ISBN: 978-981-18-5852-9
WCSE 2022 Spring Event: 2022 9th International Conference on Industrial Engineering and Applications
doi: 10.18178/wcse.2022.04.155

Navigation Risk Evaluation in Port Waters based on Improvement Fuzzy Comprehensive Evaluation

Liwan Zhou[1], Xin Luo[2], Mi Yan[2], Shengwei Li[2], Senlin Pu[2], Lei Wang[2]

[1]Wuhan Huazhong Numerical Control co., ltd

[2]Wuhan University of Technology School of Automation

Abstract. Ship navigation safety is affected by various factors. A ship navigation risk evaluation method based on Rosen gradient projection method and fuzzy comprehensive evaluation is proposed in this paper. A three-layer navigation factor fuzzy comprehensive evaluation model is established. Rosen gradient projection method is used to calculate the weight of the model. This method can greatly weaken the influence of human subjective factors, maintain a certain calculation accuracy, and make the evaluation objective and accurate. Finally, experiments verify the feasibility of this method.

Keywords: Gradient projection, fuzzy comprehensive evaluation, risk evaluation

1. Introduction

As a bridge connecting maritime transportation and land transportation, port and wharf plays an extremely important role in maritime transportation. The navigation safety of the port and its adjacent waters plays an extraordinary role in ensuring the trade between sea and sea and between sea and land[1]. With the surge in the number of ships at sea and the frequent occurrence of marine risk accidents, the safety of ship navigation at sea has always attracted the attention of shipping enterprises and academia.

In the field of maritime traffic safety, there is a relatively perfect theoretical system. Literature[2] makes statistics on relevant factors such as ship scale, channel natural environment, wind, wave and current, quantitatively analyzes and evaluates the influence of various factors on ship maneuvering, and then obtains the evaluation idea of the overall risk of ship navigation in water areas. The research object of literature[3] is aimed at the natural environment around the channel, The natural factors affecting navigation safety are quantified systematically and carefully, and verified one by one, so as to provide a reference for promoting the safety of marine traffic environment. Literature[4] proposes to take the ratio of ship traffic accident conversion number and ship conversion activity within the specified period as the "safety index" to represent the ship traffic safety status of a port or water area in a certain period.

For the evaluation method, the research in the field related to maritime safety in literature[5] combines fuzzy theory and neural network, and dares to obtain good results; In reference[6], aiming at the problem of marine navigation risk, Bayesian network is used to study the probability reasoning model between various variables by means of quantitative analysis Reference[7] proposed a probabilistic framework for assessing ship risk based on hybrid method and multiple data sources. The Bayesian network learning method uses the data from the new inspection system of the Paris Memorandum of understanding on port state control to characterize the relationship between risk parameters and conduct dynamic and static evaluation Analytic hierarchy process is widely used in the field of navigation risk evaluation, but it has the disadvantage of strong subjectivity[8]; In order to weaken the influence of subjective factors, a fuzzy analytic hierarchy process (Fuzzy AHP) model is proposed to obtain the weight of evaluation factors by using the experience of multiple groups of experts, which is actually applied to the study of marine navigation risk evaluation[9-10] The risk cloud model (RCM) of the cloud model theory proposed in document[11] can use multi-channel information to evaluate the risk in the navigation environment, adapt to uncertainty and provide full-functional analysis of the navigation environment.

Based on the above theoretical system and evaluation method, a fuzzy comprehensive evaluation method based on gradient projection is proposed for the navigation safety of the port and its adjacent waters. Firstly, a multi-layer factor evaluation model is constructed. Secondly, a weight calculation method based on gradient projection is proposed, which can greatly weaken the influence of human subjective factors, and maintain the error calculation accuracy of no more than 0.1%, making the evaluation objective and accurate. Finally, experiments verify the feasibility of this method.

2. Evaluation Model

In this study, the fuzzy comprehensive evaluation gradient projection method (FCE-GP) is used to evaluate the navigation risk of ships in the port and its adjacent waters. The specific evaluation process is shown in Figure 1. Firstly, the risk factors during navigation are sorted out, and then the risk assessment is carried out according to multiple FCE steps and the weight value calculated by GP. This section mainly introduces the FCE procedure, and the next section introduces the GP procedure.

