# Performance Evaluation of Maritime Search and Rescue in Shandong Province

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**Abstract.** Maritime emergency rescue has always been a key area of research by experts and scholars. This article draws on the practical experience of performance evaluation in the public domain, selects four dimensions of economy, efficiency, effectiveness, and fairness according to the "4E" theory, and uses game theory to combine the subject and object. The weight value is combined and optimized, and then combined with TOPSISI and gray relational analysis method to evaluate the performance of marine emergency rescue in Shandong area from 2012 to 2022. The results show that: (1) Effectiveness and economy are the most important factors affecting the performance evaluation of Shandong maritime search and rescue, among which the success rate of rescue personnel contributes the most to effectiveness, followed by the success rate of property rescue, which contributes the most to economic indicators It is the economics of the total property rescue and the economics of the rescuers (2) From 2012 to 2022, Shandong's maritime search and rescue performance score was the lowest in 2022, and the performance score was the highest in 2014, and the overall performance score fluctuated between 2012 and 2022.

**Keywords:** rescue in danger; 4E performance evaluation; portfolio empowerment; TOPSIS; gray relational analysis

## 1 Introduction

The water transportation capacity in the Shandong sea area has developed rapidly, and the passenger and cargo throughput, maritime traffic flow, and ship entry and exit of coastal ports in the province have shown a steady growth trend. It has become one of the main routes for maritime transportation in China. However, over the years, maritime hazards have occurred frequently in the Shandong waters. While causing serious casualties and property damage, it will also have adverse effects on the navigation environment, navigation order, and social public interests.

At present, research on maritime search and rescue and evaluation is mainly reflected in three aspects: ① Exploration of search and rescue system. Tan Ting [1] combined with the characteristics of joint maritime search and rescue operations, put forward suggestions for the construction of maritime search and rescue systems. Liang Xiaocheng et al. [2] put forward countermeasures and suggestions to improve



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the emergency system of maritime search and rescue by analyzing the changes and impact of the new "Maritime Traffic Safety Law" in maritime search and rescue. However, the exploration of the search and rescue model is too macroscopic and does not take into account the differences between regions. ②Assessment evaluation. Chen Zhengyan [3] constructed an evaluation index system for maritime search and rescue emergency capabilities based on the composition and functions of the Shanghai maritime search and rescue system. Ma Xiaoxue [4] analyzed the influencing factors of maritime search and rescue evaluation, and constructed the evaluation index system of China's maritime search and rescue success rate. Wang Xi [5] made a cost-benefit evaluation of Tianjin maritime rescue based on the input-output ratio, and clarified the economic and social benefits obtained after each search and rescue. Most of these evaluations are aimed at the evaluation of search and rescue capabilities, and there is no better evaluation model for the performance of maritime search and rescue. ③ Selection of evaluation methods. , the research in the field of public assistance is rich. Yang Guiyun[6] established a nursing performance evaluation model for community health service centers and provided practical tools for nursing performance evaluation. Diogo Ferreira de Lima Silva et al.· [7] used TOPSIS to evaluate the degree of freedom of 180 countries and divided them into five predefined ordered categories. S. Tripathy et al. [8] evaluated the effectiveness of optimizing the multiple performance characteristics of H-11 mold steel copper electrode PMEDM through gray correlation and TOPSIS. Sun Ji; Liu Jiajun[9] proposed a combination of CRITIC, entropy weight method and mean square variance analysis for the different emphases of each weighting method. Peng Jiaqi[10] established a model based on the combined weighting method of game theory, and compared the evaluation results with the disaster information of Zhengzhou. Yan Changjian [11] et al. constructed an integrated gray cloud whitening weight function model and cloud theory evaluation model for maritime search and rescue emergency management capabilities.

## 2 Index system construction and data sources

### 2.1 Construction of indicator system

This paper is based on the selection principle of performance evaluation indicators of 4E theory, according to its economy, efficiency, effectiveness and fairness, through field research in Shandong area, combined with the actual situation of maritime search and rescue, comprehensive analysis affects the evaluation results of maritime search and rescue success rate. Based on many factors, five first-level indicators were preliminarily formulated. On this basis, through interviews with various experts and scholars and reading a large number of documents, combined with expert opinions, the proposed evaluation index system for the success rate of maritime search and rescue has been properly revised. Finally, the evaluation system of performance indicators for maritime emergency rescue in Shandong was determined, and the indicators contained in each dimension are shown in Table 1.

