An Evaluation Method of Ship Maneuverability based on Grey Relational Theory and TOPSIS

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Abstract

The safety of maritime traffic is an important cornerstone for sustaining global economic growth, promoting the development of world trade and the movement of people. With the aim of improving the evaluation of ship maneuverability, through investigating various kind of evaluation methods, an evaluation method of ship maneuverability is suggested based on grey relational theory and TOPSIS. The grey absolute correlation degrees of evaluation indexes and the weight of each index are work out by means of the grey correlation analysis theory. Following TOPSIS, the weighted decision matrix is constructed on the basis of Hausdorff distance instead of Euclidean distance and the proximity of performances of designs to the benchmark are calculated. The design of optimal ship maneuverability can be decided according to the smallest relative degree of proximity. The rationality and effectiveness of the method is validated by practical data set.

Keywords

Maritime Traffic; Ship Maneuverability; Grey Relational Theory; Comprehensive Evaluation.

1. Introduction

The number of total loss ships caused by maritime traffic accidents is about 200 every year, and the number only decreases slightly with the growth of the year, while the number of non-total loss ships generally increases with the growth of the year, which indicates that the current global maritime traffic safety is still facing a severe situation. At the same time, the consequences of maritime traffic accidents are generally very huge, not only will cause huge economic losses and casualties, but also cause serious pollution to the Marine environment.

Ship maneuverability is one of the important navigational performance of ships, which is closely related to the safe navigation of ships. The International Maritime Organization (IMO) and various countries have put forward strict requirements for each single indicator of ship maneuverability [1]. In the past, when evaluating whether the maneuverability of a ship meets the requirements, it is basically based on a single index to evaluate its merits. In essence, if each single index meets the specified requirements, it can only be said that the maneuverability of the ship type is feasible, but not necessarily optimal. In practical work, it is often necessary to choose the ship type with the best maneuverability from many feasible ship types. Therefore, ship maneuverability evaluation is often a multi-objective, multi-index system evaluation problem [2]. In order to make accurate evaluation of ship maneuverability, a convenient and effective comprehensive evaluation method of ship maneuverability must be established on the basis of in-depth study of ship maneuverability characteristics and various systematic evaluation methods.

The IMO Resolution MSC.137 (76) "Standards for Ship Maneuverability" reflects the important role of ship maneuverability in navigation safety, and provides specific guidance for the competent authorities in formulating and implementing standards for ship maneuverability, which is conducive to improving maritime safety and strengthening the protection of the Marine environment. The indicators of ship maneuverability include the following four kinds: turning ability. It measures a ship's ability to turn with full rudder. Initial cycle capability. It is used to measure the ship's ability to change course in a direct course, reflecting the ship's ability to respond to medium rudder Angle. Yaw correction and course stabilization capability. It measures a ship's ability to steer its course. It refers to when the ship enters the state of rotation and the angular velocity reaches a certain value when the opposite direction of the rotation steering, the ship's response to the rudder. Ability to stop a ship. The ability to stop a ship is an index to measure the inertia of ship motion.

2. Comprehensive evaluation method based on TOPSIS grey correlation analysis

Grey theory is an analytical method to deal with uncertain information, while TOPSIS method can reflect the overall situation and carry out comprehensive evaluation, so it has universal applicability [3][4]. TOPSIS with grey correlation analysis is used to distinguish ship maneuverability. Firstly, the evaluation index system is established. Then, taking into account the advantages of subjective and objective weighting methods, combining them as index weighting, selecting the appropriate absolute ideal solution, using weighted Mahalanobis distance to improve the TOPSIS grey correlation analysis method, to calculate the comprehensive grey correlation degree of each device and the weighted. [5][6] Mahalanobis distance between each device and the positive and negative absolute ideal state. Finally, the comprehensive proximity degree is calculated by the comprehensive grey correlation degree and the weighted Mahalanobis distance.

2.1 Data preprocessing

The characteristic index data of each sample was used as the evaluation index matrix: In the formula, n represents the number of samples; m represents the number of indicators; a_{ij} represents the jth index of ith sample.

$$A = \begin{bmatrix} a_{11} & \cdots & a_{1n} \\ \vdots & \cdots & \vdots \\ a_{m1} & \cdots & a_{mn} \end{bmatrix} \tag{1}$$

