Analysis of the Ability of Ships to Adapt to Wind and Wave Environment

Weiling Zhang, Feng Cai and Xiao Wang

ABSTRACT

A complete index system is proposed for the evaluation of the adaptability of ships in the wind and waves. Combining the subjectivity of the analytic hierarchy process with the objectivity of the coefficient of variation method, the weight of the indicator is comprehensively determined. Coupling binding ship movements in waves, the geometric mean method is used to accurately assess the environmental adaptability of the waves of different ship. The accuracy of the evaluation model proposed in this paper is illustrated by an example.

KEYWORDS
Environment Adaptability, Indicator System, Efficiency Factor, Geometric Average Comprehensive Evaluation.

INTRODUCTION

The environmental adaptability of a ship in wind and waves means that the ship can not only guarantee its original performance under the influence of all external conditions such as wind and waves encountered[1], but can even use the environment to improve its performance in all aspects. The adaptability of ships in wind and waves has become a multiplier for maritime forces, and has even become the third important force in maritime operations[2].

Domestic research on the adaptability of ships to the environment is still in its infancy, and many of the work is still not perfect. Ying Rongrong[3] [4] and others based on the FSA (Formal Safety Assessment) fuzzy comprehensive evaluation method to assess the risk level of ship navigation. Jiao Jialong[5] used the subjective synthesis method combined with the fuzzy evaluation model to evaluate the adaptability of the ship's wind and wave environment. Yang Hu[6] based on multi-objective comprehensive evaluation of the adaptability of surface warships. Liu Meng[7] and others calculated the ship overturning moment and the wind tilting moment to make a quantitative assessment of the departure of the wind wave. Wu Yueqin et al. [8] selected the appropriate synthetic operators to propose a comprehensive environmental adaptability assessment method for equipment and lower products by fuzzy comprehensive evaluation. Han Zhiguo[9] combined the characteristics of the ship, studied the ship evaluation index system and the evaluation methods of some indicators.
WIND AND WAVE ENVIRONMENT ADAPABILITY ASSESSMENT MODEL

A complete evaluation system needs to include the following three aspects: appropriate evaluation indicators, reasonable indicator weights, and scientific measurement evaluation. Based on the existing experience, this paper establishes a set of perfect evaluation indicators from five aspects: wave resistance, rapidity, stability, maneuverability and staff work comfort. Combining the analytic hierarchy process with the coefficient of variation method, comprehensive subjective evaluation and objective data evaluation to determine the weight; using the power coefficient method combined with the weighted geometric mean evaluation method for comprehensive evaluation and scoring; finally, the subjective weight and the objective data weight preference factor are analyzed, highlighting that some ship types have strong adaptability to the wind and wave environment.

EVALUATION INDEX SYSTEM

In order to evaluate the adaptability of ships in wind and waves, it is first necessary to establish a scientific and reasonable indicator system. This paper has established a set of comprehensive evaluation indicators based on various factors, as shown in Table I.

| Primary Indicator | Secondary Indicators | Indicator Description |
|-------------------|----------------------|-----------------------|
| Wave Resistance   | 6 Degrees of Swing   | Including Roll, Sway, Heave, Pitch, Sway, Shake |
|                   | Deck Wave            | Number of waves on the Deck per unit time |
|                   | Propeller Emptying Car| Number of propeller outlets per unit time |
|                   | Longitudinal total bending moment | Ratio of ultimate bending moment to longitudinal bending moment |
|                   | Bottom Sniper        | The number of slams at the bottom of the hull per unit time |
| Rapidity Stability| Wave Resistance Coefficient | Waves increase the proportion of resistance |
|                   | Thrust Reduction Factor| Thrust deduction and thrust ratio |
|                   | Wind Resistance Rating| The ship can withstand the level of the cross wind |
|                   | Balance Number       | Ratio of minimum overturning moment to wind pressure tilting moment |
| Manipulability    | Direct Flight Stability| The ratio of the distance of a certain upward displacement and the direct distance |
|                   | Heading Change Ability| Measured by the ship's rudder index T |
| Staff Work Comfort| Work Efficiency       | The time to complete the normalization work, the shorter the time, the better. |
|                   | Emergency Action capability | The time to complete an emergency mission, the shorter the time, the better |

How to Calculate the Weight Value

For the index weight setting, this paper firstly adopts the subjective analytic hierarchy process, and uses the expert scoring principle to analyze the weight of each index. At the same time, combined with the data itself, the coefficient of
gravity is used to objectively give the weight of each index, and finally introduce objective and subjective preferences. The factor is used to comprehensively determine the weight distribution of the indicator.