## 2.2 Data sources

The data used in this article is sourced from the website of Shandong Maritime Safety Administration https://www.sd.msa.gov.cn/ According to the inquiry, the economic costs of property, personnel, and other aspects were based on Wang Xi's[5] research on the economic investment and social benefits of maritime search and rescue.

The index weight of the AHP in qualitative analysis comes from the questionnaire survey. A total of 100 questionnaires were distributed, and 92 were returned, all of which were valid questionnaires. Among them, those who accepted the questionnaire survey were teachers with associate professor and above titles, captains of Dalian Maritime University, and relevant experts from Shandong Maritime Safety Administration and other units. The data of the qualitative indicators come from the questionnaire survey. A total of 60 questionnaires were sent out, and 56 questionnaires were received. Among them, teachers with the title of associate professor or above from Dalian Maritime University, relevant experts from Shandong Maritime Safety Administration and other units, major accidents and above rescued persons.

**Table 1.** Performance evaluation system for maritime emergency rescue

| Level 1 indicators | Level 2 indicators | Level 3 indicators | Indicator Interpretation | Indicator properties |
|---|---|---|---|---|
| Economic indicators$A_1$ | Equipment economy$A_{11}$ | Economy of aircraft$A_{111}$ | Number of aircraft involved in search and rescue/rescue times | — |
| | | Economy of Ship Quantity$A_{112}$ | Number of ships involved in search and rescue/times of rescue | — |
| | Personnel economy$A_{12}$ | The economics of participating in rescuers$A_{121}$ | Expenditure of participating rescuers/total assistance expenditure | — |
| | | Economical efficiency of duty personnel in | On-duty personnel | — |

| | | | | |
|---|---|---|---|---|
| | | search and rescue centerA122 | cost/total rescue cost | |
| | material economyA13 | Fuel economyA131 | Fuel Consumption Funds Used / Total Salvage Costs | — |
| | | The economics of relief suppliesA132 | Material cost/total rescue cost | — |
| | Fund economyA14 | Economics of bailout fundsA141 | Total salvage cost/total salvage assets | + |
| Efficiency indexA2 | Organization SpecificationA21 | The perfection of the rescue departmentA211 | Qualitative analysis | + |
| | | Clarity of department responsibilitiesA212 | Qualitative analysis | + |
| | Institutional System PerfectionA22 | Rationality of the content of the aid systemA221 | Qualitative analysis | + |
| | | Rescue business process coordinationA222 | Qualitative analysis | + |
| | People Performance ManagementA23 | Staff motivationA231 | Qualitative analysis | + |
| | | Rationality of personnel promotion mechanismA232 | Qualitative analysis | + |
| | Rescue efficiencyA24 | Timeliness of rescueA241 | Qualitative analysis | + |
| | Control efficiencyA25 | Maritime danger prevention and control rateA251 | Number of near misses avoided/near misses at sea | + |
| Effectiveness | Effective use of resourcesA31 | Reasonable mobilization of rescue re- | Qualitative analysis | + |

| | | | | |
|---|---|---|---|---|
| indexA3 | | sourcesA311 | | |
| | Aid EffectivenessA32 | Rescuer success rateA321 | Number of people successfully rescued/total number of people rescued | + |
| | | Salvage property success rateA322 | Successfully rescued property/total property rescued | + |
| | Effectiveness of social influenceA33 | Improving the image of the rescue departmentA331 | Qualitative analysis | + |
| | | Rescued personnel satisfactionA332 | Qualitative analysis | + |
| Fairness indicatorA4 | Investment fairnessA41 | Invest geographicallyA411 | Qualitative analysis | + |
| | | Investment amount is fairA412 | Qualitative analysis | + |
| | Bailout fairnessA42 | Fairness in emergency rescue processA421 | Qualitative analysis | + |

