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Evaluation of maritime emergency rescue capability based on network analysis

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Abstract. Maritime emergency rescue operations are complex and random, it leads to the complexity of the evaluation of maritime emergency rescue capability. In this paper, we considered the relationship between the evaluation indexes of maritime emergency rescue capability, used Analytic Network Process to determine the weight of each index, took into account the feedback relationship between indicators to determine the index weight, improved the scientific and reliability of the model, and combined with fuzzy comprehensive evaluation to evaluate the rescue capability. According to the evaluation results which combined with the index weight, maritime sector can propose a targeted improvement measures to effectively improve maritime emergency rescue capability.

1. Introduction

With the vigorous development of the international shipping, maritime transport occupies a more and more important place in the development of economic globalization. In order to improve maritime emergency rescue capability, it is very important to evaluate the ability of maritime emergency rescue, point out the problems contrapuntally and put forward the corresponding solution. If the establishment of risk control system according to the existing problems and the corresponding solutions will be able to effectively promote maritime emergency rescue capability, reduce the maritime accident losses, but also can avoid resource waste in the process of maritime emergency rescue capability.

For the evaluation of emergency rescue capability in disaster, scholars at home and abroad have also done a lot of research. Yang Li and others used the improved AHP, entropy weight method and fuzzy comprehensive evaluation method to establish the evaluation model of coal mine emergency rescue capability[1]. Duan Zongtao and others used the analytic hierarchy process and fuzzy comprehensive evaluation method to establish the evaluation index system of expressway emergency rescue ability, designed the calculation model of evaluation results[2]. Miao ChengLin et al divided accidents into three links in advance, matter and afterwards to research the ability of prevention, detection, control, recovery, etc[3]. Daniel da Silva Avanzi et al used multi-criteria decision analysis (MCDA) to establish a applied in disaster management (DM) to assist the evaluation system[4].

According to the existing research results, we can see that there are a lot of researches on the evaluation of emergency rescue capability in disaster, however, there are few researches on the evaluation of maritime emergency rescue capability, there is no mature solution can effectively solve this problem at present. Different from the traditional evaluation model using AHP method to determine the weight of index, in this paper, the Analytic Network Process (ANP), which takes into account the correlation between the indexes, is used to sort the maritime emergency rescue capability index. Then, fuzzy comprehensive evaluation is used to evaluate the maritime SAR capability of the



rescue department. The evaluation results can truly reflect the excellent degree of maritime emergency rescue capability of rescue departments, according to the importance of the rescue capability evaluation index, we can find out the weakness of the rescue capability, it provides an accurate and effective reference for further improving maritime SAR capability.

2. Maritime rescue capability evaluation model

2.1 Rescue capability evaluation index system

Maritime rescue capability evaluation index system is composed of each index and the relationship between them.

Maritime rescue capability index. Through the analysis of the existing research results and the actual rescue case, we summed up the upper and lower two levels of maritime rescue capability evaluation index as shown in figure 1.

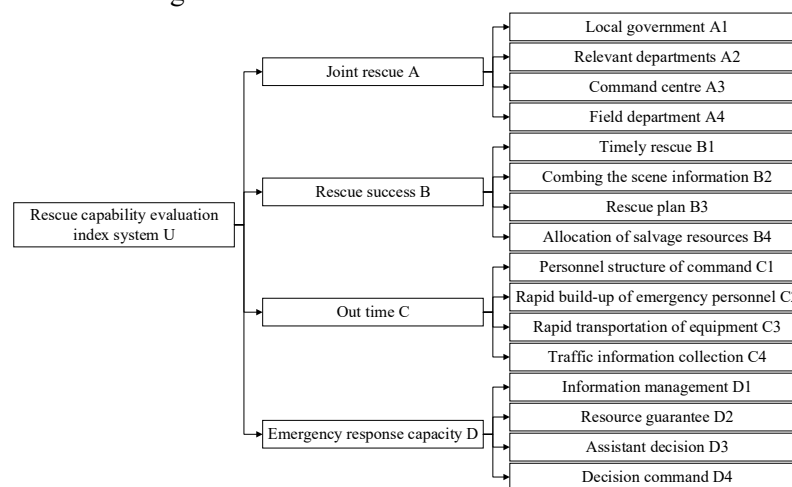


Figure 1. Assessment indexes of maritime rescue capability

2.2 Importance ranking of rescue capability evaluation index

Identifying and strengthening the construction of relative important indicators can help the maritime sector to effectively improve the maritime emergency rescue capability. We use the Analytic Network Process (ANP) which takes into account the relationship between the indicators to sort the emergency rescue capability index[5].

