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Comprehensive Evaluation Cloud Model for Ship Navigation Adaptability

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ABSTRACT: In this paper, using cloud model and Delphi, we build a comprehensive evaluation cloud model to solve the problems of qualitative description and quantitative transformation in ship navigation adaptability comprehensive evaluation. In the model, the normal cloud generator is used to find optimal cloud models of reviews and evaluation factors. The weight of each evaluation factor is determined by cloud model and Delphi. The floating cloud algorithm is applied to aggregate the bottom level's evaluation factors, and comprehensive cloud algorithm is used to aggregate the highest level's evaluation factors to get comprehensive evaluation cloud model. Finally, evaluation result is got by matching comprehensive evaluation cloud model and optimal cloud model of reviews. As case study, the model is applied to the small LNG ship's navigation adaptability in Southeast Asia. Compared with the fuzzy comprehensive evaluation method, the model proposed in this paper is more intuitive and reliable in comprehensive evaluation of the small LNG ship's navigation adaptability.

1 INTRODUCTION

The ship navigation safety is one of the most important contents of water traffic. Based on the navigation environment and the ship's characteristics, the comprehensive evaluation of ship navigation adaptability can not only evaluate the adaptability of the environment for the ship, but also assess the status of the ship navigation safety.

Nowadays, the comprehensive evaluation methods are mainly the fuzzy comprehensive evaluation method, analytic hierarchy process, grey theory, expert scoring method, and other new methods that integrate two or more comprehensive methods (Li Z.F. et al. 2013 & Liu F-H.F. et al.2005& Ho W. 2008). The comprehensive fuzzy evaluation and analytic hierarch process are applied to evaluate power generation projects' quality for providing theoretical support for selection decision (Liang Z.H. et al. 2006). Grey system theory is put into use to evaluate the degree of air quality affected by traffic and take Japan as an example to verify the method (Pai T.Y. et al. 2007). Improved comprehensive fuzzy evaluation method which uses entropy method to correct subjective weight is applied in evaluating the risk of waterway near Qingdao port (Nie X.L. et al. 2013). The fuzzy matter-element model based on entropy weight is used to comprehensively evaluate water quality (Zhang X.Q. et al. 2005). A method of grey system based on entropy weight is made the evaluation of ship suppliers system (Liu L.G. et al. 2012). The entropy weight method in extension theory is applied to evaluate gas grade of ten through the tunnel of coal seam (Huang R.D. et al. 2012).

According to the analysis of comprehensive evaluation methods, we can find that these methods can provide a certain reference value for ship navigation adaptability evaluation, but they rely on mathematical model of a precise operation in evaluation process or use a threshold to classify evaluation results, regardless of the uncertainty (including fuzziness and randomness) appearing in the evaluation process. Cloud model is an important theoretical model of uncertainty in artificial intelligence, which can integrate fuzziness and randomness of the spatial entities together. So we can see that cloud model can overcome the limitation of the above methods (Li D.Y. et al. 2004& Chen H. et al. 2011). In this paper, we will make deeply analysis on the factors affecting the ship navigation adaptability, and propose a comprehensive evaluation method based on cloud model for ship navigation adaptability.

2 CLOUD MODEL

Cloud model is a qualitative transformation model for uncertainty, which can well deal with the transformation between one's qualitative concept and its quantitative value (Liu C.Y. et al. 2004).

Expectation signed as E_x, entropy signed as E_n, and super-entropy signed as H_e are numerical characteristics of cloud model and performance the quantitative characteristics of qualitative concept. Expectation is the central value in the domain of discourse. Entropy measures ambiguity and probability of qualitative concept and reflects uncertainty of qualitative concept. The entropy value is higher, the range of value accepted by concept is greater and the concept is fuzzier. Super-entropy reflects degree of aggregation of numerical value's uncertainty in the number domain, namely entropy of entropy. The value of super-entropy expresses cloud dispersion and thickness.

Cloud generator is an algorithm used to generate cloud according to numerical characteristics, which can be divided into forward cloud including basic cloud, normal cloud, X condition cloud and Y condition cloud, and reverse cloud. Normal cloud is universal cloud model, so we will use normal cloud model to conversion the evaluation criteria and factor(Liu C.Y. et al. 2005). One of reverse cloud models don't have certainty degree (Lu H.J. et al. 2003), so we choose this one to generator numerical characteristics.

