An Evaluation Method of the Emergency Plan for Maritime Search and Rescue Based on Cloud Model

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Abstract

To solve the problem of the randomness and fuzziness in the evaluation process when evaluating the emergency plan for marine search and rescue, a comprehensive evaluation method combining the Analytic Compatible Matrix method and Cloud Model was proposed. Firstly, combined with the Emergency Plan for National Maritime Search and Rescue and related literature, an evaluation index system for the emergency plan was established; Then, the weight of each index in the evaluation system was determined by the Analytic Compatibility Matrix method ; Finally, the uncertain mapping between evaluation indicators and comment clouds was achieved by the cloud model. The case study shows that this method reveals the inherent fuzziness and randomness in the evaluation process, and realizes the mutual conversion between qualitative concept and quantitative numerical values. The evaluation result is intuitive and realistic, and can provide support for the maritime department.

Keywords

Cloud Model; Analytic Compatible Matrix method; emergency plan for marine search and rescue; Evaluation.

1. Introduction

With the vigorous development of the shipping industry, more attention should be paid to shipping safety. At present, the emergency management system with "one plan and three systems" (emergency law, emergency system, emergency mechanism and emergency plan) as the core is gradually established and perfected in governments, enterprises and institutions at all levels in china, which has an important role in promoting effective response to emergencies and improving emergency management capabilities. Among them, emergency plan is the fastest, most direct and effective emergency response method in the face of emergencies. Therefore, it is significance to evaluate the emergency plan for maritime search and rescue scientifically and effectively.

In view of the emergency plan evaluation, Alexander [1] and Perry [2] put forward relevant proposals for the plan formulation and suggested that it be used as a standard for evaluating the quality of the plan. Zhang Yingju [3] proposed an evaluation model for emergency plan based on Grey System Theory and Analytic Hierarchy Process. Sun Wei [4] used the set pair analysis method to express and portray the Yangtze River maritime search and rescue system, and established the set pair evaluation model of maritime search and rescue capability about Yangtze River. There are uncertainties in the evaluation process of emergency plan for maritime search and rescue. The current evaluation methods, including grey theory and set pair analysis, mostly only consider the fuzziness of the evaluation process, ignoring the impact of randomness. The Cloud Model combines the advantages of traditional fuzzy mathematics and probability statistics, abandons the concept of traditional membership functions, effectively compensates for the deficiencies of fuzziness and randomness in such evaluations, and illustrates the degree of uncertainty [7].

In summary, based on the existing research, this paper established evaluation index system. The weight of each index was determined by Analytic Compatible Matrix method. Cloud model was used to solve the fuzziness and randomness in the evaluation process. The rationality of the proposed method was verified by a case analysis.

2. Method

2.1 Cloud theory

2.1.1 Normal Cloud Model

Definition: Let U be the universe of discourse and C be a qualitative concept in U, If $\forall x \in U$ is a random instantiation of concept C, which satisfies $x \in N\left(Ex, En'^2\right)$ and $En' \sim N\left(En, He^2\right)$, and the certainty degree $\mu(x) \in [0,1]$ of x belonging to C is a membership distribution, which satisfies

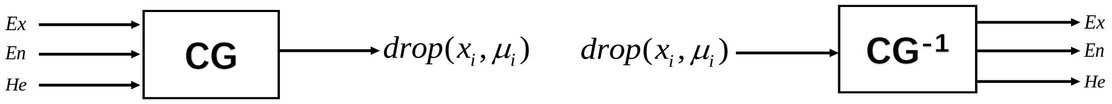
$$\mu_i = \exp\left\{\frac{-(x-En)^2}{\left(2En'^2\right)}\right\} \tag{1}$$

then the distribution of x in U is called a normal cloud, and the cloud droplet can be denoted as $(x, \mu(x))$.

The overall quantitative properties of a concept can be ideally depicted in a cloud T utilizing three numerical characters: expectation Ex, entropy En, and hyper entropy He; cloud T can be given as $T = (Ex, En, He)$. Ex is the mathematical expectation of the cloud droplets belonging to a qualitative concept in the universe. En represents the fuzziness and randomness of the qualitative concept and reflects the dispersion extent of the cloud droplets. He measures the uncertainty of En and determines the thickness of the cloud.