The network structure of maritime rescue capability evaluation. The feedback relationship between the evaluation indexes of maritime rescue capability is mainly based on practical experience and expert opinion, determined the network structure of maritime rescue capability evaluation, figure 2.

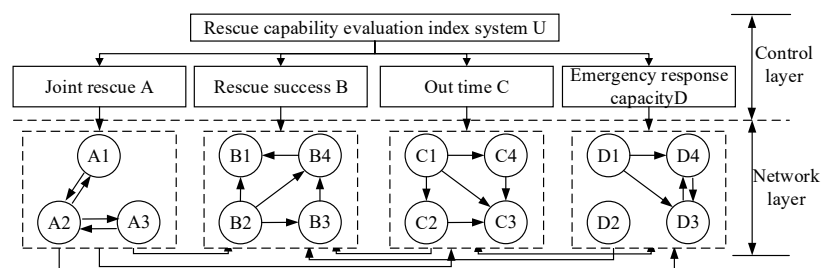


Figure 2. The network structure of maritime rescue capability evaluation

The importance ranking of four criteria layers. Because the criterion layer index is independent of each other, the corresponding weights can be determined by the traditional AHP method. Indicators

are determined according to the 1~9 scale table, and the Delphi method is used to reciprocally compare index of the degree of relative importance, so as to construct paired comparison matrix B. Table 1 is the criterion layer index of paired comparison matrix and the weight vector of matrix B.

Table 1. criterion layer index of paired comparison matrix and the weight vector of matrix B.

Criterion layer	A	B	C	D	Weight value w1
A	1	1/2	1	3	0.2109
B	2	1	1	5	0.3388
C	2	1	1	5	0.3388
D	1/3	1/5	1/5	1	0.0647

We tested the consistency of the results, random consistency ratio $CR=0.08643 < 0.1$, it passed the consistency test.

Importance ranking of network layer indexes. There are several criteria for evaluating the network structure of maritime emergency rescue, in order to rank the importance of network layer metrics, first of all, we need to determine the unweighted super matrix of subordinate indexes of each criterion. By researching and analyzing the joint rescue principles, combined with the Delphi method to determine the judgment matrix of reciprocally compare index.

(1) Determination of unweighted super matrix W

According to figure 2, the lower element A of joint rescue principles, local government A1 as the criterion, comparison of the relative importance of the criteria A1 according to the relevant departments A2, command center A3 and field A4, the sorting vector $(\omega_{11}^{(11)}, \omega_{12}^{(11)}, \omega_{13}^{(11)})^T$ is obtained by combining the characteristic root method. Then took the relevant departments A2, command center A3 and field Department A4 as criteria, repeated the steps above, the corresponding sort vectors are obtained, and the vector matrix W_{11} is integrated.

$$W_{11} = \begin{bmatrix} \omega_{11}^{(11)} & \omega_{11}^{(12)} & \omega_{11}^{(13)} & \omega_{11}^{(14)} \\ \omega_{12}^{(11)} & \omega_{12}^{(12)} & \omega_{12}^{(13)} & \omega_{12}^{(14)} \\ \omega_{13}^{(11)} & \omega_{13}^{(12)} & \omega_{13}^{(13)} & \omega_{13}^{(14)} \\ \omega_{14}^{(11)} & \omega_{14}^{(12)} & \omega_{14}^{(13)} & \omega_{14}^{(14)} \end{bmatrix} = \begin{bmatrix} 1 & \frac{1}{3} & \frac{1}{5} & \frac{1}{5} \\ 3 & 1 & \frac{1}{3} & \frac{1}{5} \\ 5 & 3 & 1 & 1 \\ 5 & 3 & 1 & 1 \end{bmatrix} \quad (1)$$

Similarly, the vector matrix W_{ij} of the lower level element set of other criterion layer is obtained, and then they were integrated, we established the unweighted super matrix W.