# 3 Performance evaluation of marine emergency rescue in Shandong area

## 3.1 Model Construction and Evaluation

Taking the data collected in Shandong area from 2012 to 2022 as the research sample, According to formulas (1) to (7), it is used to verify the practicability and rationality of combined weighting-gray correlation and TOPSIS method for the performance evaluation of emergency rescue in Shandong sea area. First of all, based on the comprehensive analysis of the present situation of rescue at sea in Shandong waters, and through field visits and surveys, expert questionnaires and other methods to collect relevant index data of rescue at sea in Shandong area, the weight of the evaluation index is determined by the combination weighting method of game theory, and the weight of the evaluation index is determined by using the gray Correlation and

TOPSIS method for performance evaluation of marine emergency rescue in Shandong area.

The grey relational TOPSIS method retains the advantages and disadvantages of the traditional TOPSIS method, ranking by calculating the distance between alternative solutions and ideal solutions. At the same time, the introduction of grey relational analysis can overcome the problem of low discrimination in the evaluation of traditional TOPSIS methods, and also reflect the similarity of the geometric shapes of the data curves of the schemes. The Binding energy of the two can more comprehensively reflect the real situation of each scheme. The calculation process of the grey correlation TOPSIS method is as follows:

(1) Building a weighted standardized decision matrix based on indicator weights:

$$\boldsymbol{T} = \begin{bmatrix} t_{11} & \cdots & t \\ \vdots & \ddots & \vdots \\ t_{m1} & \cdots & t_{mn} \end{bmatrix} \tag{1}$$

(2) Determine the positive ideal solution $T^+$ and negative ideal solution $T^-$ of the weighted standardized decision matrix:

$$T^+ = \left(v_1^+, v_2^+, \cdots v_n^+\right) = \left\{\max v_{ij} \middle| j \in J_1, \min v_{ij} \middle| j \in J_2\right\},$$
$$T^- = \left(v_1^-, v_2^-, \cdots v_n^-\right) = \left\{\min v_{ij} \middle| j \in J_1, \max v_{ij} \middle| j \in J_2\right\} \tag{2}$$

(3) Calculating Euclidean distances $d_j^+$ and $d_j^-$ based on TOPSIS method.:

$$d_i^+ = \sqrt{\sum_{j=1}^{n} (v_{ij} - v_j^+)^2}\ , d_i^- = \sqrt{\sum_{j=1}^{n} (v_{ij} - v_j^-)^2} \tag{3}$$

(4) Calculate the grey correlation coefficient matrices $r_i^+$ and $r_i^-$ between the positive and negative ideal solutions of each scheme:

$$r_{ij}^+ = \frac{\min\limits_{i=1}^{m}\min\limits_{j=1}^{n}\left|t_j^+ - t_{ij}\right| + \rho \max\limits_{i=1}^{m}\max\limits_{j=1}^{n}\left|t_j^+ - t_{ij}\right|}{\left|t_j^+ - t_{ij}\right| + \rho \max\limits_{i=1}^{m}\max\limits_{j=1}^{n}\left|t_j^+ - t_{ij}\right|}, r_{ij}^- = \frac{\min\limits_{i=1}^{m}\min\limits_{j=1}^{n}\left|t_j^- - t_{ij}\right| + \rho \max\limits_{i=1}^{m}\max\limits_{j=1}^{n}\left|t_j^- - t_{ij}\right|}{\left|t_j^- - t_{ij}\right| + \rho \max\limits_{i=1}^{m}\max\limits_{j=1}^{n}\left|t_j^- - t_{ij}\right|} \tag{4}$$

$$r_i^+ = \frac{1}{n}\sum_{j=1}^{n} r_{ij}^+ \ , r_i^- = \frac{1}{n}\sum_{j=1}^{n} r_{ij}^- \tag{5}$$

(5) Perform dimensionless processing on $d_j^+$、$d_j^-$、$r_i^+$、$r_i^-$:

$$D_i^+ = \frac{d_i^+}{i = \max\{d_i^+\}}, R_i^- = \frac{r_i^-}{\max\{r_i^-\}}, R_i^+ = \frac{r_i^+}{\max\{r_i^+\}} \tag{6}$$

(6) Calculate the proximity between the evaluation unit and the "ideal solution":

$$S_i^+ = \alpha_1 D_i^- + \alpha_2 R_i^+ , S_i^- = \alpha_1 D_i^+ + \alpha_2 R_i^- , Q_i = S_i^+ / \left( S_i^+ + S_i^- \right) \quad (7)$$

Among them, $\alpha_1$ and $\alpha_2$ are preference coefficients. In this paper, $\alpha_1 = \alpha_2 = 0.5$, and the larger the $Q_i$ value, the higher the performance evaluation of the evaluation unit.