2.1.2 Cloud generator

Cloud model uses cloud generator to realize the mutual conversion between qualitative concept and quantitative numerical values. Cloud generator can be divided into forward cloud generator and reverse cloud generator, as shown in fig.1.



(a) Forward cloud generator (b) Reverse cloud generator

Fig. 1 Cloud generator

The numerical characters of cloud T is known as $T = (Ex, En, He)$, forward cloud generator generates N cloud droplets $(x, \mu(x))$ which conform to the normal cloud distribution and it realizes the mapping between qualitative concept and quantitative numerical values, algorithm is as follows:

Step 1: En as the Expectation and He^2 as the Variance, generate a normal random number: $En' = NORM(En, He^2)$;

Step 2: Ex as the Expectation and He^2 as the Variance, generate a normal random number: $x_i = NORM(Ex, En'^2)$;

Step 3: Generate a membership degree: $\mu_i = \exp\left\{\frac{-(x-En)^2}{\left(2En'^2\right)}\right\}$;

Step 4: Repeat the above three steps until N cloud droplets are generated.

Reverse cloud generator converts a certain amount of sample data into the numerical characters of cloud, which realizes the transformation from quantitative numerical values to qualitative concept, algorithm is as follows:

Step 1: According to sample points x_i ($i=1,2,3,\cdots,N$; N is sample number), calculate mean value of the sample: $Ex=\overline{X}=\frac{1}{N}\sum_{i=1}^{N}x_i$;

Step 2: Calculate Variance of the sample: $S^2=\frac{1}{N-1}\sum_{i=1}^{N}(x_i-\overline{X})^2$;

Step 3: Calculate Entropy and Excess Entropy: $En=\sqrt{\frac{\pi}{2}}\times\frac{1}{N}\sum_{i=1}^{N}|x_i-Ex|, He=\sqrt{S^2-En^2}$.

2.2 Analytic Compatible Matrix method

Analytic Hierarchy Process (AHP) requires consistency check of the judgment matrix A to calculate the weight. It may be necessary to repeatedly reconstruct the judgment matrix because consistency cannot be achieved. The Analytic Compatible Matrix method can not only reduce the workload caused by repeatedly constructing the judgment matrix, but also ensure the consistency of the judgment matrix, thus simplifying the process determining the index weight. The basic idea of Analytic Compatible Matrix method is to modify the elements a_{ij} in the matrix judgment matrix $A=(a_{ij})$ obtained from the 9-level scale and the pair comparison method and make it meet the consistency. The calculation steps are as follows:

Step 1: Construct the judgment matrix: $A=(a_{ij})_{n\times n}, a_{ij}=1, a_{ij}=\frac{1}{a_{ji}}$;

Step 2: Let $b_{ij}=\sqrt{\prod_{k=1}^{n}a_{ik}a_{kj}}$, get compatible matrix: $B=(b_{ij})_{n\times n}$, $B=(b_{ij})_{n\times n}$, $b_{ii}=1$, $b_{ij}=\frac{1}{b_{ji}}$, $b_{ij}=b_{ik}gb_{kj}$;

Step 3: Calculate the index weight: $\omega_j=\frac{c_j}{\sum_{k=1}^{n}c_k}(j=1,2,...,n)$, and $c_j=\sqrt[n]{\prod_{k=1}^{n}b_{jk}}$ $(j=1,2,...,n)$.

The evaluation process of the proposed method is shown in fig.2.

3. Case analysis

3.1 Evaluation index system and weights

Based on the "National Emergency Plan for Maritime Search and Rescue " and related research, the evaluation index system of Emergency Plan for Maritime Search and Rescue was established. The primary index set was: **U = {U1, U2, U3}** = {organization system, emergency support, emergency response and disposal}. The weights of each index were determined through expert questionnaire combined with the Analytic Compatible Matrix method, as shown in Table 1.