$$W = \begin{bmatrix} W_{11} & W_{12} & W_{13} & W_{14} \\ W_{21} & W_{22} & W_{23} & W_{24} \\ W_{31} & W_{32} & W_{33} & W_{34} \\ W_{41} & W_{42} & W_{43} & W_{44} \end{bmatrix} = \begin{bmatrix} 0.0679 & 0.1524 & 0.3899 & 0.3899 \\ 0.5261 & 0.0872 & 0.2042 & 0.1826 \\ 0.1322 & 0.4165 & 0.3829 & 0.0673 \\ 0.0712 & 0.3174 & 0.2358 & 0.3756 \end{bmatrix} \quad (2)$$

(2) Set weight matrix a

Since each network layer index is affected by the size of comparative in the corresponding element concentration judgment, therefore, each column vector of the super matrix W of each vector matrix is not normalized. In order to solve the above problems, paired comparison of element groups, we figured out the judgment matrix, calculated the eigenvector and got the weighted matrix a:

$$a = W^T = \begin{bmatrix} a_{11} & a_{12} & a_{13} & a_{14} \\ a_{21} & a_{22} & a_{23} & a_{24} \\ a_{31} & a_{32} & a_{33} & a_{34} \\ a_{41} & a_{42} & a_{43} & a_{44} \end{bmatrix} \quad (3)$$

In the formula: $a_{ij} = 0$ expresses the indicator i does not affect the index j , the sum of the elements of the matrix A is 1.

(3) Set weighted super matrix $\bar{W}$

The weighted matrix a multiplied by the unweighted super matrix W could be calculated from the weighted super matrix $\bar{W}$, Each column vector element of $\bar{W}$ represents the size of the impact on column index affect by the corresponding network layer index, if there is no influence, it will be 0.

$$\bar{W} = a \times W = W^T \times W \quad (4)$$

(4) The limit of weighted matrix $\bar{W}$

Due to the relationship between feedback and negative feedback in the network of maritime rescue capability evaluation, the two indicators could be compared directly and indirectly, thus increasing the complexity of determining index priority. Therefore, in order to determine the priority of the stability index, the limit $\bar{W}_l$ of weighted super matrix $\bar{W}$ was found out:

$$\begin{aligned} \bar{W}_l &= \lim_{t \rightarrow \infty} \bar{W}^t \\ &= \begin{bmatrix} 0.0046 & 0.0801 & 0.0519 & 0.0278 \\ 0.0801 & 0.0076 & 0.0850 & 0.0579 \\ 0.0519 & 0.0850 & 0.1466 & 0.0159 \\ 0.0278 & 0.0579 & 0.0159 & 0.1411 \end{bmatrix} \end{aligned} \quad (5)$$

The first line represents the weight W_2 of the corresponding network layer under the criterion A, and so on, the last line represents the weight W_5 of the corresponding network layer under the criterion D. Thus we got the criterion layer index and its corresponding weight and index layer index and its corresponding final weight as shown in Table 2:

Table 2. Criterion layer index and its corresponding weight, index layer index and its corresponding final weight

Criterion layer index and its weight	A	0.2109	B	0.3388	C	0.3388	D	0.0647
Index level index and corresponding final weight	A1	0.0046	B1	0.0801	C1	0.0519	D1	0.0278
	A2	0.0801	B2	0.0076	C2	0.0850	D2	0.0579
	A3	0.0519	B3	0.0850	C3	0.1466	D3	0.0159
	A4	0.0278	B4	0.0579	C4	0.0159	D4	0.1411

2.3 Fuzzy comprehensive evaluation

The maritime emergency rescue work involves multi departmental joint decision-making and coordinated implementation; therefore, the evaluation of maritime emergency rescue capability is a complex fuzzy problem that needs fuzzy comprehensive evaluation method to evaluate the emergency rescue capability of the maritime sector.

(1) Set index set and comment set

According to the established emergency rescue capability evaluation system, set up the first level

index set U and the second index set U_1, U_2, U_3, U_4 :

$$U = \{A, B, C, D\}, U_1 = \{A_i\}, U_2 = \{B_i\}, U_3 = \{C_i\}, U_4 = \{D_i\} \quad i = 1, 2, 3, 4 \quad (6)$$

According to the characteristics of the evaluation index of maritime emergency rescue capability, it was divided into five qualitative levels:

$$V = \{\text{excellent, good, medium, qualified, poor}\} \quad (7)$$

Excellent index indicates that the indicator can greatly improve the ability of maritime emergency rescue, and so on; poor index indicates that the index will deteriorate the maritime emergency rescue capability.