2.1. Establishment of the Evaluation Factor U

In this paper, the risk factors of ship navigation in the waters near the port are divided into two primary indicators: "traffic conditions" and "natural conditions". The traffic conditions are subdivided into "port conditions", "channel conditions", "ship traffic flow" and natural conditions are subdivided into secondary indicators such as "meteorological conditions", "hydrology" and "Geology". The above secondary indicators can be subdivided into the following tertiary indicators. The multi-layer factor set is conducive to the accuracy of the evaluation results.

- Security level.In accordance with the relevant provisions of the International Ship and port Facility Security code, the governments of Contracting States shall ensure that port facility security assessments are carried out, reviewed and approved for port facilities. ISPS code specifies three international security levels. Operational and physical security measures shall be taken by the port to ensure its operation at the level of security level 1.

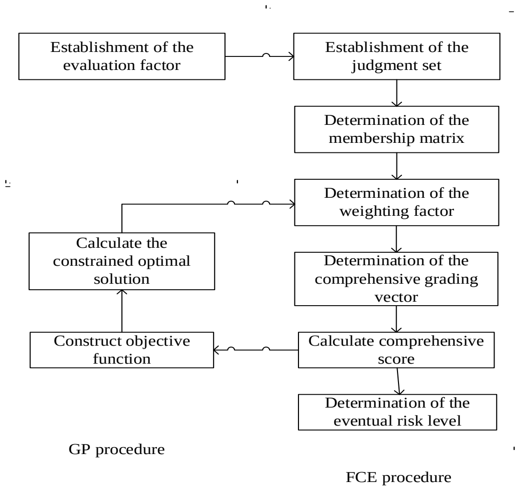

Fig. 1:overall block diagram of navigation risk assessment

- Effective length of berth. The effective length of berth refers to the horizontal distance along the wharf direction that can effectively use the berth in and out during the berthing and unberthing of ships.The regulations on the administration of ship pilotage points out that the effective length of the berth shall be at least 120% of the total length of the guided ship;
- Abundant water depth.The regulations on the administration of ship pilotage points out that the port must ensure that the berth has sufficient water depth and there are no obstacles under the water; The surplus water depth recommended by the European drinking water association EMPA is: for overseas waterways, the surplus water depth = 20% of the ship's draft; For waterways outside the port, the free water depth = 15% of the ship's draft; For waterways in the port, the free water depth = 10% of the ship's draft.
- Channel width."Channel width" is the ship operation space provided by a port for ships on the channel. Its size is one of the main symbols of maritime traffic safety in the port waters. The ratio of

maximum length to channel width is usually used as the standard. If the traffic congestion of the route is not considered, it is generally considered that the route width should be 1.5 times the maximum captain.