Normal cloud model is described as follows:

Input : (E_x, E_n, H_e), the required number of cloud droplets n.

Output : $drop(x_i, y_i),\ i = 1,2,3\cdots n$.

1 Generate normal random number E_n' whose expectation is E_x and standard deviation is H_e.
2 Generate normal random number x_i whose expectation is E_n and standard deviation is E_n'. x_i is a cloud droplet belong to domain space.
3 $\mu_i = \exp[-(x_i - E_x)^2 / 2(E_n')^2]$. μ_i is membership degree of x_i belonging to qualitative concept.
4 Repeat steps from (1) to (3) until generating n cloud droplets.

Improved reverse cloud model is described as follows:

Input : $x_i (i = 1,2,3\cdots n)$.

Output : (E_x, E_n, H_e)

1 $\bar{x} = \frac{1}{n}\sum_{i=1}^{n} x_i$; $B = \frac{1}{n}\sum_{i=1}^{n}\left|x_i - \bar{x}\right|$; $S^2 = \frac{1}{n-1}\sum_{i=1}^{n}(x_i - \bar{x})^2$.

2 $E_x = \bar{x}$.

3 $E_n = \sqrt{\pi/2} \times B$.

4 $H_e = \sqrt{S^2 - E_n^2}$.

Table 1. The evaluation index system of small LNG ship's navigation adaptability in Southeast Asia

Factor in basic layer U_i (weight w_i)	Factor in element layer U_{ij}	Weight w_{ij}	Review and quantization Excellent (100~90]	Good (90~80]	Medium (80~70]	Poor (70~60]	Inferior (<60]
Adaptability of natural condition U_1 (0.2455)	wind U_{11} (h/1000n mil)	0.2000	0~10	10~30	30~50	50~70	>70
	sea fog U_{12} (h/1000n mil)	0.0521	0~10	10~20	20~30	30~40	>40
	tropical cyclone U_{13} (h/1000n mil)	0.2144	0~5	5~10	10~15	15~20	>20
	current U_{14} (m/s)	0.0614	<0.5	0.5~2.0	2.0~4.0	4.0~6.0	>6.0
	storm U_{15} (m)	0.2160	0~2	2~4	4~6	6~8	>8
	surge U_{16} (m)	0.2561	0~2	2~4	4~6	6~8	>8
Adaptability of navigation condition U_2 (0.2386)	traffic density U_{21} (ship/6 n mile2)	0.4934	0~4	5~9	10~14	15~20	>21
	traffic structure U_{22} (%)	0.3108	0~4	4~10	10~20	20~30	>30
	complexity of course U_{23} (intersection number of habit route)	0.1958	None	Less	General	More	Much
Adaptability of safety & security condition U_3) (0.2891)	pilotage condition U_{31}	0.2865	Excellent	Good	Medium	Poor	Inferior
	NAVAID guide U_{32}	0.1703	Much perfect	Perfect	General	Imperfect	None
	traffic management infrastructure U_{33}	0.3406	Much complete	Complete	General	Incomplete	None
	maritime safety administration U_{34}	0.2026	Much good	Good	General	Bad	Much bad
Adaptability of social condition U_4（0.2268）	economic condition U_{41}	0.1958	Much good	Good	General	Bad	Much bad
	social stability U_{42}	0.5034	Much stable	Stable	General	Unstable	Unrest
	development level of shipping industry U_{43}	0.3008	Much high	High	General	Low	Much low

3 CONSTRUCTION OF COMPREHENSIVE EVALUATION CLOUD MODEL

3.1 *Establishment of Evaluation Index System*

The establishment of evaluation index system is a prerequisite for scientific comprehensive evaluation and its principles are scientificity, maneuverability, comprehensiveness, comparability and relative independentability. According to navigation environment characteristics of Southeast Asia, we select one comprehensive evaluation factor, four basic evaluation factors and sixteen element evaluation factors to establish evaluation index system.