Dimensionless processing of sample data of 23 evaluation indicators of maritime emergency rescue in Shandong area. Calculation of the evaluation index weight: firstly, use the Analytic Hierarchy Process (AHP) to obtain the subjective weight $\omega$ of the index; then, use the entropy weight method to obtain the objective weight $\lambda$ of the index according to the original data of maritime emergency rescue in Shandong; finally, based on the game theory ,the subjective weights and objective weights of indicators are combined using game theory to combine weights $\beta^*$ . According to the weighted decision-making matrix, determine the Euclidean distance from the feasible solution to the positive ideal point and the negative ideal solution of the evaluation index for each year of maritime emergency rescue in Shandong area, and then calculate the gray correlation coefficient of the positive and negative ideal solution, respectively, for the gray correlation coefficient and the Euclidean distance. The results of dimensionless processing are shown in Table 2. Finally, the results of closeness S, S and comprehensive performance evaluation Q are shown in Table 2.

**Table 2.** Performance evaluation results of each year in Shandong region

| Years | $D_i^+$ | $D_i^-$ | $R_i^+$ | $R_i^-$ | $S_i^+$ | $S_i^-$ | $Q_i^+$ |
|---|---|---|---|---|---|---|---|
| 2012 | 0.1385 | 0.2018 | 0.8552 | 0.8172 | 0.9517 | 0.8298 | 0.5342 |
| 2013 | 0.1388 | 0.1982 | 0.8620 | 0.8090 | 0.9473 | 0.8257 | 0.5343 |
| 2014 | 0.1320 | 0.2172 | 0.8740 | 0.8022 | 0.9977 | 0.8046 | 0.5536 |
| 2015 | 0.1358 | 0.2002 | 0.8780 | 0.7961 | 0.9609 | 0.8107 | 0.5424 |
| 2016 | 0.1299 | 0.2066 | 0.8721 | 0.7983 | 0.9724 | 0.7972 | 0.5495 |
| 2017 | 0.1554 | 0.1860 | 0.8440 | 0.8286 | 0.9088 | 0.8791 | 0.5083 |
| 2018 | 0.1592 | 0.1816 | 0.8211 | 0.8481 | 0.8856 | 0.9002 | 0.4959 |
| 2019 | 0.1373 | 0.1896 | 0.8531 | 0.8088 | 0.9223 | 0.8221 | 0.5287 |
| 2020 | 0.1989 | 0.1690 | 0.8608 | 0.8258 | 0.8792 | 0.9869 | 0.4712 |
| 2021 | 0.1578 | 0.1847 | 0.8292 | 0.8397 | 0.8974 | 0.8918 | 0.5016 |
| 2022 | 0.1700 | 0.1345 | 0.8125 | 0.8467 | 0.7724 | 0.9264 | 0.4547 |

### 3.2 Result analysis

The performance of marine emergency rescue in Shandong region from 2012 to 2022 is shown in Figure 1.