According to the establishment of the evaluation index of maritime emergency rescue capability system, we determined the weights of indicators at all levels through ANP, combined with fuzzy evaluation model which based on membership function, comprehensively evaluated a particular Marine emergency rescue unit ability of emergency rescue. The synthetic algorithm of fuzzy comprehensive evaluation is shown in formula (8):

$$B = W \circ R \quad (8)$$

In the formula: ANP is the weight vector of the index weight of the maritime emergency rescue capability index determined by W ; R is a fuzzy relation matrix; B represents the fuzzy comprehensive evaluation matrix of this level; “ $\circ$ ” is a composition operator which is $M(\bullet, \oplus) : \bullet$ is defined as $a \bullet b = a \times b = ab$; $\oplus \bullet$ is defined as $a \oplus b = (a + b) \wedge 1$.

The way to determine the membership degree of each index. For a certain evaluation index of the evaluation set partitioning with membership function description which is describe by isosceles triangle membership function. The mathematical description of the membership function of the i index is shown in figure (9):

$$r_i(v_k) = \begin{cases} \frac{s_i - m_k}{n_k - m_k} & m_k \leq s_i \leq n_k \\ \frac{p_k - s_i}{s_i - n_k} & n_k \leq s_i \leq h_k \\ 0 & \text{other} \end{cases} \quad (9)$$

In the formula m_k, n_k, p_k are the corresponding constants of the t th rating, for the standardized indicators, corresponding comment to the 5 levels are $n_1=0, n_2=0.25, n_3=0.5, n_4=0.75, n_5=1$, in order to ensure that each index can get at least 4 comment, isosceles triangle bottom is 1.6;

Comprehensive evaluation results of Marine emergency rescue capability. After determining the membership of each index, According to the basic principle of fuzzy comprehensive evaluation, the comprehensive evaluation results of maritime emergency rescue capability are obtained as shown in formula (10):

$$B = W \circ R = w_1 \circ [w_2 \circ R_2, w_3 \circ R_3, w_4 \circ R_4, w_5 \circ R_5]^T = (b_1, b_2, b_3, b_4, b_5) \quad (10)$$

3. Case study

The case study on emergency rescue capability evaluation of a maritime emergency rescue department in Bohai Bay, Expert scoring method was used to evaluate the emergency rescue capability of the department. The score interval is set to 1-100, the higher the score, the better the index; the specific score is shown in Table 3:

Table 3. Indicators scoring about the emergency rescue abilities assessment

evaluating indicator	A1	A2	A3	A4	B1	B2	B3	B4	C1	C2	C3	C4	D1	D2	D3	D4
score	76	68	78	85	73	83	67	55	96	88	82	54	53	49	80	57

Classification of the indicators at all levels of the score using min-max method for normalization; the standard evaluation matrix C'_i is obtained as shown in formula (11):

$$C'_{ij} = \frac{C_{ij} - C_{imax}}{C_{imax} - C_{imin}} \quad (11)$$

In the formula, C_{ij} represents j th indicators in the i level, C_{imin} and C_{imax} represent the lowest and highest score in the i level.

On the basis of the Analytic Network Process, we can get the weight of each index and rank weight. According to the formula (10), the result of fuzzy calculation is:

$$B=[0.1075 \quad 0.1466 \quad 0.1508 \quad 0.1193 \quad 0.0836] \quad (12)$$

Thus, the rescue ability of the maritime emergency rescue unit is qualified. It is able to take appropriate rescue action within a certain period of time, meet the requirements of general emergency rescue. For further optimization, according to the index score and the importance index of ANP, we can analyze the corresponding index gradually, then targeted to improve. According to table 6 and table 4, the attributes of relevant departments A2, resource protection D2 and decision command D4 are slightly poor, and the index weight is highly more important, therefore, the department needs to strengthen contact with relevant departments, increase the reserve of rescue resources and optimize command decision method.

4. Conclusion

In this paper, we considered the relationship between the indexes of maritime rescue capability, used ANP instead of AHP to determine the weight of each index, combined with isosceles triangle membership function, used fuzzy comprehensive evaluation to make the evaluation result of maritime rescue capability, it can improve the reliability of evaluation results. Rescue departments can understand their own defects by this method, and can contrapuntally improve relevant index according to index attributes and weights, and then it can effectively improve the capability of maritime rescue with smaller inputs.

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