Research on Evaluation Model of Maritime Search and Rescue Emergency Management Capabilities Based on Improved Grey Cloud Model

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Abstract. Considering the problems of randomness and fuzziness in evaluating indexes from maritime search and rescue emergency management capabilities, and the shortcoming of classic gray whitening-weight function in dealing with complex problems, a novel grey cloud clustering comprehensive evaluation model based on improved grey cloud whitening weight function and improved analysis hierarchy process (IAHP) was presented. The weight of each index is determined by using the IAHP, which is good for decision makers to improve accuracy in the judgment process of any two index. A model of integrated the advantages of grey cloud model and an IAHP are established to evaluate the guangzhou maritime search and rescue emergency management capability by improved grey variable weight clustering theory. From the evaluation result of the model, the proposed model increases the reliability of emergency management capability assessment for maritime search and rescue and provides a new approach to evaluate emergency management capability of maritime search and rescue.

1. Introduction
With the rapid development of social economy, the more frequent maritime activities and the increasing sea traffic density, ship accidents have occurred frequently. Therefore, the higher requirements for the maritime search and rescue capability are put forward. Under this context, the evaluation of search and rescue management capacity is becoming more and more important. Common evaluation models are AHP[1], fuzzy comprehensive evaluation[2] and so on. AHP is too subjective. After the membership function of fuzzy comprehensive evaluation being numerical accurately, it would lose its fuzziness. And in the process of determining the membership function, the subjective factors have a strong influence and the randomness is weak, which affects the reliability evaluation result to a certain extent. In fact, the Guangzhou maritime search and rescue emergency management capacity evaluation system is extremely complex, each indicator of which is intricate and interrelated. At the same time most of the indicators is uncertain due to lack of data, ambiguity of information and other reasons. And the traditional evaluation model is difficult to carry out an effective quantitative assessment. In view of the above shortcomings, this paper takes into account the advantages of both gray clustering theory and normal cloud model theory, then get an improved gray-cloud whitening-weight function clustering model[3, 4]. The improved gray-gray whitening-weight model not only can overcome the "soft" edge problem of the evaluation index and achieve the effective conversion of qualitative and quantitative evaluation, but also can effectively dilute the subjective ambiguity of evaluation and other factors. The IAHP determines the weight of the indicators and improves the accuracy of the decision-makers to compare the index. Then we get the evaluation level.
by calculating the clustering coefficient of the Guangzhou maritime search and rescue emergency management capacity assessment model.

2. An Improved Whitening Weight Model Based on Gray Cloud

2.1. The Basic Concept of Gray Cloud

The gray cloud model is developed on the basis of cloud theory, the whitening-weight of gray numbers is usually expressed by any random number. The whitening-weight function is represented by a random curve with a nonuniform thickness, as shown in Figure 1.

We suppose $U_x$ is a precise numerical quantitative domain, the whitening-weight’s distribution of on $U_x$ is called grey-cloud Whitening-weight or grey-cloud for short[5]. About numerical characteristics of grey cloud, peak value is $C_x$, left and right boundary is $(L_x, R_x)$, $E_n$ and $H_e$ is entropy and hyper entropy respectively. The peak $C_x$ is the value of the whitening-weight equal to 1. Each digital feature has the following relationship:

$$C_x = \frac{L_x + R_x}{2} \quad (1)$$
$$E_n = \frac{R_x - L_x}{6} \quad (2)$$
$$H_e = \frac{E_n}{\alpha} \quad (3)$$

The mathematical expectation of the gray cloud model:

$$NGL(x) = \exp \left[ -\frac{(x - C_x)^2}{2E_n^2} \right] \quad (4)$$

Figure 1  A diagram of Grey Cloud Model

2.2. A Whitening-Weight Function Model Based on Gray Cloud

Because the normal cloud model has unique mathematical properties and certain universality[6], this paper is based on the analysis of normal gray clouds.

The algorithm steps are as follows:

Creating $E_n$ as expected value, $H_e'$ is the standard deviation of the normal random number $E_n'$.

