Navigation Safety Evaluation of Xiamen port Based on AHP-Fuzzy

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Keywords: Xiamen Port; navigation safety; Comprehensive evaluation; Countermeasures

Abstract. In order to safeguard the maritime navigation safety of Xiamen port and improve the efficiency of port operations, protect the marine environment, based on the analysis of various factors affecting the safety of Xiamen port navigation, we established navigation safety evaluation index system of Xiamen port, and then applied the Analytic Hierarchy Process AHP- Fuzzy comprehensive evaluation to evaluate the navigation safety of Xiamen port, and get the main factors affecting the navigation safety of Xiamen. According to the evaluation results, and combined with the characteristics and Present situation of Xiamen port, the paper proposed corresponding countermeasures and suggestions of various risks control.

1 Introduction

Xiamen port is one of the major coastal ports in China. It is an important hub of China's maritime transport, the hub of the southeast coast, and is the major shipping port for Taiwan[1]. There are many kinds of ship in Xiamen port, such as ship carrying dangerous goods and oil tanker, which contribute to busy traffic. Especially, since “three links” with Taiwan, increasing the vessel traffic flow, navigable waters environment becomes increasingly complex, sea traffic safety facing greater potential threat, has become the focus and content of the study in the future development of Xiamen port area[2].

However, most of the traffic risk assessment using traditional qualitative methods, such as the [3-6]in the literature only for traffic safety evaluation method, not for specific areas of security evaluation. The fuzzy comprehensive evaluation method in [7] was used to evaluate the risk of the port in Xiamen, but the results were not analyzed. BP Neural network in literature[8] was used to evaluate the traffic safety of urban roads and highways, but the results were not analyzed. In this paper, the AHP - fuzzy comprehensive evaluation method is used to evaluate the safety of navigation in Xiamen port, and to obtain the main factors that affect the safety of navigation in Xiamen port. According to the evaluation results, combined with the characteristics and present situation of Xiamen port, the countermeasures and suggestions are put forward to control all kinds of risks.

2 The establishment of risk identification and evaluation index system of Xiamen port

2.1 Risk analysis of marine transportation in Xiamen port

The research object of port navigation safety evaluation index system is the various factors affecting the safety of navigation. According to the traffic safety assessment content [9], the first level indicators are identified as human factors, ship factors, navigation environment factors and management factors, the factors are analyzed as follows:

(1)Human factors

The concept of "human" in the human factors contains not only the direct cause of marine accident crew, ship traffic management department related personnel, develop contingency plans for various technical and management personnel, but also contains pilotage operation involved in the pilot team, pilotage equipment, the pilot, pilotage environment pressure. In addition, improper operation of pilot will also cause maritime traffic accident. Therefore, human factors should be analyzed from professional level, team cooperation ability, operating environment, working environment, knowledge structure and the decision making ability.

(2)Ship factors

One of the important factors of maritime accidents is the ship. Therefore, the status of the condition of the ship should be evaluated. In addition, the ship itself is more complex, mainly composed of hull and a lot of equipment and instruments, etc. These factors play important role in analyzing maritime accidents.

(3)Navigation environment factors

Navigation environment factors that affect the safety of the ship could be summarized as the following:①ship collision and grounding because of busy traffic and poor natural environment, ②ship collision, stranding and grounding because of wind, current, wave, fog and channel which lead to ship deviation or difficulties of ship handing behaviors, ③due to the influence of the wind, wave, flow of the anchor, causing the ship collision, running aground or stranded[10].therefore, should consider the following aspects: hydrology and meteorology, the channel, anchorage, port terminals, traffic flow beacons and obstruction.

(4)Management factors

The main management content includes navigation environment, navigation order, as well as human activities related to management. The main management way includes regulations of ship traffic management, on-site cruise control, navigation mark management, water traffic management and organization, navigation security, etc. Ship traffic management involves lots of content, but ship management related to navigation has been included, mainly in the following several parts: contingency plans, pilotage, cruise factors, tugboat factors and VTS.