**ANALYTIC HIERARCHY**

As the most commonly used and most effective evaluation method, AHP is widely used in various evaluation systems. The specific description is as follows:

Comparison score index for each layer by the experts twenty-two respectively, and intermediate values 1, 3, 5, 7, 9 with each other to represent the degree of importance between indicators and build judgment matrix. Solving the eigenvector corresponding to the largest eigenvalue of the judgment matrix, and normalizing it as the weight of each factor on the upper-level index $W_i$.

Computational consistency indicator $CR = \frac{CI}{RI}$, in which $CI = \frac{\lambda_{max} - n}{n - 1}$. When $CR \leq 0.1$, the judgment matrix is considered to meet the consistency requirement.

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**COEFFICIENT OF VARIATION METHOD**

Coefficient of variation method is an objective method of weighting by directly using the information contained in each indicator and calculating the weight of the indicator. The greater the difference in indicators, the more difficult it is to achieve, the more it can measure the gap in the evaluation unit; if the difference is not obvious, then this indicator is used to measure the evaluation unit and loses its meaning. In order to eliminate the influence of different indicators, the paper uses the following coefficient of variation method:

$$V_i = \frac{\sigma_i}{\bar{x}_i} (i = 1, 2, 3, ...)$$

Where: $V_i$ means the coefficient of variation of each indicator;

$\sigma_i$ means the standard deviation of the first indicator;

$\bar{x}_i$ means the average of the first indicator.

The weight of each indicator is.

$$W_i^2 = \frac{V_i}{\sum_{i=1}^{n} V_i}$$

**COMPREHENSIVE WEIGHT CALCULATION**

Introducing a preference factor $\beta$, the weight of the integrated weight is the weight of the chromatographic analysis weight and the coefficient of variation coefficient.
Using the Power Factor Method to Measure the Efficacy Factor of the Indicator

The power factor method is used to measure the relative position of the actual value of the indicator and the allowable range of variation [11]. Since the ship often operates in the wind and waves, there are often upper and lower limits for certain indicators. This measurement method is very suitable here. The measurement process is as follows:

Determine the allowable range, the satisfaction value $x^h_i$ and the disallowed value $x^s_i$ of each indicator. Satisfaction is the most ideal state of the indicator. The value of the disallowed value is the boundary value that the indicator should not appear. It is often given by a document or an experienced expert.

Calculate the efficacy factor of each indicator:

$$f_i = \frac{x^h_i - x^s_i}{x^h_i - x^l_i}$$

(4)

Comprehensive Scoring with Weighted Geometric Averaging

The weighted geometric evaluation method is especially suitable for things with strong relationship between indicators, and is more sensitive to changes in indicators, especially small changes. Since the movement of ships in wind and waves often has strong coupling, the evaluation method is especially suitable for the evaluation of the adaptability of ship wind and wave. The rating formula is as follows:

$$F = \sqrt[\sum w_i]{\prod y_i^{w_i}}$$

(5)

$$y_i = f_i M + (100 - M), M \neq 0,100$$

(6)

Where: $M$ is for the score, the score for a single indicator is $[100 - M, 100]$.

EXAMPLE ANALYSIS

According to the ship type data given in article [13], the following five types of ship types are comprehensively evaluated under the sea conditions of the sea speed of 30 kn.

Due to limited conditions, only some typical data are listed in the text, as shown in Table II. The weight of the first level indicator is obtained by the analytic hierarchy process $\{0.3,0.6,0.1\}$. 

$$W_i = W_i^1 + \beta W_i^2$$

(3)
TABLE II. INDICATOR DATA.

| Primary Indicator | Secondary Indicators | R0 | V1 | V2 | UV1 | UV2 | Maximum | Minimum |
|-------------------|----------------------|----|----|----|-----|-----|---------|---------|
| Wave Resistance   | Heave                | 2.54 | 2.72 | 2.68 | 3.03 | 2.74 | 3.03 | 2.54 |
|                   | Pitch                | 3.56 | 2.83 | 2.47 | 2.95 | 2.68 | 3.56 | 2.47 |
|                   | Acceleration        | 6.22 | 4.63 | 4.52 | 4.97 | 4.49 | 6.22 | 4.49 |
|                   | Deck Wave           | 15  | 16  | 14  | 11  | 13  | 16  | 11  |
| Rapidity          | Wind Speed          | 22.6 | 23.4 | 23.5 | 22.9 | 23.3 | 23.5 | 22.6 |
|                   | Hull Roughness      | 8.0  | 7.8  | 7.5  | 8.1  | 7.9  | 8.1  | 7.5  |
| Stability         | Balance Number      | 143  | 168  | 176  | 188  | 176  | 188  | 143  |
|                   | Anti-horizontal Speed | 1.58 | 1.84 | 1.79 | 1.76 | 1.91 | 1.91 | 1.58 |

In order to comprehensively consider objective and subjective factors, this paper takes the preference factor and the weight distribution is shown in Table III.