According to Equation (2), normalization of Equation (1) can be obtained: $X = \left(x_{ij}\right)_{mn}$

$$x_{ij} = \frac{a_{ij}}{\frac{1}{m}\sum_{i=1}^{m} a_{ij}} \tag{2}$$

2.2 Build positive and negative ideal samples.

The mechanism of TOPSIS is to select positive and negative optimal solutions, and score the samples to be evaluated by detecting the degree of proximity between the evaluated object and the optimal and the worst solutions. If R^+_0 represents a positive ideal sample and R^-_0 represents a negative ideal sample, then:

$$\begin{cases} R_0^+ = \left(\max\limits_{1\le i\le n} x_{ij} \,|j = 1\cdots m\right) \\ R_0^- = \left(\min\limits_{1\le j\le m} x_{ij} |j = 1\cdots m\right) \end{cases} \tag{3}$$

2.3 The comprehensive grey relational degree was calculated

The traditional grey correlation degree is to quantitatively measure the proximity degree of each factor through the proximity degree of the sequence curve shape of each factor, while the grey absolute correlation degree reflects the similarity degree of the data change rate, that is, describes the similarity degree of the derivative. Using absolute grey relational degree to improve the traditional grey relational degree to form a comprehensive grey relational degree can better describe the similarity degree of two sequences.

$$\theta_i = \alpha\delta_i + (1-\alpha)\tau_i \tag{4}$$

In the formula, δ_i is the grey relational degree, τ_i is the absolute grey relational degree, and α is the weight of the traditional grey relational degree.

2.4 Calculate the weighted Markov distance

Let the positive covariance matrix be the covariance matrix of the matrix composed of the positive gray correlation matrix and the optimal solution, and the negative covariance matrix be the covariance matrix of the matrix composed of the negative gray correlation matrix and the worst solution. Then the weighted Mahalanobis distance between the ith evaluation sequence and the optimal and the worst solution is $d_i^+ d_i^-$.

2.5 Calculate the approximation degree of the comprehensive state

The state proximity degree of the comprehensive grey correlation and the weighted Mahalanobis distance are respectively:

$$\begin{cases} P_i = \frac{d_i^-}{d_i^+ + d_i^-} \\ Q_i = \frac{\theta_i^+}{\theta_i^+ + \theta_i^-} \end{cases} \tag{5}$$

The comprehensive state proximity degree is:

$$A_i = a_1 P_i + (1 - a_1) Q_i \tag{6}$$

3. The actual validation

In order to verify the rationality of the evaluation method in the paper, in the Matlab environment, to realize the calculation of each evaluation index, comprehensive correlation degree, Markov weighted distance and comprehensive evaluation results. Ship maneuverability test data, see Table 1.

Table 1 Ship maneuverability test data

object	turning ability	Initial cycle capability.	Yaw correction and course stabilization capability	Ability to stop a ship
1	2.94	3.06	16	19.17
2	3.01	3.39	14	14.57
3	2.70	3.33	11	13.54
4	3.78	4.47	9	11.15
5	2.95	3.15	10	11.87

The ideal solution is calculated according to the formula:

$$R^+ = [0.2158 \quad 0.2139 \quad 0.2022 \quad 0.1920]$$
$$R^- = [0.3021 \quad 0.3124 \quad 0.3476 \quad 0.3413]$$

The comprehensive state posting schedule is obtained as Table 2.

Table 2 Synthesize posted progress sorting results

object	1	2	3	4	5
A	0.3455	0.5486	0.7814	0.6146	0.8736

It can be seen from Table 2 that the comprehensive handling performance of the five ships is ranked as follows: (5) > (3) > (4) > (2) > (1), that is type 5 has the best comprehensive handling performance, while ship type 1 has the worst comprehensive handling performance. The method uses grey correlation analysis method to determine the index weight, which ensures the rationality of the weight; The classical TOPSIS principle is used to establish the evaluation model, which ensures the scientific nature of the evaluation model. Therefore, the evaluation results are correct and effective.

4. Conclusion

In this paper, an evaluation method based on the improved TOPSIS grey correlation analysis of ship maneuverability is proposed. Taking a certain 5 ships as the object, the evaluation index system is established from multiple perspectives. Finally, the main conclusions are drawn as follows through experiments.

By using the mixed weighting method to calculate the weight of each index, the unique advantages of each single method are taken into account and the rationality of the weight of the comprehensive index is improved; Weighted Mahalanobis distance is used to measure the similarity between the samples to be evaluated and the positive and negative ideal samples, so that the accuracy of the comprehensive evaluation results of this method is higher.

On the basis of the traditional grey correlation analysis method, the dynamic resolution coefficient is considered to replace the constant resolution coefficient; And from two different angles of proximity and similarity, the traditional grey relational degree which describes the shape proximity of sequence curves of various factors and the absolute grey relational degree which reflects the similarity of data change rate are combined to get the comprehensive relational degree. Finally, the ranking results of the maneuverability of multiple ships calculated by the method proposed in this paper are more practical and provide more accurate guidance for ship control and maintenance.

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