3.2 *Determination of Evaluation Object, Evaluation Factor and Evaluation Set*

The small LNG ship's navigation adaptability in Southeast Asia is the final evaluation object signed as U. Factors in basic layer are second level indicators, whose factor set is $U=\{U_1,U_2,U_3,U_4\}$. Factors in element layer are third level indicators, whose factor sets are $U_1=\{U_{11},U_{12},U_{13},U_{14},U_{15},U_{16}\}$, $U_2=\{U_{21},U_{22},U_{23}\}$, $U_3=\{U_{31},U_{32},U_{33},U_{34}\}$, $U_4=\{U_{41},U_{42},U_{43}\}$. The evaluation set of each evaluation factor's attribute is determined by asking experts and collecting their reviews. The evaluation set in this paper is $V=\{\text{Excellent, Good, Medium, Poor, Inferior}\}$, and its corresponding value is $V=\{(100,90],(90,80],(80,70],(70,60],(60,0]\}$.

3.3 *Determination of Evaluation Factor's Weight Based on Cloud Model*

Empowerment method based on cloud model utilizes visual cloud to judge whether the experts' reviews are consistent or not, and it achieves gradual optimization and gives an ideal and right weight to evaluation factor (Han B. et al.2012 & Pang Y.J. et al.2001.). The specific steps to determine weight of evaluation factor are described as follows:

Firstly, Select n experts who are familiar with and fully understand the meaning of the evaluation factor to score. Assumed that an evaluation factor's influence degree is decided by m evaluation factors and marked as $\{U_{i1},U_{i2},\cdots,U_{im}\}$.

Secondly, assumed that n experts score evaluation factor $U_{ij}(j=1,2,\cdots,m)$ and its score set is $\{V_1,V_2,\cdots,V_n\}$. Then using improves reverse cloud generator to get the weight numerical characteristics $(E_{xij},E_{nij},H_{eij})$ of U_{ij} .

Thirdly, based on $(E_{xij},E_{nij},H_{eij})$, cloud atlas of U_{ij} is obtained through forward cloud generator.

Fourthly, observe condensation of cloud droplets in cloud atlas. If the distribution of cloud droplets is showed as mist, we could indicate that cohesion of cloud droplets is bad and the experts has not unified evaluation comments. So we should feedback and re-consolidate evaluation comments.

Fifthly, repeat above operation until achieve gradual optimization and unify the experts' evaluation comments to get cohesive cloud atlas which is final weight cloud of evaluation factor.

Sixthly, repeat steps from (2) to (5) until get weight cloud of m evaluation factors.

Seventhly, get the weight of U_{ij} according to equation marked as $w_{ij}=E_{xij}\Big/\sum_{j=1}^{m}E_{xij}$.

3.4 *Description of the Concept Cloud Model of Review and Evaluation Factor in Element Index Layer*

Evaluation factors in evaluation index system and evaluation reviews in evaluation set are qualitative variables which can become quantitative variables with upper and lower bounds shown as $[C_{\min},C_{\max}]$ after experts score. Then we use the following equation to calculate cloud parameters of the quantitative variables.

$$\begin{cases} E_{\mathrm{x}}=(C_{\min}+C_{\max})/2 \\ E_n=(C_{\max}-C_{\min})/6 \\ H_e=k \end{cases} \tag{1}$$

Where, k is a constant, which is adjusted by the stability of the variable. For reviews with unilateral boundary of value range such as $[C_{\min},+\infty]$ and $[-\infty,C_{\max}]$, we can firstly determine the expectation of its default boundary, then compute its cloud parameters by equation (1).

Assumed that there are N experts to judge evaluation factors in element layer. So that we can get N evaluation cloud models marked as $(E_{xi},E_{ni},H_{ei})(i=1,2,\cdots,N)$. Then, a comprehensive cloud model is obtained by using comprehensive cloud algorithm to gather N cloud models. The comprehensive cloud algorithm is shown as follows:

$$\begin{cases} E_x=\dfrac{E_{\mathrm{x}1}\times E_{n1}+E_{\mathrm{x}2}\times E_{n2}+\cdots+E_{\mathrm{xN}}\times E_{nN}}{E_{n1}+E_{n2}+\cdots+E_{nN}} \\ E_n=\dfrac{E_{n1}+E_{n2}+\cdots+E_{nN}}{N} \\ H_e=\dfrac{H_{e1}\times E_{n1}+H_{e2}\times E_{n2}+\cdots+H_{eN}\times E_{nN}}{E_{n1}+E_{n2}+\cdots+E_{nN}} \end{cases} \tag{2}$$

3.5 *Jump Operation of Cloud Model of Evaluation Factor*

Since a single evaluation factor's cloud model is a language indicator, an algorithm should be used to gather multiple cloud models in same level to be a more generalized cloud model to let lower evaluation factors' cloud models jump to higher. According to the different characteristics of evaluation factor of each layer, different levels of evaluation factor take different algorithm. The evaluation factors in lower layer is independent and non-related, so we choose floating cloud algorithm to gather clouds , and comprehensive cloud algorithm to the highest level.

