3 \\8 & 1/8 & 1/9 & 1/6 & 1/7 & 1/8 & 1/3 & 1/3 & 1/5 & 1 \end{bmatrix}$$

The maximum eigenvalues and their corresponding Eigenvectors are found in the following table:
### Table 3. Maximum eigenvalues and Eigenvectors of object layer pair criterion layer

| Criterion layer | 1      | 2      | 3      | 4      | 5      |
|----------------|--------|--------|--------|--------|--------|
| feature vector | 0.02   | 0.06   | 0.09   | 0.05   | 0.04   |
|                | 0.03   | 0.34   | 0.17   | 0.17   | 0.23   |
|                | 0.10   | 0.12   | 0.18   | 0.10   | 0.13   |
|                | 0.02   | 0.13   | 0.26   | 0.17   | 0.09   |
|                | 0.08   | 0.21   | 0.16   | 0.34   | 0.35   |
|                | 0.20   | 0.03   | 0.04   | 0.05   | 0.05   |
|                | 0.13   | 0.02   | 0.03   | 0.03   | 0.04   |
|                | 0.23   | 0.07   | 0.05   | 0.03   | 0.02   |
|                | 0.19   | 0.02   | 0.03   | 0.07   | 0.04   |

| Maximum characteristic root | 9.44 | 10.09 | 9.50 | 9.77 | 9.76 |
| coincidence indicator | 0.055 | 0.13 | 0.06 | 0.09 | 0.09 |

\[ RI = 1.45(n=9) \] passed the consistency check. The combination weight of object P1 to the target layer is \( 0.02 \times 0.45 + 0.06 \times 0.05 + ... + 0.04 \times 0.30 = 0.037 \)

The weight vector of the object layer to the target layer can be obtained by the same calculation and combination of the other objects. \( W = (0.037, 0.035, 0.011, 0.005, 0.008, 0.004, 0.003, 0.002, 0.001) \)

From the final result, it can be concluded that the impact of the 9 stages on the power supply system of the entire ship is: diesel engine, main switch cooling water system, PMS system, generator, oil system, main switchboard, fuel system, air system. Turbine managers need to focus on the top devices.

### 5. Expanded Application of Models

Through the above analysis and calculation, we have integrated all the criteria to obtain the degree of influence of each object on the reliability of power supply. Based on the establishment and calculation of the above models, we can also make the following applications:

#### 5.1. Optimization of Power Supply Options

In the practical use of ship power stations, power supply is usually 2 to 4 generator sets (taking 5 generator sets as an example), and the rest of the sets are on standby. The power supply of a single unit has been analyzed above. Since the total ship electricity load is generally between 1100KW-1400KW (a single unit of 770KW), when multiple generator sets supply power, if a single unit fails, the remaining units the power supply to the entire ship may still be normal. Therefore, the value of the influence of the three objects of the diesel engine, the generator, and the main switch in the object on the criterion layer is about to change. When two units are powered, if a single unit fails, the remaining one unit cannot continue to supply power to the entire ship, so the value remains unchanged. If three or four units are supplied with power, if the single unit fails, the remaining units can still supply power to the entire ship, so a new value is required. For the recalculation, the final rankings of the target layer's weight vector for the target layer are: cooling water system, PMS system, oil system, diesel engine, main switch, generator, main switchboard, fuel system, air system, among them The ranks of diesel engines, main switches, and generators all dropped significantly, and the top-ranking cooling water systems are easy to maintain and test.

Therefore, during the mission of the ship, when sailing from docks and narrow waterways, the power supply of the 3 units is the best power supply solution.

#### 5.2. Application of Model Partial Results

From the value of the performance of nine objects on different criteria, we can also get the points of equipment management: a. In terms of spare parts declaration, we have focused on the equipment that
performs weakly in terms of maintainability and detectability, such as Diesel engine, generator, main switch, PMS system, etc. During the patrol of equipment operation, the main concern is high detectable objects: fuel system, oil system, cooling water system, air system. During the mission, the main concern is the operational status of the equipment that affects the urgency and degree of decision: main switchboard and maintenance. The main concern is the equipment fuel system, cooling water system, and air system, which are highly reliable in terms of reliability and low maintenance.

6. Conclusion
The analytic hierarchy model established in this paper regards the object to be analyzed as a system, analyzes and calculates according to the decomposition, comparison, judgment, and comprehensive thinking modes, and obtains the weak links in the power supply system, and deals with the problems that traditional optimization methods cannot solve. The combination of qualitative and quantitative results clear, easy for decision makers to understand and master directly. This article also extends the application of the model: optimization of the power supply program, proposed some suggestions for turbine management. The analytic hierarchy model established in this paper has strong applicability in the reliability analysis of other systems of ships, which can give decision makers a good scientific reference.

References
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