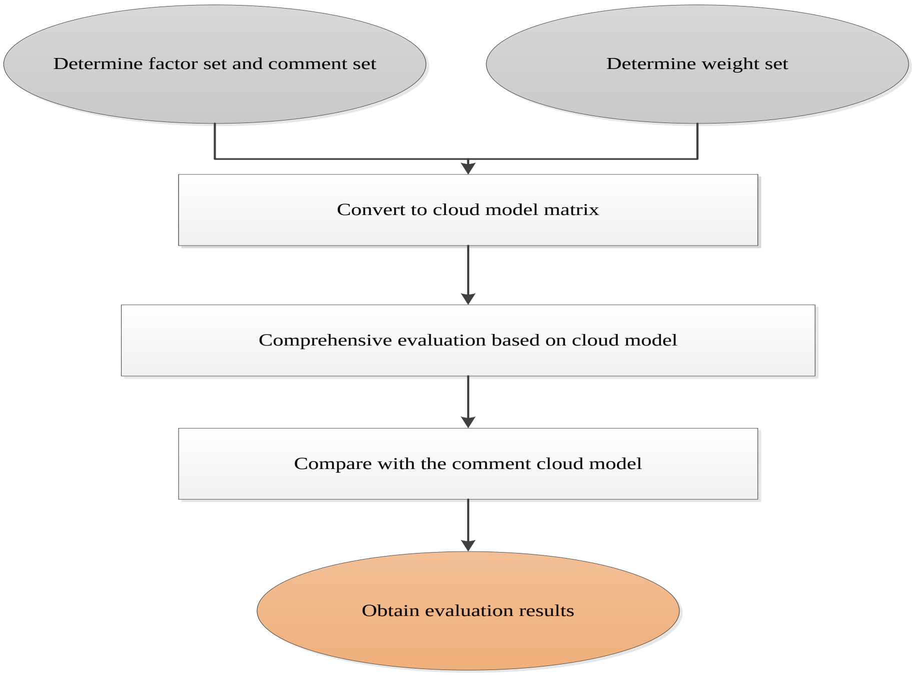


Fig. 2 Evaluation Process

Table 1 Evaluation index system and weights

Primary index	Weight	Secondary index	Weight
Organization system U1	0.1428	Leading organization U11	0.5396
		Command organization U12	0.2970
		Consultant expert U13	0.1634
Emergency support U2	0.4286	Regulations preparedness U21	0.1813
		Management of hazardous sources and areas U22	0.0702
		Communication guarantee U23	0.1642
		Emergency equipment U24	0.0819
		Professional search and rescue power U25	0.1642
		Social search and rescue power U26	0.1740
		Propaganda、Training and Exercises U27	0.0894
Emergency response and disposal U3	0.4286	Reporting of dangers U31	0.0894
		Starting of emergency plan U32	0.0894
		Emergency Response U33	0.3182
		Emergency Disposal U34	0.5030

3.2 Comments of Cloud Model

The evaluation grades of the emergency plan for maritime search and rescue are excellent, good, medium, general and poor. That is, C= {C1, C2, C3, C4, C5} = {excellent, good, medium, general, poor}. The evaluation grade score uses percentile system:C1 = [90,100], C2 = [80,90), C3 = [70,80), C4 = [60,70), C5 = [0,60).

Comments are usually divided into two categories, namely unilateral constraint and bilateral constraint, which are described by one-dimensional normal cloud model. Unilateral constraint refers to those whose range of values can only be upper limit or lower limit, such as "excellent" or "poor".

Bilateral constraint refers to those whose values have both upper and lower limits, such as "medium" or "general".

Let the value of unilateral constraint be $[C_{\min}, C_{+def}]$ or $[C_{-def}, C_{\max}]$, where C_{+def} and C_{-def} are the upper and lower limits of the evaluation interval respectively, and the parameters of the comment cloud model can be calculated by equation (2) [8]:

$$\begin{cases} Ex = C_{+def} \ \ or \ \ C_{-def} \\ En = (C_{+def} - C_{\min})/3 \text{ or } (C_{\min} - C_{-def})/3 \\ He = k \end{cases} \tag{2}$$

Let the value of the Bilateral constraint be $[C_{\min}, C_{\max}]$, the parameters of the comment cloud model can be calculated by equation (3):

$$\begin{cases} Ex = (C_{\min} + C_{\max})/2 \\ En = (C_{\max} - C_{\min})/6 \\ He = k \end{cases} \tag{3}$$

Take the value k = 0.5, the parameters of comment cloud model of the emergency plan for maritime search and rescue can be calculated, as shown in Table 2.