2.2 The establishment of marine traffic risk identification and evaluation index system of Xiamen port

According to the evaluation content of traffic safety in maritime traffic project, combining with the current situation of Xiamen port navigation safety, considering the characteristics of index value, referring to the port navigation safety evaluation index constructed in this article, and then extracting navigation safety evaluation index system of Xiamen port, detailed in the following table:

Table 1 Port navigation safety evaluation index system

Target layer index A	First level index B	Second level index C	Third level index D
Xiamen port navigation safety level A	Human factors B1	Professional level C1	
		Team cooperation ability C2	
		Manipulator condition C3	
		Working environment C4	
		Knowledge structure C5	
		Decision making	

		ability C6	
	Ship factors B2	Ship dimension C7	
		Ship age C8	
		Strength of ship structure C9	
		Books and materials on ship C10	
		Ship equipment C11	
	Navigation environment factors B3	Port and Wharf C12	Risk level of wharf apron waters D1
			The gap of port berth capacity D2
			Berth risk level of channel intersection D3
			The threat of pier turning waters of main channel D4
		Hydro meteorological C13	Standard wind days D5
			Local winds affected D6
			The number of days which visibility is less than 100m D7
			Maximum velocity of main channel waters D8
			The maximum velocity of flow and main channel angle D9
			Maximum tidal range D10
			The average high tidal level D11
			The average tidal range D12
			The influence of local wave D13
			The average thickness of the ice D14
			The average ice age D15
		Channel C14	The width of the narrowest point channel D16
			The length of the channel D17
			The number of channel turning points D18
			The maximum bending degree of channel D19
			The number of channel crossing point D20
			The distance of obstacle D21
			The number of obstacle D22
			Channel saturation D23
			Channel depth surplus degrees/ maximum design type D24

		Aids to Navigation C15	The standard of beacon layout D25
			The advanced nature of the beacon D26
			Beacon completeness D27
			The rationality of visual aids D28
		Traffic flow C16	Maximum steering angle of traffic flow D29
			Intersection number of traffic flow D30
			The speed control of traffic flow D31
			The ratio of ship carrying dangerous goods D32
			Large ship traffic volume per year D33
			Weighted traffic/day D34
		Anchorage C17	Distance from the channel D35
			Bottom quality D36
			Anchorage types D37
			Anchorage capacity D38
			Frequency of strong winds in anchorage D39
	Managament factors B4	Tugboat C18	The number of tugboat D40
			Horsepower of tugboat D41
			Types of tugboat D42
		Cruise C19	Performance of cruise ship D43
			Equipment of cruise ship D44
			Emergency cruise D45
			Daily cruise D46
			Cruise effect D47
			Cruise staff D48
		VTS C20	VTS processing ability D49
			VTS coverage D50
			VTS staff D51
			VTS application effect D52
			VTS information level D53
			VTS video monitoring range D54
		Pilotage C21	Accident frequency of pilotage D55
			The equipment of pilot boatD56
			The pressure of pilot environment D57
		Emergency plan C22	Emergency command system integrity D58
			The integrity of the plan system D59
			The maneuverability of the plan D60
			The configuration of emergency command center D61

			The level of emergency response procedures D62
			The social level of search and rescue forces D63
			The conditions of emergency funds D64
			Emergency D65

3 The establishment of Xiamen maritime traffic safety evaluation model

(1)set up factors set

In this paper, with U_1, U_2, U_3, U_4 on behalf of evaluation index of the human factor, ship factor, navigation environment factor and management factors. The factors set as follows:

U={human factor U1, ship factor U2, navigation environment factor U3,management factor U4}

(a)Human factorset

Human factor U1={professional level U11,team cooperation ability U12，operator condition U13,working environment U14，knowledge structure U15，decision making ability U16}

(b)Ship factor set

Ship factor U2={ship dimension U21, ship age U22,strength structure of ship U23,books and materials on the ship U24，ship equipment U25}

(c)Navigation environment set

Navigation environment factor U3={port and pier U31,hydrometeorology U32,channel U33, beacon U34，traffic flow U35，anchorage U36 }

(d)Management factorset

Environment factor U4={tugboat U41,cruise U42,（VTS）U43, pilot U44, emergency plan U45}

The rest hierarchy can be deducedfrom this.