TABLE III. INDICATOR WEIGHT TABLE.

| Primary Indicator | Secondary Indicators | Mean | Standard Deviation | Coefficient of Variation | Variation Weight | AHP Weight | Comprehensive Weight |
|-------------------|----------------------|------|--------------------|--------------------------|-----------------|------------|----------------------|
| Wave Resistance   | Heave                | 2.74 | 0.16               | 0.06                     | 0.13            | 0.25       | 0.06                 |
|                   | Pitch                | 2.90 | 0.37               | 0.13                     | 0.29            | 0.25       | 0.08                 |
|                   | Acceleration        | 4.97 | 0.65               | 0.13                     | 0.30            | 0.25       | 0.08                 |
|                   | Deck Wave           | 13.80| 1.72               | 0.12                     | 0.28            | 0.25       | 0.08                 |
|                   | Wind Speed          | 23.14| 0.34               | 0.01                     | 0.36            | 0.75       | 0.33                 |
|                   | Hull Roughness      | 7.86 | 0.21               | 0.03                     | 0.64            | 0.25       | 0.27                 |
| Rapidity          | Balance Number      | 170.20| 15.03             | 0.09                     | 0.59            | 0.25       | 0.04                 |
| Stability         | Anti-horizontal Speed | 1.78 | 0.11               | 0.06                     | 0.41            | 0.75       | 0.06                 |

In order to clearly distinguish the differences in the adaptability of wind and wave environment for these ship types, the scores of the scores and the scores of the single indicators are as shown in Table IV.

TABLE IV. SCORE SHEET.

| Primary Indicator | Secondary Indicators | R0 | V1 | V2 | UV1 | UV2 |
|-------------------|----------------------|----|----|----|-----|-----|
| Wave Resistance   | Heave                | 20 | 74 | 100| 65  | 85  |
|                   | Pitch                | 20 | 94 | 99 | 78  | 100 |
|                   | Acceleration        | 36 | 20 | 52 | 100 | 68  |
|                   | Deck Wave           | 20 | 91 | 100| 47  | 82  |
| Rapidity          | Wind Speed          | 50 | 70 | 100| 40  | 60  |
|                   | Hull Roughness      | 20 | 64 | 79 | 100 | 79  |
| Stability         | Balance Number      | 20 | 83 | 71 | 64  | 100 |

In order to further analyze the different effects of subjective weight and objective weight in the evaluation process, this paper calculates the scores of these ship types under different preference factors, as shown in Table V.

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| Preference factor | R0 | V1 | V2 | UV1 | UV2 |
|------------------|----|----|----|-----|-----|
| 0                | 27 | 74 | 90 | 50  | 79  |
| 0.1              | 28 | 74 | 90 | 50  | 78  |
| 0.2              | 28 | 73 | 90 | 51  | 77  |
| 0.3              | 28 | 73 | 91 | 51  | 77  |
| 0.4              | 29 | 72 | 91 | 51  | 76  |
| 0.5              | 29 | 72 | 91 | 51  | 76  |
| 0.6              | 30 | 71 | 91 | 51  | 75  |
| 0.7              | 30 | 70 | 91 | 51  | 75  |
| 0.8              | 31 | 70 | 91 | 51  | 74  |
| 0.9              | 31 | 69 | 91 | 52  | 73  |
| 1                | 32 | 69 | 91 | 52  | 73  |

CONCLUSION

This paper comprehensively considers many factors and establishes a comprehensive evaluation index system for ship weather and wave environment adaptability. Using the efficiency coefficient metrics, the results are visualized in the form of comprehensive scores, and the environmental adaptability of different ship types is effectively distinguished.

Through the calculation of the example, the different preference factors are analyzed, which shows that the environmental adaptability of the ship V2 is the best both objectively and subjectively, and the environmental adaptability of R1 is the worst. The result is consistent with the actual, indicating the accuracy of the evaluation method in this paper.

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