Table 2 Parameters of Comment cloud model

Evaluation grade	Scores	Parameters of cloud model
excellent	[90,100]	(100, 3.3, 0.5)
good	[80,90)	(85, 1.7, 0.5)
medium	[70,80)	(75, 1.7, 0.5)
general	[60,70)	(65, 1.7, 0.5)
poor	[0,60)	(0, 20, 0.5)

According to the parameters of comment cloud model in Table 2, a five-level standard cloud model with the comment value as the abscissa and the membership degree as the ordinate was established, as shown in Fig. 3.

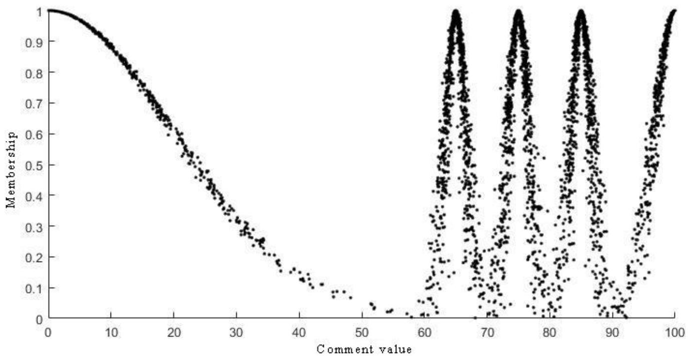


Fig. 3 Comment cloud model

3.3 Cloud model of evaluation index

1) The secondary index parameters of cloud model are calculated by reverse cloud generator.

2) The primary index parameters of cloud model are calculated by the floating cloud algorithm [9], see equation (4).

$$\begin{cases} Ex = \dfrac{E_{x1}\omega_1 + E_{x2}\omega_2 + \cdots + E_{xn}\omega_n}{\omega_1 + \omega_2 + \cdots + \omega_n} \\ En = \dfrac{E_{n1}\omega_1^{\ 2} + E_{n2}\omega_2^{\ 2} + \cdots + E_{nn}\omega_n^{\ 2}}{\omega_1^{\ 2} + \omega_2^{\ 2} + \cdots + \omega_n^{\ 2}} \\ He = \dfrac{H_{e1}\omega_1^{\ 2} + H_{e2}\omega_2^{\ 2} + \cdots + H_{en}\omega_n^{\ 2}}{\omega_1^{\ 2} + \omega_2^{\ 2} + \cdots + \omega_n^{\ 2}} \end{cases} \tag{4}$$

3)The parameters of cloud model in the final evaluation results are calculated by the comprehensive algorithm in the virtual cloud, see equation (5).

$$\begin{cases} Ex = \dfrac{E_{x1}E_{n1}\omega_1 + E_{x2}E_{n2}\omega_2 + \cdots + E_{xn}E_{nn}\omega_n}{E_{n1}\omega_1 + E_{n2}\omega_2 + \cdots + E_{nn}\omega_n} \\ En = E_{n1}\omega_1 + E_{n2}\omega_2 + \cdots + E_{nn}\omega_n \\ He = \dfrac{H_{e1}E_{n1}\omega_1 + H_{e2}E_{n2}\omega_2 + \cdots + H_{en}E_{nn}\omega_n}{E_{n1}\omega_1 + E_{n2}\omega_2 + \cdots + E_{nn}\omega_n} \end{cases} \tag{5}$$

3.4 Evaluation index parameters of cloud model

Firstly, based on the expert score, each secondary index parameters of cloud model are calculated by the reverse cloud generator, as shown in Table 3.

Then, based on the secondary index parameters of cloud model, the primary index parameters of cloud model are calculated by the floating cloud algorithm shown in equation (4).