(2)weight determination [11]

In this paper, we take the first layer of evaluation factors which including human factor, ship factor, navigation environment factor and management factor, as example to illustrate the calculation method of each index weight and the calculation process. According to the expert questionnaire, available judgment matrix is as follows:

$$C = \begin{bmatrix} 1 & 3 & 2 & 2 \\ 1/3 & 1 & 1/2 & 1 \\ 1/2 & 2 & 1 & 2 \\ 1/2 & 1 & 1/2 & 1 \end{bmatrix}. \quad (1)$$

(I)Column regulation

$$\sum_{k=1}^{4} c_{k1} = 1 + 1/3 + 1/2 + 1/2 = 7/3 ; \quad (2)$$

$$\bar{c}_{11} = 0.4286 ; \bar{c}_{21} = 0.1428 ; \bar{c}_{31} = \bar{c}_{41} = 0.2143;$$

By analogy ：

New matrix will be available by above calculation ：

$$C' = \begin{bmatrix} 0.4286 & 0.4286 & 0.5 & 0.3333 \\ 0.1428 & 0.1428 & 0.125 & 0.1667 \\ 0.2143 & 0.2858 & 0.25 & 0.3333 \\ 0.2143 & 0.1428 & 0.125 & 0.1667 \end{bmatrix} \quad (3)$$

(II)Add each line of C'：

$$C_1 = \sum_{j=1}^{4} \bar{c}_{1j} = 1.6905 \; C_2 = \sum_{j=1}^{4} \bar{c}_{2j} = 0.5773 ; \; C_3 = \sum_{j=1}^{4} \bar{c}_{3j} = 1.0834 ; \; C_4 = \sum_{j=1}^{4} \bar{c}_{4j} = 0.6488 .$$

(III)Normalized vector $c = (1.6905, 0.5773, 1.0834, 0.6488)^T$：

$$\sum_{i=1}^{4} C_i = 1.6905 + 0.5773 + 1.0834 + 0.6488 = 4$$

Calculate the corresponding weight：

$$w_1 = \frac{C_1}{\sum_{i=1}^{4} C_i} = 0.4226 \; ; \quad (4)$$

$$w_2 = 0.1443 ; w_3 = 0.2709 ; w_4 = 0.1622 .$$

(IV)Calculate the maximum characteristic root of the judgment matrix C：

$$Cw = \begin{bmatrix} 1 & 3 & 2 & 2 \\ 1/3 & 1 & 1/2 & 1 \\ 1/2 & 2 & 1 & 2 \\ 1/2 & 1 & 1/2 & 1 \end{bmatrix} \begin{bmatrix} 0.4226 \\ 0.1443 \\ 0.2709 \\ 0.1622 \end{bmatrix} = \begin{bmatrix} 1.7217 \\ 0.5828 \\ 1.0952 \\ 0.6533 \end{bmatrix} . \quad (5)$$

$$\lambda_{\max} = \sum_{i=1}^{4} \frac{(Cw)_i}{n w_i} = 4.0458 . \quad (6)$$

(V)Test the consistency of the matrix

$$CI = \frac{\lambda_{\max} - n}{n - 1} = \frac{4.0458 - 4}{4 - 1} = 0.015267, \quad (7)$$

lookup table available, when the dimension $n = 4$, and RI=0.8980 , therefore CR :

$$CR = \frac{CI}{RI} = \frac{0.015267}{0.8980} = 0.017 < 0.10 . \quad (8)$$

CR has the satisfactory consistency.

Therefore, the judgement matrix of human factor, ship factor, navigation environment factor and management factor has consistency, and the weight of these four factors are shown in table below:

Table 2 index weight of U_1 layer

U	Human factor U_1	Ship factorU_2	navigation environment factorU_3	Management factor U_4
Weight value	0.4226	0.1443	0.2709	0.1622

In the same way, factors weight of Xiamen navigation safety evaluation index system can be calculated.