Floating cloud algorithm is shown as follows:

$$\begin{cases} E_x = \dfrac{E_{x1}\times w_1 + E_{x2}\times w_2 + \cdots + E_{xn}\times w_n}{w_1 + w_2 + \cdots + w_n} \\ E_n = \dfrac{w_1^2}{w_1^2 + w_2^2 + \cdots + w_n^2} E_{n1} \\ \quad + \dfrac{w_2^2}{w_1^2 + w_2^2 + \cdots + w_n^2} E_{n2} \\ \quad + \cdots + \dfrac{w_n^2}{w_1^2 + w_2^2 + \cdots + w_n^2} E_{nn} \\ H_e = \dfrac{w_1^2}{w_1^2 + w_2^2 + \cdots + w_n^2} H_{e1} \\ \quad + \dfrac{w_2^2}{w_1^2 + w_2^2 + \cdots + w_n^2} H_{e2} \\ \quad + \cdots + \dfrac{w_n^2}{w_1^2 + w_2^2 + \cdots + w_n^2} H_{en} \end{cases} \quad (3)$$

Comprehensive cloud algorithm is shown as follows:

$$\begin{cases} E_x = \dfrac{E_{x1}E_{n1}w_1 + E_{x2}E_{n2}w_2 + \cdots + E_{xn}E_{nn}w_n}{E_{n1}w_1 + E_{n2}w_2 + \cdots + E_{nn}w_n} \\ E_n = E_{n1}w_1 + E_{n2}w_2 + \cdots + E_{nn}w_n \\ H_e = \dfrac{H_{e1}E_{n1}w_1 + H_{e2}E_{n2}w_2 + \cdots + H_{en}E_{nn}w_n}{E_{n1}w_1 + E_{n2}w_2 + \cdots + E_{nn}w_n} \end{cases} \quad (4)$$

Where, $w_i (i = 1,2,\cdots,n)$ is weight of evaluation factor. (E_{xi}, E_{ni}, H_{ei}) are numerical characteristics of each evaluation factor. n is the number of evaluation factors.

4 PROCESS OF SMALL LNG SHIP'S NAVIGATION ADAPTABILITY COMPREHENSIVE EVALUATION

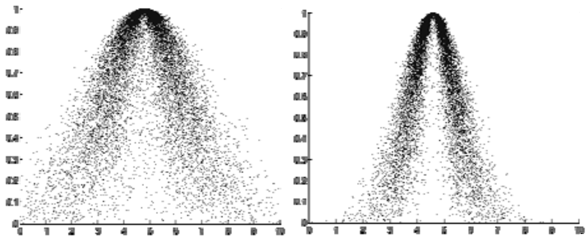
We take the route from Haikou to Malaysia in Southeast Asia as example to evaluate small LNG ship's navigation adaptability to verify the feasibility of the method proposed in this paper, and also make comparative analysis with fuzzy comprehensive evaluation method.

4.1 *Comprehensive Evaluation Cloud model*

4.1.1 *Determine the Weight of Evaluation Factor*

According to the empowerment method introduced in section 3.3, the weight of each evaluation factor in evaluation index system can be ensured. Now, take one evaluation factor named "wind" as example.

Firstly, there are ten experts scoring for "wind" marked as （5，5，5，7，5，3，7，3，3，5）. We can get numerical characteristics value which is (4.8，1.3536，0.5879). Then we get the cloud atlas shown in Fig.1(a) based on forward cloud generator. From the Fig.1(a), we can see that the dispersion of cloud droplets is relatively large and the cloud atlas is shown as mist . So we should collate experts' scores to feedback to experts and prepare next round of experts' scoring. Repeat above operation until unify experts' cognition. and get final numerical characteristics signed as (4.6，0.8021，0.2602) of "wind" whose cloud atlas is shown in Fig.1(b). So do the remaining five evaluation factors . The final weight of "wind" is 0.2000 through normalizing the above six expectations. All weights of the evaluation factors are recorded in Table 1.