Table 3 Evaluation index parameters of cloud model

Primary index	Parameters of Cloud model	Secondary index	Parameters of Cloud model
U1	（83.89, 5.03, 0.49）	U11	（83.21, 5.12, 0.51）
		U12	（82.76, 4.72, 0.44）
		U13	（85.33, 5.06, 0.48）
U2	（85.40, 4.56, 0.54）	U21	（84.31, 4.85, 0.5）
		U22	（85.56, 3.65, 0.54）
		U23	（87.23, 5.53, 0.52）
		U24	（83.28, 4.45, 0.57）
		U25	（86.63, 5.01, 0.57）
		U26	（90.35, 5.21,0.52）
		U27	（78.72, 5.32,0.46）
U3	（81.32, 5.33, 0.45）	U31	（85.21, 4.97, 0.55）
		U32	（80.57, 4.99, 0.51）
		U33	（78.18, 5.79, 0.48）
		U34	（77.97, 5.23, 0.40）

4. Result and discussion

The parameters of cloud model for the final evaluation result which was calculated by the comprehensive cloud algorithm of equation (5) was (82.25, 4.93, 0.57). According to the forward direction cloud generator, the final evaluation result and the five evaluation levels were simulated to generate the cloud droplets, as shown in Fig.4.

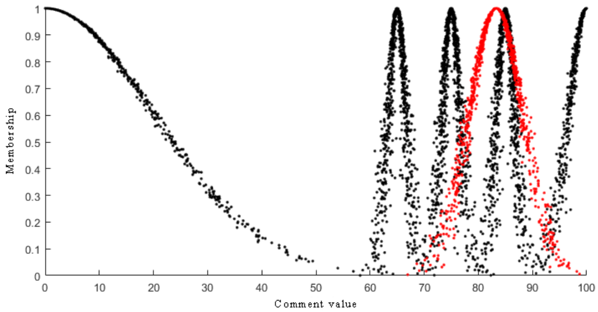


Fig. 4 Evaluation cloud's cloud droplet

It can be seen from Fig.4 that the cloud droplets of the evaluation cloud are mostly distributed between good and medium, and are closer to good. Therefore, it can be judged that the maritime administration department in charge of the sea area can solve the maritime accidents well. The distribution of the cloud droplets of the evaluation cloud is close to the expected value， which indicates that the actual level of the maritime search and rescue emergency plan and the evaluation results are less deviated and the credibility is higher. In addition, cloud droplets are concentrated near the cloud's expected curve, and the fluctuation is not obvious, which indicates that the stability of the evaluation results is good.

5. Conclusion

1) Comprehensive Evaluation method based on Cloud Model combined with the Analytic Compatible Matrix method was proposed, it simplifies the calculation of index weight, abandons the traditional concept of membership degree, and takes the fuzziness and randomness of each evaluation index into account. The uncertainty transformation from qualitative concept to quantitative value is realized by cloud generator, which provides a new method for quantitative evaluation of emergency plans for maritime search and rescue.

2) Case analysis shows that the evaluation method can visualize the evaluation results to form a cloud droplet map, thus, not only the expected value, but also the stability and reliability of the evaluation results can be seen from the map, it also improves the accuracy of the evaluation results.

References

[1] ALEXANDER D. Towards the development of a standard in emergency planning[J]. Disaster Prevention &Management, 2013, 14(2): 158-175.

[2] PERRY R W, LINDELL M K. Preparedness for emergency response: guidelines for the emergency planning process[J]. Disasters, 2003, 27(4): 336-350.

[3] Zhang Yingju. Research on implementation effect evaluation model of emergency plans based on improved multi-level and grey evaluation method[J]. Natural Science Journal of Xiangtan University, 2017, 39(1): 114-118

[4] Sun Wei. Research on search and rescue capability of Yangtze River based on set pair comprehensive evaluation model[D]. Wuhan University Of Technology, 2012

[5] Li Deyi, Meng Haijun, SHI Xuemei. Membership clouds and membership cloud generators[J]. Journal of Computer Research and Development 1995, 32(6): 15-20.

[6] Li Deyi, LIU Changyu. Study on the universality of the normal cloud model[J]. Engineering Sciences, 2004, 6(8): 28-34.

[7] Xu Zhengjie, Zhang Youpeng, Su Hongsheng. Application of risk assessment on fuzzy comprehensive evaluation method based on the cloud model[J]. Journal of Safety and Environment, 2014, 14(2):69-72

[8] Huang Liangliang, Yao Anlin, Qi Yunqing, et al. Emergency maturity assessment method of petrochemical enterprises based on cloud model[J]. Chemical Engineering of Oil and Gas, 2015, (2): 118-122