4 Xiamen maritime traffic safety comprehensive evaluation

(1)To build judgmentset

The judgment set is also called evaluation set, which is a collection of the evaluation results of the evaluation object. The judgment set rules the choice scope of all the evaluation factors in the evaluation results. The results can be qualitative, also can be quantified by the score[11]. According to the relevant national standards and the actual situation of Xiamen port, the evaluation level is defined as 5 levels, the index evaluation set and evaluation criteria of target level (top level) are as follows:

$$V = \{v_1, v_2, v_3, v_4, v_5\} = \{\text{low}, \textit{lower}, \textit{general}, \textit{high}, \textit{dangerous}\} = \{0\text{-}1, 1\text{-}2, 2\text{-}3, 3\text{-}4, 4\text{-}5\}. \quad (9)$$

The membership degree is the basis of solving practical problems by using fuzzy comprehensive evaluation theory. The correct membership function is the key to describe fuzzy control [11]. The evaluation criteria for each risk level of the lowest level indicators were determined by statistical analysis method, the relevant research results, relevant technical standards, expert consultation and questionnaire survey. Evaluation level of assignment by adopting the combination of quantitative and qualitative methods, including: historical data, industry standard, the method of literature, expert evaluation method and other theories. With “the distance between anchorage and channel” comment sets an example, explaining the process of the establishment of the quantitative indicators of membership degree, as following table 3:

Table 3 evaluation standard of distance between anchorage and channel

Evaluation standard	level				
	Lower risk	Low risk	general	dangerous	High dangerous
distance	≥5	3 ~ 5	1.5 ~ 3	1 ~ 1.5	≤1

Note: according to the plane design specification requirements of seaport in China, the safe distance between edge of harbor anchorage and sideline of channel should meet the following requirements: outside the port of anchorage should not be less than 2 to 3 times of the length of the design ship; when using single anchor or single buoy mooring, port anchorage should not be less than the length of the design ship; adopting double buoy mooring should not be less than 2 times of the width of design ship. Therefore.

By above knowledge, $v_1 = 5$, $v_2 = 3\sim5$, $v_3 = 1.5\sim3$, $v_4 = 1\sim1.5$, $v_5 = 1$, and the average distance between anchorage and channel (the times of length of design ship)$x_1 = 2$. Detailed calculation as followings:

Because $v_3 > x_1 > v_4$, therefore $r_3 = \frac{3-2}{3-1.5} = 0.667$, $r_4 = 1 - r_3 = 0.333$, $r_1 = r_2 = r_5 = 0$.

As a result, the evaluation sets of distance between anchorage and channel is [0, 0, 0.667, 0.333, 0]. It means 66.7% risk of distance between anchorage and channel of navigation safety of Xiamen port belongs to “general”, while 33.3% belongs to “dangerous”. According to above steps to calculate indicators of membership grade and to gather all of membership grade, then to get comprehensive evaluation matrix. Take environment factor of navigation as an example, as following table 4:

Table 4 Comprehensive evaluation matrix of environment factor of navigation

<table>
<tr><th rowspan="2">Target layer A</th><th rowspan="2">First level B</th><th rowspan="2">Second level C</th><th rowspan="2">Third level D</th><th colspan="5">Fuzzy comprehensive evaluation matrix</th></tr>
<tr><th>lower</th><th>low</th><th>general</th><th>dangerous</th><th>High dangerous</th></tr>
<tr><td rowspan="5">Navigation safety level of Xiamen port</td><td rowspan="5">Navigation factor (0.2845)</td><td rowspan="5">Anchorage (0.0929)</td><td>Distance from channel 0.2506</td><td>0.00</td><td>0.00</td><td>0.667</td><td>0.333</td><td>0.00</td></tr>
<tr><td>Bottom type of anchorage0.1614</td><td>0.2</td><td>0.35</td><td>0.25</td><td>0.15</td><td>0.05</td></tr>
<tr><td>Type of anchorage 0.1164</td><td>0.2</td><td>0.25</td><td>0.35</td><td>0.15</td><td>0.05</td></tr>
<tr><td>Anchorage capability 0.3227</td><td>0.1</td><td>0.3</td><td>0.4</td><td>0.15</td><td>0.05</td></tr>
<tr><td>Frequency of strength wind 0.1489</td><td>0.2</td><td>0.35</td><td>0.25</td><td>0.15</td><td>0.05</td></tr>
</table>