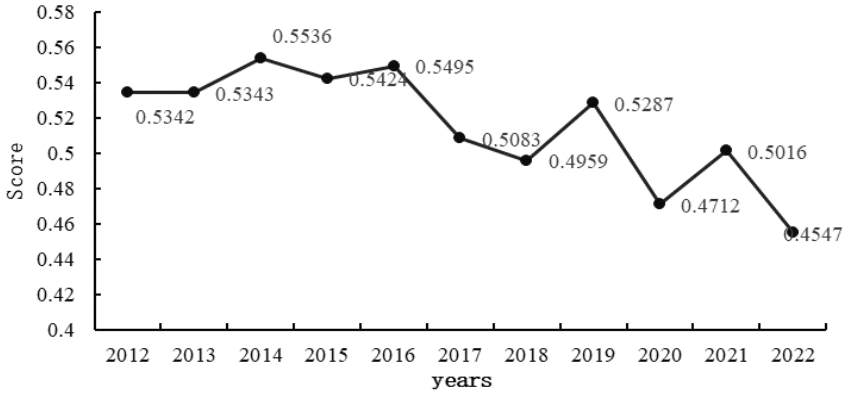


**Fig. 1.** 2012-2022 Shandong Maritime Emergency Rescue Performance Evaluation Level

Overall, the performance score of maritime emergency rescue in Shandong region reached its highest point in 2014, which was 0.5536, and reached the lowest point in 2022, which was 0.4547. In addition, during the period from 2012 to 2022, the overall performance score of Shandong Maritime Emergency Rescue will gradually decline amid fluctuations.

The reason for this can be explained from the reaction of the indicator data. In 2022, although the number of rescues will be 88, the number of ships mobilized will be as high as 4,710, and an average of 54 ships will be dispatched for each search and rescue, which is the highest in history. In addition, this year, the Maritime Safety Administration spent 301.6262 million yuan on maritime traffic safety, which is the most over the years, but the success rate of rescuers is only 83.3%. Problems such as unreasonable resource allocation and excessive investment are gradually exposed, resulting in the performance of Shandong sea area. Ratings fell overall. In 2014, the reason why the performance score was the highest was because the indicator data showed that the Shandong region participated in 127 maritime emergency rescues in that year, and the number of ships mobilized was 884, with an average of 7 ships dispatched for each search and rescue operation. The ratio is relatively high. In addition, the Maritime Safety Administration spent 284.23 million yuan on maritime traffic safety that year, which was relatively high, and the success rate of maritime search and rescue was 96.1%, the highest in the past 11 years. And on April 16, 2014, the "Shiyue" ship carrying 475 people sank 20 kilometers north of Pingfeng Island, Jindo County, Jeollanam-do, South Korea, killing 313 people and injuring 142. In order to deeply learn the lessons of the accident, the Shandong Maritime Affairs Department has adopted a number of measures to avoid and reduce the occurrence of maritime dangers, which has also improved the performance score of maritime danger rescue to a certain extent. It is worth noting that due to the outbreak of the new crown epidemic in 2020, due to the decline in efficiency and timeliness due to epidemic prevention requirements in China's maritime search and rescue process, and the increase in economic costs due to the demand for epidemic prevention materials, the performance score decreased. In addition, during the period from 2012 to 2022, although the num-

ber of rescues is decreasing year by year, the number of ships and aircraft dispatched by the rescue is gradually increasing, but the success rate of personnel and rescues has not increased significantly, resulting in a decline in performance scores.

## 4 Conclusions and recommendations

Based on the "4E theory", this paper establishes a performance evaluation index system for maritime emergency rescue, including economic index, efficiency index, effectiveness index and fairness index. Using AHP and entropy weight method to obtain the basic weight of the evaluation index, and further use the game theory to carry out combined weighting. Finally, empirical research is carried out using methods such as TOPSIS and gray relational analysis. The results show that: ①During the period from 2012 to 2022, the performance score in 2014 is the highest, and the performance score in 2022 is the lowest. Although the number of near-miss accidents has decreased, resource consumption has increased, resulting in a fluctuating decline in the performance score of Shandong Maritime Emergency Rescue. ② The weighting method based on game theory combines the weights obtained by AHP and entropy weight method through effective game play to jointly determine the comprehensive weight of the evaluation index. This method can give full play to the advantages of each weighting method, overcome the limitations caused by a single method, and make the weights more objective and accurate. ③In the empowerment method of game theory, the success rate of rescue personnel is the most important indicator, followed by the efficiency of property rescue. In terms of each dimension, according to the importance of each indicator, the order of importance is effectiveness, economy, efficiency, and fairness. Among them, the impact of economic indicators and effectiveness indicators is relatively high. The interaction of many index factors in different years is the main reason for the differences in the performance evaluation of maritime emergency rescue.

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