- Channel curvature.Turning radius of channel refers to the minimum radius of curvature on the center line of channel. Assuming that the turning radius of the channel is r and the length of the ship is L, generally: $r \geq (4 \sim 5)L$.
- Vessel crossing angle.Generally, the number of cross confluence points and the angle of each cross confluence are mainly used to reflect the risk degree of channel cross confluence. Among them, the crossing channel has the most impact on the safety of ship navigation. The maximum crossing angle of the channel is used as the index value to evaluate the crossing condition of the route. From 0 degree to 90 degree, the risk increases with the increase of crossing angle.
- Water traffic density.Ship density reflects the busy degree of ship traffic in the water area to a certain extent, but also brings difficulties to navigation safety, and objectively reflects the degree of danger. The number of ships per unit water area is used as the measurement standard of water traffic density, and the unit is ship / square kilometer.
- Visibility."Visibility" refers to the maximum horizontal distance that can be seen by normal eyesight at sea. In foggy weather and low visibility, the safe driving of passenger ships will be greatly affected. The safety level corresponding to visibility is determined according to the 1972 International Convention on rules for preventing collisions at sea and relevant data, with the unit of N miles.
- Wind speed.Windy weather occurs frequently along the coast, which has a great impact on the safe operation of passenger ships. The wind grade is mostly defined according to the Beaufort wind grade: the wind is divided into 13 grades from 0 to 12 according to the wind speed. The unit is wind grade.
- Rainfall.Statistics show that most of the ship accidents caused by rainfall are caused by sudden violent storms at sea.Generally speaking, when the rainfall is more than 25mm, it will affect the ship's water navigation. The unit is mm / day.
- Wave height. Wave height is usually expressed by wave level, which is the degree of fluctuation of the sea surface caused by the strength of wind. The higher the wave, the greater the level. The wave height is evaluated according to the commonly used Dow wave level.
- Ice. Sea ice has an important influence on the vertical distribution of marine hydrological elements, seawater movement, marine thermal status and the formation of ocean bottom water.The amount of ice is the ratio of the area of dense sea ice in the unit sea surface to the area of the whole sea surface. The amount of ice is used as the evaluation standard.
- Current Speed. Due to the different flow directions and sizes in four seasons, the impact on ship safety is related to the ship's course, which will directly affect the ship's sailing time and operating benefits. The velocity of countercurrent is used as the evaluation standard.
- Reef. We often determine whether there is a threat to ship navigation by measuring the height of the reef from the water surface.
- Undercurrent. At the same time, in the sea area with rich ocean currents, attention should also be paid to the direction and speed of undercurrent. The velocity of undercurrent is also used as the standard for evaluation.

A three-level risk factor set is established from the above risk factors, as shown in Table 1.

Table 1: Multilayer Risk Factor Set

	Primary index	**Secondary index**	**Tertiary index**
Risk evaluation of navigation in port waters	**Traffic conditions** u_1	**Port conditions** u_{11}	**Security level** u_{111}
			Effective length of berth u_{112}
			Abundant water depth u_{113}
			Channel width u_{114}

		Channel conditions u_{12}	**Channel curvature** u_{121}
		Ship traffic flow u_{13}	**Channel curvature** u_{131}
			Water traffic density u_{132}
	Natural condition u_2	**Meteorological conditions** u_{21}	**Visibility** u_{211}
			Wind speed u_{212}
			Rainfall u_{213}
			Wave height u_{214}
		Hydrology u_{22}	**Ice** u_{221}
			Current Speed u_{222}
		geology u_{23}	**reef** u_{231}
			Undercurrent u_{231}

2.2. FCE procedure

- Establish the evaluation set V. Give the evaluation set $V = (v_1, v_2, ..., v_m)$, that is, the set of various evaluation results that the evaluator may make for the evaluation object. The judgment set of this study consists of five criteria, namely very unsafe, relatively unsafe, general, relatively safe and safe, which are represented by v_1、 v_2、 v_3、 v_4 and v_5 respectively, and the corresponding scores are as follows:

Table 2: Judgment Set and Score

	Very unsafe	relatively unsafe	commonly	relatively safe	safe
judgment set	v_1	v_2	v_3	v_4	v_5
Score	**5.5**	**6**	**7.5**	**8.5**	**10**

- Determine the first level index membership matrix R.The fuzzy set theory was first proposed by Zadeh[12], which expresses the membership of elements in the set through characteristic function. The membership relationship is no longer represented by the set of two values (0 and 1), but by any value in the interval [0,1], which corresponds to the membership[13]. For factor set $U = (u_1, u_2, ..., u_n)$ and evaluation set $V = (v_1, v_2, ..., v_m)$,n represents the number of factor sets, u_i represents the i-th factor of each layer in the factor set; m represents the number of evaluation set standards, and v_j represents the j-th standard. Fuzzy mapping is determined as Formula 1.Then represented by fuzzy matrix R,R is the single factor evaluation matrix, where r_{ij} represents the membership degree of the i-th factor u_i to the j-th evaluation standard v_j .

$$f : U \to \Gamma(V),$$
$$u_i \to f(u_i) = (r_{i1}, r_{i2}, ..., r_{im}) \in \Gamma(V) \quad (1)$$

$$R = [\begin{matrix} r_{11} & r_{12} & \cdots & r_{1m} \\ r_{21} & r_{22} & \cdots & r_{2m} \\ \cdots & \cdots & \cdots & \cdots \\ r_{n1} & r_{n2} & \cdots & r_{nm} \end{matrix}]$$