(a) the weight cloud in first time (b) the final weight cloud

Figure 1. Weight of evaluation cloud based on Delphi

4.1.2 *Determine Concept Cloud Model of Review and Evaluation Factor in Element Index Layer*

1 The cloud models of reviews in evaluation set are shown as follows: excellent is (100,10/3,0.5); good is (85,5/3,0.5); medium is (75,5/3,0.5); poor is (65,5/3,0.5); inferior is (0,20,0.5).

2 Cloud models of each evaluation factor in element layer are got according to seven experts' scores, recorded in Table 2.

Table 2. Cloud model of evaluation factor in element index layer

Factor in element layer	cloud model (E_x, E_n, H_e)
wind	(85,11.6667,0.5)
sea fog	(85,11.6667,0.5)
tropical cyclone	(85,11.6667,0.5)
current	(85,11.6667,0.5)
storm	(85,11.6667,0.5)
surge	(85,11.6667,0.5)
traffic density	(91.6667,15,0.5)
traffic structure	(100,23.3333,0.5)
complexity of course	(100,23.3333,0.5)
pilotage condition	(85,11.6667,0.5)
NAVAID guide	(98.8462,21.6667,0.5)
traffic management infrastructure	(100,23.3333,0.5)
maritime safety administration	(100,23.3333,0.5)
economic condition	(85,11.6667,0.5)
social stability	(85,11.6667,0.5)
development level of shipping industry	(85,11.6667,0.5)

4.1.3 *Implement Jump Operation of Evaluation Factor's Cloud Model*

1 Cloud models of each evaluation factor in basic layer are got by floating cloud algorithm, recorded in Table 3.

Table 3. cloud model of evaluation factor in basic index layer

Factor in basic layer	cloud model (E_x, E_n, H_e)
Adaptability of natural condition	(85,2.3885,0.5)
Adaptability of navigation condition	(95.8883,6.8001,0.5)
Adaptability of safety & security condition	(95.5060,5.2506,0.5)
Adaptability of social condition	(85,4.4594,0.5)

2 The numerical characteristics of comprehensive evaluation cloud model is $(92.0942, 4.7382, 0.5)$ and the cloud atlas is shown in Fig.2.

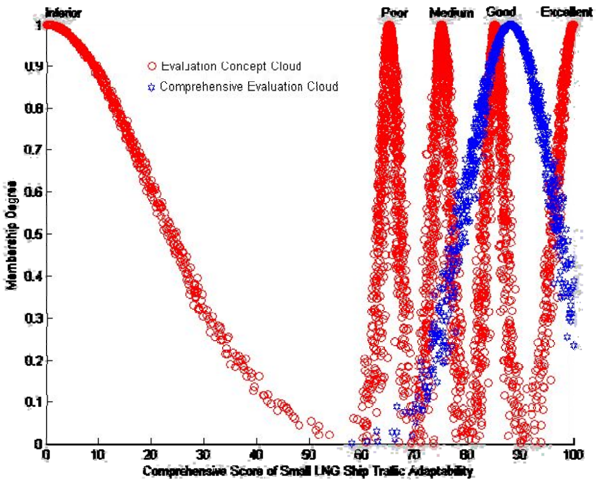


Figure 2. Cloud model's numerical characteristics graph of comprehensive evaluation of small LNG ship's navigation adaptability in Southeast Asia

In Fig.2, five red clouds are review clouds; the blue cloud is comprehensive evaluation cloud. We can see the distribution of final comprehensive evaluation result in the original reviews clouds, and expectation of small LNG ship's navigation adaptability is 92.0942, covering between "good" and "excellent" but mainly biasing in favor of "good".

4.2 *Fuzzy Comprehensive Evaluation Method*

The process of fuzzy comprehensive evaluation method used to small LNG ship's navigation adaptability is described as follows: firstly, the evaluation criteria should be described by the membership function, so that the membership matrix of evaluation factor can be built; secondly, comprehensive evaluation matrix is computed by composite operation between weight matrix of evaluation factors and membership degree of evaluation factors. In this paper, triangular membership function is used to confirm membership degree of each evaluation factor. The weights of each evaluation factor are the same recorded in Table1.