Calculate the correlation between the value $x$ and the normal gray cloud $u$, The formula is as follow:

$$f_{ij} = u(x_i) = \exp \left[ -\frac{(x - C_x)^2}{2E_n^2} \right] \quad (5)$$

The whitening weights value obtained in the above equation are one of the whitnets weights
random numbers. Because the value of the whitening weights is different every time, this causes a random result to determine the results of the error [7]. But it obeys certain rules, we take the average of 100 times as the final whitening weight value.

\[
 f_{wij} = \frac{f_{j1}(x) + f_{j2}(x) + \cdots + f_{jn}(x)}{n}
\]

Where \( n \) represents the times of calculations, \( n = 100 \), \( f_{jk} \) is the value calculated for \( k \) th time.

3. Steps of Building Evaluate Model

Maritime search and rescue emergency management capacity building is a complex process, and there are many factors that can impact maritime search and rescue capacity [8]. Such as the environment, equipment, personnel, technology and other aspects. After consulting the relevant information, expert advice and reference literature [9], determine the 24 indicators and establish the evaluation index system shown in Table 1. Many indicators are difficult to quantify and there is no specific index value, it is difficult to evaluate the maritime search and rescue emergency management capacity in scientific, objective and reasonable. In this paper, an improved gray cloud model and IAHP are used to evaluate the clustering process of Guangzhou maritime search and rescue emergency management capability. It can better achieve the level of assessment of Guangzhou maritime search and rescue emergency management capacity.

3.1. Determine the Digital Features and Construct the Whitening-Weight Model

In this paper, only three of the index systems constructed are quantitative indicators. The indicators are communication coverage, ship traffic monitoring system coverage, and forecasting accuracy of hazard sources. While there are 21 qualitative indicators. For quantitative indicators, the value was 97%, 80%, 85%. This paper is divided into four evaluation grades, namely, four gray categories, which are "poor", "middle", "good", "excellent". And the peak of whitening model is 0.65, 0.75, 0.85, 0.95, according to the interval to calculate the corresponding level of entropy and super entropy. The model of building a four-level gray-cloud whitening weight is shown in Figure 2.

![Figure 2](image_url)

**Figure 2** Function of Cloud Based on Grey Cloud Whitening Weight

3.2. Determine the Weight of the Indicator

The traditional 1-9 scale analytic analysis exists the problems that the difference is not obvious, determining the scale is difficult, operating is more cumbersome and other issues. Therefore, this article uses IAHP [11]. Compared with the traditional AHP, this method has a good judgment on the rationality of transmission and scale value, which is helpful for decision makers to improve the accuracy in the process of comparison judgment.
Where A is the comparison matrix derived by the expert.

\[
a_{ik} = \begin{cases}
-1 & \text{Factor } i \text{ is inferior to factor } k \\
0 & \text{Factor } i \text{ is superior to factor } k \\
1 & \text{Factor } i \text{ is equals factor } k
\end{cases}
\]

Where, \( a_{ik} \) is the importance comparison of factor \( i \) with \( k \) factor.

3.3. Calculate Evaluation Coefficient

Select 5 experts with the authority to score the index, the score recorded as \( e_i^k \) \((k = 1,2,\cdots,24)\). For the index \( U_i (i=1,2,\cdots,24) \), the evaluation coefficients of the four gray classes are recorded as the evaluation coefficients \((x_{ij} (j=1,2,3,4))\) of the four gray groups. And the evaluation coefficients of the four gray groups are obtained in turn. The formula is written as:

\[
x_{ij} = \sum_{k=1}^{4} f_j(e_i^k)
\]

The \( F_{ij}(i \times j) \) matrix is obtained by normalizing the gray evaluation coefficients.

3.4 The Comprehensive Evaluation

We get the comprehensive clustering coefficient according to the weight \( \omega \) and gray evaluation coefficient matrix \( F_{ij} \), the formula is:

\[
\sigma_j = \sum_{i=1}^{k} \omega_i \cdot F
\]

The maximum value in \( \sigma_j \) is the value of the comprehensive evaluation results, recorded as \( \sigma_j^* \). The corresponding gray cloud class of maximum value of \( \sigma_j^* \) is the final evaluation results of Guangzhou maritime search and rescue emergency management capacity.