- Determining the weight factor W .Weight vector refers to the relative prominence of the evaluation index. In this study, the weight factor is initialized to any value in the interval (0,1), and then determined by Rosen gradient projection method.
- Determination of comprehensive grading vector B. After determining the weight set w and the single factor evaluation matrix R, the fuzzy operation principle of the comprehensive grading vector of the upper level can be expressed as[14]:

$$B = A \circ R = (b_1, b_2, ..., b_m) \quad (2)$$

"∘" It is called fuzzy operator. At present, m (●, ⊕) mode is adopted,and w_i represents the weight value corresponding to the i-th factor.

$$b_j = \sum_{i=1}^{n} w_i \circ r_{ij} = \min\{1, \sum_{i=1}^{n} w_i \cdot r_{ij}\},\ j = 1, 2, \cdots, m \quad (3)$$

- Calculate the comprehensive score S. After the final level comprehensive score vector $B = (b_1, b_2, ..., b_m)$ is obtained, the comprehensive score calculated according to formula 4. Then the weight is calculated iteratively. After ensuring a certain error accuracy, the maximum corresponding safety level is selected as the evaluation result according to the max principle.

$$S = 5.5 \times v_1 + 6.5 \times v_2 + 7.5 \times v_3 + 8.5 \times v_4 + 10 \times v_5 \quad (4)$$

3. Rosen Gradient Projection Method

Set the objective function as:

$$\text{V} = \frac{1}{2} \sum \text{e}^2 = \frac{1}{2} \sum \left(S^* - S \right)^2 \quad (5)$$

S^* is the evaluation score given by the expert according to the existing conditions. S is the score calculated by the evaluation model.

Step 0. Give the initial feasible point x_0 and let k = 0;

Step 1.Determines valid $A_1 x_k = b_1$ and non valid constraints $A_2 x_k > b_2$ at x_k, where $A = \begin{bmatrix} A_1 \\ A_2 \end{bmatrix}$ and $b = \begin{bmatrix} b_1 \\ b_2 \end{bmatrix}$;

Step 2.Let $M = \begin{bmatrix} A_1 \\ E \end{bmatrix}$, If M is empty, let P = I (identity matrix). Otherwise, let $P = I - M^T (MM^T)^{-1} M$;

Step 3.Calculation $d_k = -P \nabla f(x_k)$. If $\|d_k\| \neq 0$, turn to step 5; Otherwise, turn to step 4;

Step4.Calculation $\omega = (MM^T)^{-1} M \nabla f(x_k) = \begin{bmatrix} \lambda \\ \mu \end{bmatrix}$, If $\lambda \geq 0$, the calculation is stopped, the output x_0 is KT point. Otherwise, select a negative component λ, such as $\lambda_j < 0$, to modify the matrix, that is, remove the row corresponding to λ_j in A_1 and turn to step 2;

Step5.Solve the one-dimensional search problem and determine the step size α_k:

$$\min\ f(x_k + \alpha d_k)\ s.t.\ 0 \leq \alpha \leq \overline{\alpha} \quad (6)$$

Wherein , $\overline{\alpha}$ is determined by the following formula:

$$\bar{\alpha}=\begin{cases}\min\left\{\frac{(b_2-A_2x_k)_i}{(A_2d_k)_i}\mid(A_2d_k)_i<0\right\},(A_2d_k)_i<0\\ +\infty\quad(A_2d_k)_i\geq 0\end{cases} \tag{7}$$

Step 6.Let $x_{k+1}=x_k+\alpha_k d_k$, $k=k+1$,turn to step 1.

4. Case Analysis

Assuming that the large passenger ship is selected as the experimental ship type, the length is not less than 150m, and the safety critical value of the affluent water depth is set to 1m, the factor set u and the evaluation set V are determined. According to the above factors, the three-layer fuzzy evaluation model shown in the table below is established, and the corresponding safety level is determined by referring to relevant literature as follows.