(1) Calculation of comprehensive evaluation

According to formula

$$B_i = W_i * R_i . \tag{10}$$

Note: B_i is comprehensive fuzzy calculation, which combines the indicator of penultimate layer; W_i is the weight matrix, R_i is the matrix of fuzzy comprehensive evaluation, which means the relationship of evaluation set of the indicator of penultimate layer.

It is able to work out the comprehensive evaluation matrix of upper level by calculating all of the indicators of bottom level. By analogy, the matrix of fuzzy comprehensive evaluation of target level can be figured out.

Matrix of fuzzy comprehensive evaluation of navigation safety level of Xiamen port, as following table.

Table 5 Matrix of fuzzy comprehensive evaluation of navigation safety level of Xiamen port

Navigation	Fuzzy comprehensive evaluation matrix

safety level of Xiamen port	lower	low	general	dangerous	High dangerous
	0-1	1-2	2-3	3-4	4-5
	0.1771	0.3250	0.2786	0.1808	0.0385

(2)Make results of fuzzy comprehensive evaluation clearer

The method of Centroid de-fuzziness make the results of evaluation much clearer：

The results of fuzzy comprehensive evaluation

=0.1771*0.5+0.3250*1.5+0.2786*2.5+0.1808*3.5+0.0385*4.5=2.0786

According to evaluation set V={lower,low,general,danger,high danger}={0-1,1-2,2-3,3-4,4-5}；

2.0786∈[2-3]，it able to get the result of navigation safety level of Xiamen port is “general”.

5 Measurements and suggestions to improve the safety level of maritime transportation of Xiamen port

In order to improve the safety level of maritime transportation of Xiamen port, it should take corresponding measurements to reduce risk. some countermeasures and suggestions are available as following:

(1) With the rapid development of economy of Xiamen port, more and more large ship will be in and out of Xiamen port. Large ships need to take advantage of the tide to be into harbor and the existing channel is for one-way, which resulting in impossible for encounter and avoidance between ships in the channel, and thus brings difficulties to the supervision of ships in Xiamen port. Therefore, the supervision of large ships will be focus of the present and future regulation.

(2) Due to terrain of Xiamen bay and close range between anchorage and channel, there is traffic risk. Therefore, it needto strengthen the supervision of mooring ship, to prevent the anchor into the channel.

(3) From the evaluation results, the performance and the characteristics of the cruise ship in Xiamen harbor can not fully meet the needs of port development. So,it suggests that improving the performance of cruise ship, increasing the related proposals, enhancing the purpose, planning, coverage and effectiveness of cruise work, strengthening the key segment, key part, key water area and dynamic law enforcement of key ship, as well as maintaining the order of navigation.

(4) The traffic flow of Xiamen port is complex, with lots of intersections between ships.Some ships do not comply with the relevant provisions of maritime navigation, improper operation of some crews and pilot factors, which are the main causes of contact damage accident. Therefore, it should strengthen the supervision of large ships and increase the supervision of facilities and equipment.

6 Conclusion

The research on the maritime traffic safety of port is the foundation to promote the rapid and efficient development of port.This paper uses the mathematical method to evaluate the safety of port navigation, and combines the characteristics and the present situation of Xiamen port, then to put forward corresponding measurements and suggestions to control various kinds of risks.Hopefully, these measurements and suggestions may provide maritime transportation safety of Xiamen port with reference.

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