4. Evaluation of Emergency Management Capability of Guangzhou Maritime Search and Rescue

Guangzhou maritime search and rescue emergency management capacity evaluation index system includes 24 indicators, of which 21 indicators for the qualitative indicators. The uncertainties and flexibility of the evaluation indicators themselves influence the results of traditional performance evaluation methods. Therefore, this paper adopts an improved grey cloud model to realize the whitening process. By applying a normal cloud to a whitening weight function and considering the imperfection, ambiguity and randomness of the indicators in the evaluation to improve the credibility of the whitening weights. The results of the model effectively complete the qualitative evaluation and quantitative assessment of the conversion. The evaluation model is calculated as follows:

4.1. IAHP to Determine Weights

The weight of each evaluation index values are shown in table 1.
Table 1  The index System and Weight Value Below

| First-grade | Second-grade                                                                 | Final weight |
|-------------|-----------------------------------------------------------------------------|--------------|
| Social forces | Search and rescue team 0.07484  Past ships save each other 0.05702  The crew quality 0.03013  Legal construction level 0.04054 |              |
| Environment support capabilities | Public information management ability 0.02335 |              |
| Resources support capabilities | Emergency materials 0.02311  Maritime search and rescue equipment financial support 0.06248  Capital integration scheduling level 0.04775  Search and rescue force arrangement 0.04064 |              |
| Crisis prevention and management ability | fraction of Communication coverage rate 0.02277  VTS coverage rate 0.02438  Hazard prediction ability completeness of emergency plan 0.02358  Speed of emergency department commanding and decision-making ability 0.02356 |              |
| Emergency handling ability | Decision command 0.05926  Ability of concerted action 0.09068  Ability to deal with the problem 0.03689  Incentive level of reward and punishment 0.01287 |              |
| Learning growth ability | Process mechanism 0.05192  theory and technology level of training 0.02508  0.02013 |              |

4.2 Index assessment coefficient
Evaluate the score of indicators of Guangzhou maritime search and rescue emergency by means of expert assessment. Five experts participated in the evaluation scoring. The scores are shown in Table 2.
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Table 2  The Evaluation Scores of 5 Experts

| $P_1$ | $P_2$ | $P_3$ | $P_4$ | $P_5$ | $P_1$ | $P_2$ | $P_3$ | $P_4$ | $P_5$ |
|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| U11   | 0     | 0     | 0.    | 0.    | 0     | U42   | 0.    | 0.    | 0.    |
| U12   | 0     | 0     | 0.    | 0.    | 0     | U43   | 0.    | 0.    | 0.    |
| U13   | 0     | 0     | 0.    | 0.    | 0     | U44   | 0.    | 0.    | 0.    |
| U21   | 0     | 0     | 0.    | 0.    | 0     | U51   | 0.    | 0.    | 0.    |
| U22   | 0     | 0     | 0.    | 0.    | 0     | U52   | 0.    | 0.    | 0.    |
| U23   | 0     | 0     | 0.    | 0.    | 0     | U53   | 0.    | 0.    | 0.    |
| U31   | 0     | 0     | 0.    | 0.    | 0     | U54   | 0.    | 0.    | 0.    |
| U32   | 0     | 0     | 0.    | 0.    | 0     | U55   | 0.    | 0.    | 0.    |
| U33   | 0     | 0     | 0.    | 0.    | 0     | U61   | 0.    | 0.    | 0.    |
| U34   | 0     | 0     | 0.    | 0.    | 0     | U62   | 0.    | 0.    | 0.    |
| U35   | 0     | 0     | 0.    | 0.    | 0     | U63   | 0.    | 0.    | 0.    |
| U41   | 1     | 0     | 1     | 0.    | 1     | U64   | 0.    | 0.    | 0.    |

The Indicators are quantified, according to the structure of the whitening weight model. Bring the score of the five experts give into the formula (5), then get a regular random number. According to the large number theorem, we use the formula (6) to find the average, because it can avoid large error for randomness. For index $U_{11}$, the valuation coefficient

$$x_{11} = \sum_{k=1}^{4} f_{ij}^k (e_i^k) = f_{11}^1 (0.65) + f_{11}^2 (0.75) + f_{11}^3 (0.65) + f_{11}^4 (0.60) + f_{11}^5 (0.80),$$

$$m = 100.$$ The MATLAB programming tool can get $f_{11}^1 (0.65) = 1$, $f_{11}^2 (0.75) = 0.1355$, $f_{11}^3 (0.60) = 1$, $f_{11}^4 (0.80) = 0.0111$, get the evaluation coefficient $x_{11} = 3.1465$. Similarly, $x_{12} = 1.889$, $x_{13} = 0.7384$, $x_{14} = 0.0111$. After the normalization $f_{11} = (0.5439, 0.3265, 0.1276, 0.0290)$. The evaluation coefficient matrix obtained by the above method is as follows:

$$F_1 = \begin{bmatrix} 0.5439 & 0.3265 & 0.1276 & 0.0019 \\ 0.0322 & 0.0385 & 0.5448 & 0.3845 \\ 0.1427 & 0.5179 & 0.2402 & 0.0992 \\ 0.2073 & 0.4654 & 0.3035 & 0.0238 \\ 0.4686 & 0.4014 & 0.1281 & 0.0019 \\ 0.3075 & 0.5459 & 0.1448 & 0.0018 \\ 0.1633 & 0.6719 & 0.1630 & 0.0018 \\ 0.1634 & 0.6716 & 0.1632 & 0.0018 \\ 0.0852 & 0.6510 & 0.2425 & 0.0213 \\ 0.0263 & 0.2258 & 0.2905 & 0.4574 \\ 0.1036 & 0.6786 & 0.2157 & 0.0021 \\ 0.0000 & 0.0000 & 0.0575 & 0.9425 \end{bmatrix}$$

$$F_2 = \begin{bmatrix} 0.0072 & 0.4113 & 0.5525 & 0.0290 \\ 0.0000 & 0.1067 & 0.7867 & 0.1067 \\ 0.6480 & 0.3268 & 0.0253 & 0.0000 \\ 0.4050 & 0.5469 & 0.0481 & 0.0000 \\ 0.0019 & 0.1263 & 0.4086 & 0.4633 \\ 0.0019 & 0.1253 & 0.4129 & 0.4599 \\ 0.8349 & 0.1630 & 0.0020 & 0.0000 \\ 0.6298 & 0.2606 & 0.1076 & 0.0020 \\ 0.4693 & 0.4000 & 0.1287 & 0.0019 \\ 0.1403 & 0.5342 & 0.3022 & 0.0234 \\ 0.6490 & 0.3255 & 0.0254 & 0.0000 \\ 0.4361 & 0.2688 & 0.2705 & 0.0245 \end{bmatrix}$$

According to formula (8) we get the evaluation coefficient

$$\sigma_s = \omega \cdot F = (0.28729, 0.37162, 0.22495, 0.11615)$$

Where $s$ is the number of the four gray categories. According to the clustering rules, we know $\sigma_s = \max(\sigma_s) = 0.37162$.

The corresponding evaluation level is obtained by the same method:

Social forces $\sigma_{s1} = \max(\sigma_{s1}) = 0.04786$, Environment support capabilities

$$\sigma_{s2} = \max(\sigma_{s2}) = 0.05941$$
Resources support capabilities $\sigma_{\text{rs}} = \max(\sigma_{\text{rs}}) = 0.14830$, Crisis prevention and management ability $\sigma_{\text{ct}} = \max(\sigma_{\text{ct}}) = 0.03444$, Emergency handling ability $\sigma_{\text{eh}} = \max(\sigma_{\text{eh}}) = 0.10865$, Learning growth ability $\sigma_{\text{lg}} = \max(\sigma_{\text{lg}}) = 0.04646$.

An improved gray cloud model was used to evaluate the maritime search and rescue emergency management capabilities of Guangzhou, the evaluation result of which is grade "middle". And then evaluate the first-grade indicators of the index system respectively, the corresponding evaluation levels of which are "good", "middle", "middle", "good", "poor" and "middle". From the above evaluation results, we concluded that Guangzhou maritime search and rescue emergency management capability remains to be improved and strengthened. It is important to note that the evaluation level of emergency disposal ability is "poor". Therefore, the relevant departments need to reinforce the management and clear organizational structure and improve the efficiency of command and decision-making capacity to strengthen the departmental linkage, so that the emergency handling capacity is more harmonious, quicker and more efficient.

5. Conclusion
This paper establishes a novel grey clustering comprehensive evaluation model that integrates the advantages of improved grey cloud model and IAHP to evaluate the Guangzhou maritime search and rescue emergency management capability. The IAHP has a good judgment transitivity and the rationality of scale value, which is helpful for decision makers to improve the accuracy in the process of comparison judgment. The constructed models can be more objective and accurate to depict the grey and random nature of the evaluation. Fully taking into account the randomness and fuzziness of information, it can better evaluate the maritime search and rescue emergency management capability. The model also has a strong applicability, which can provide reference for complex system simulation evaluation in industrial, social, military and other fields.

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