Table 3: Risk factor set and its corresponding evaluation level

	Very unsafe	relatively unsafe	commonly	relatively safe	safe
u_{111}	3	2	1		
u_{112}	≤1.15	1.15-1.25	1.2-1.25	1.25-1.3	≥1.3
u_{113}	<0.8	0.8-0.9	0.9-1.0	1.0-1.2	>1.2
u_{114}	0.8-1	0.6-0.8	0.4-0.6	0.2-0.4	0-0.2
u_{121}	60-90	45-60	30-45	15-30	0-15
u_{131}	70-90	60-70	45-60	20-45	0-20
u_{132}	>10	9-10	7-9	5-7	0-5
u_{211}	≤0.5	0.5-1	1-2	2-5	>5
u_{212}	≥7	6-7	5-6	4-5	<4
u_{213}	≥80	50-80	25-50	10-25	<10
u_{214}	>7	6-7	5-6	2-5	≤2
u_{221}	>5	4-5	3-4	1-3	0-1
u_{222}	>5	3-5	2-3	1-2	0-1
u_{231}	<8	8-10	10-15	15-20	>20
u_{231}	>5	3-5	2-3	1-2	0-1

For the above factor set, the weights under each secondary index are effective constraints $\sum w_i=1$ and non effective constraints $0<w_i<1$. The above constraints are substituted into the gradient projection algorithm, and then the gradient projection algorithm is trained by using the expert data set to obtain the appropriate factor weights at all levels.

The initial three-level factor weight is set to $\frac{1}{n}$, and n is the number of three-level factors under the second-level factor, and the above conditions are substituted into the weight calculation process, and set the step size to 0.001. When the accuracy reaches 0.001, the iteration ends, and the test results are shown in Figure 2-4.