Each membership function is expressed as follows:

$$\mu_{V_1}(U_{ij}) = \begin{cases} 1, & U_{ij} < 55 \\ (65 - U_{ij})/10, & 55 \le U_{ij} < 65 \\ 0 & 65 \le U_{ij} \end{cases}$$

$$\mu_{V_2}(U_{ij}) = \begin{cases} (U_{ij} - 55)/10, & 55 \le U_{ij} < 65 \\ (75 - U_{ij})/10, & 65 \le U_{ij} < 75 \\ 0 & U_{ij} < 55 \quad or \quad 75 \le U_{ij} \end{cases}$$

$$\mu_{V_3}(U_{ij}) = \begin{cases} (U_{ij} - 65)/10, & 65 \le U_{ij} < 75 \\ (85 - U_{ij})/10, & 75 \le U_{ij} < 85 \\ 0 & U_{ij} < 65 \quad or \quad 85 \le U_{ij} \end{cases}$$

$$\mu_{V_4}(U_{ij}) = \begin{cases} (U_{ij} - 75)/10, & 75 \le U_{ij} < 85 \\ (95 - U_{ij})/10, & 85 \le U_{ij} < 95 \\ 0 & U_{ij} < 75 \quad or \quad 95 \le U_{ij} \end{cases}$$

$$\mu_{V_5}(U_{ij}) = \begin{cases} 0, & U_{ij} < 85 \\ (U_{ij} - 85)/10, & 85 \le U_{ij} < 95 \\ 1 & 95 \le U_{ij} \end{cases}$$

The membership degree of each evaluation factor is calculated and recorded in table 4:

Table 4. Membership degree of each evaluation factor

Factor in basic layer	Factor in element layer	Score	Inferior	Poor	Medium	Good	Excellent
Adaptability of natural condition U_1	wind U11	83			0.2	0.8	
	sea fog U_{12}	84			0.1	0.9	
	tropical cyclone U_{13}	85.5				0.95	0.05
	current U_{14}	86.5				0.85	0.15
	storm U_{15}	83.5			0.15	0.85	
	surge U_{16}	85.5				0.95	0.05
Adaptability of navigation condition U_2	traffic density U_{21}	89.5				0.55	0.45
	traffic structure U_{22}	91.5				0.35	0.65
	complexity of course U_{23}	90.5				0.45	0.55
Adaptability of safety & security condition U_3	pilotage condition U_{31}	88.5				0.65	0.35
	NAVAID guide U_{32}	90				0.5	0.5
	traffic management infrastructure U_{33}	92.5				0.25	0.75
	maritime safety administration U_{34}	91.5				0.35	0.65
Adaptability of social condition U_4	economic condition U_{41}	82.5			0.25	0.75	
	social stability U_{42}	85.5				0.95	0.05
	development level of shipping industry U_{43}	82.5			0.25	0.75	

The membership degree of small LNG ship's navigation adaptability is $U = (0 \quad 0 \quad 0.0472 \quad 0.6466 \quad 0.3062)$. The final evaluation result is "good" in accordance with the principle of maximum membership.

4.3 *Contrastive Analysis*

Comparing the evaluation processes and results between fuzzy comprehensive evaluation method and the comprehensive evaluation cloud model , we can draw the following conclusions:

1 In the evaluation process of fuzzy comprehensive evaluation method, the membership degree of each evaluation factor is subjective values given by experts, which makes the result unreliable and non-objective. However, the comprehensive evaluation cloud model reduces the subjective factors of experts during identification of evaluation criteria and evaluation of evaluation factor, and fully reflects the fuzziness and randomness in the evaluation process.
2 For the evaluation results, the fuzzy comprehensive evaluation method only gives a concrete membership degree. But the comprehensive evaluation cloud model can not only provides a specific comprehensive evaluation result, but also be intuitive to show the distribution of the comprehensive evaluation result in original figure.

5 CONCLUSION

In this paper, cloud model is used to process evaluation factor and review, so that the randomness and fuzziness of qualitative in the evaluation process are fully reflected. The empower method of evaluation factor based on cloud model and Delphi takes full consideration of fuzziness and randomness of real-world awareness and overcomes the limitation of traditional subjective factor and awareness , therefore , the weights are reasonable.

The comprehensive evaluation cloud model for small LNG ship's navigation adaptability is a new method for quantitative evaluating ship's navigation adaptability. But with the development of water transport and ship design industry, we should constantly improve the evaluation system and evaluation set.

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