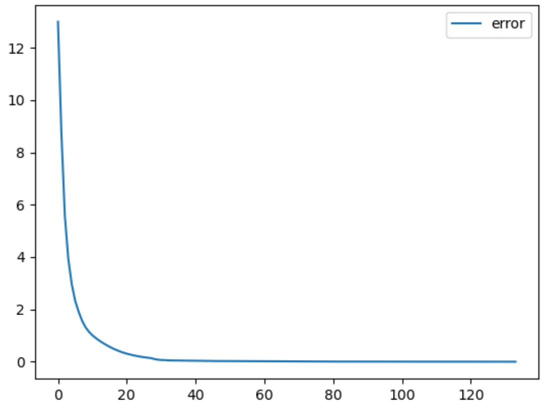

Fig. 2: SSE of data set

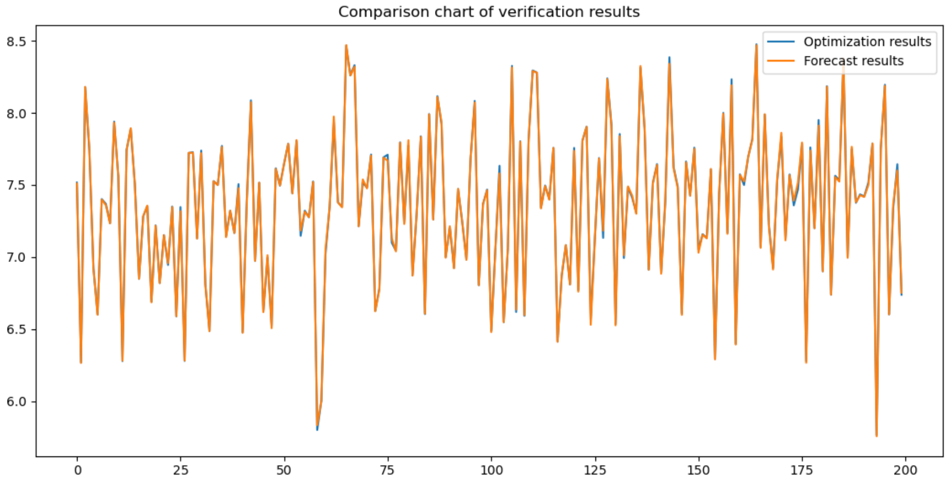

Fig. 3: Optimization results and forecast results

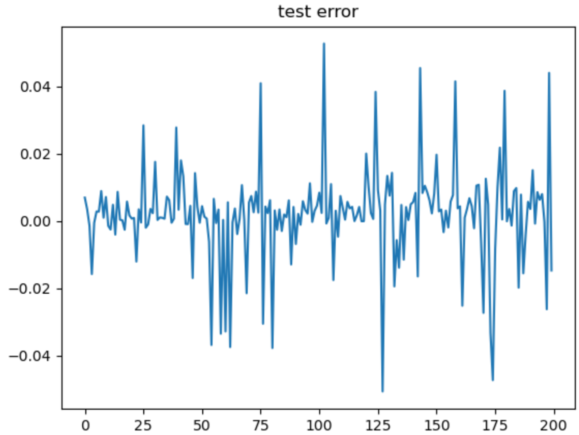

Fig. 4: Optimization results and forecast results

The multi-layer fuzzy comprehensive evaluation method has the characteristics of fuzziness, quantification and hierarchy. It can make a comprehensive, correct and quantitative evaluation of navigation. By adding the gradient projection algorithm to calculate the weight, the result is more objective and accurate than the analytic hierarchy process and entropy weight method.

5. Conclusion

A risk evaluation model based on gradient projection fuzzy comprehensive evaluation is proposed for ships sailing in the port and its adjacent waters. A multi-layer fuzzy evaluation model is constructed. The gradient projection method can optimize the weight value with high accuracy, avoid the influence of subjective factors, and make the evaluation process objective.

6. References

[1] Statheros, T. , G. Howells , and K. Mcdonald-Maier . "Autonomous Ship Collision Avoidance Navigation Concepts, Technologies and Techniques." The Journal of Navigation 61.1(2008):p.129-142.

[2] MD Woodward. "Evaluation of inter-facility uncertainty for ship manoeuvring performance prediction." Ocean Engineering 88.sep.15(2014):598-606.

[3] Gasparotti, Carmen , and L. Domnisoru . "Navigation safety assessment based on short term seakeeping limit criteria for a feeder type container ship of 1300 TEU." (2015).

[4] Fang Xianglin, Wang FengChen, Wu Zhaolin "Ship traffic safety evaluation method - safety index method." Journal of Dalian Maritime University. 04 (1992): 337-341 .

[5] S.T. Ung et al. Test case based risk predictions using artificial neural network[J]. Journal of Safety Research, 2006, 37(3) : 245-260.

[6] Zhang, J. , et al. "Maritime Transportation Risk Assessment of Tianjin Port with Bayesian Belief Networks." Risk Analysis An Official Publication of the Society for Risk Analysis 36.6(2016):1171.

[7] Yu, Q. , et al. "An integrated dynamic ship risk model based on Bayesian Networks and Evidential Reasoning." Reliability Engineering System Safety (2021):107993.

[8] X Zhou, L. Cheng , and M. Li . "Assessing and mapping maritime transportation risk based on spatial fuzzy multi-criteria decision making: A case study in the South China sea." Ocean Engineering 208(2020):107403.

[9] B, Sahin, S, et al. " Risk assessment of arctic navigation by using improved fuzzy-ahp approach." Transactions of the Royal Institution of Naval Architects (2015).

[10] "Engineering - Ocean Engineering; New Data from Nanjing University Illuminate Findings in Ocean Engineering (Assessing and Mapping Maritime Transportation Risk Based On Spatial Fuzzy Multi-criteria Decision Making: a Case Study In the South China Sea)." Journal of Engineering .(2020).

[11] Yan-Fei Tian, et al."Featured risk evaluation of nautical navigational environment using a risk cloud model." Journal of Marine Engineering & Technology 19.3(2020).

[12] Zadeh L.A."Fuzzy sets as a basis for a theory of possibility." Fuzzy Sets and Systems 1.1(1978).

[13] Zhang Jialiang, et al."Risk assessment of floating offshore wind turbines based on fuzzy fault tree analysis." Ocean Engineering 239.(2021).

[14] Yin Zhang, et al."Risk evaluation of large-scale seawater desalination projects based on an integrated fuzzy comprehensive evaluation and analytic hierarchy process method." Desalination 478.C(2020).