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Comprehensive Risk Evaluation Analysis of Sea Waterway Nautical Navigational Environment Based on Fuzzy Theory

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Abstract:

The nautical navigational environment (NNEt) is a subsystem of the waterway transportation system (WTS) composing of 'human-machine-environment'. NNEt of sea waterway is closely related to navigation safety. It is necessary to identify, assess and prevent risks in NNEt to ensure safe operation of WTS. It is also of great significance to identify and evaluate risk of NNEt scientifically and reasonably for shipping development. Tiaozhoumen Waterway is one of the important passages for ships' entering and leaving Ningbo-Zhoushan Port. It is of great significance to identify and evaluate NNEt risk of the water way for taking safety guard measuares. In this paper, a method flow for risk evaluation analysis of NNEt based on fuzzy theory is proposed, and applied to comprehensive risk evaluation of Tiaozhoumen Waterway, Zhoushan Port. Risk factors in NNEt of Tiaozhoumen Waterway are identified using a systematic and hierarchical way. The membership degree to any of the five fuzzy concepts (the linguistic terms for indicating risk level) is obtained based on fuzzy statistical method. The weighted average method is used to defuzzy, in order to obtain quantitative evaluation results of concerned risk factors. Then, relative importance of risk factors are compared from perspective of the significance of risk. The research results of risk identification and evaluation can provide basis or reference for taking different and targeted risk prevention measures.

Keywords*: Risk identification, Risk evaluation, Fuzzy statistics, Membership principle, Tiaozhoumen Waterway.*

I. INTRODUCTION

According to statistics [1], in recent years, the volume of goods trade completed by water transportation as the main means accounts for more than 80% of the total trade volume, and the types of goods are mostly strategic energy materials and raw materials of bulk commodity. This shows that waterway transportation has occupied an indispensable position in the development of current national economy. The waterway transportation system (WTS) is a huge one composing of 'human-machine-environment'. Here, the 'environment' refers to nautical navigational environment (NNEt), which is one of the three subsystems. Accordingly, NNEt [2] refers to the various external conditions necessary to the water activities of a ship or other type of facility. It is comprehended NNEt is a

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general saying of all sorts of natural and social factors impacting on a ship's or facility's safety of activities.

NNEt is strongly with safety of nautical navigation. It is necessary to identify, assess and prevent risks in NNEt to ensure safe operation of WTS. With the continuous expansion of waterway transportation, port constructions are developing rapidly, hydraulic structures become gradually intensive. At the same time, as the main tool of waterway transportation, ships also show the trend of large size, diversification and high-speed. What is worse, the complex ship traffic flow makes the collision risk between ships. All these facts, while promoting the vigorous development of water transportation industry, also increase the potential risks of navigation to a certain extent. The reasonable risk evaluation of NNEt will provide important reference for safe navigation of ships and the decision-making of maritime safety management. Thus, it is of great significance to carry out reasonable risk evaluation of NNEt, for taking risk prevention measures, guarding navigation safety of ships. However, there are uncertainties when conducting risk evaluation of NNEt system in practice. For example, expert opinions or their decision-making results are often with fuzziness or randomness. Under the circumstance of uncertainty, it requires proper methods to enable both the feasibility of evaluation process and scientific evaluation results.

Scholars at home and abroad have carried out a lot of studies on risk assessment of NNEt and established various models for risk analysis under uncertainty. Balmat et al [3] presented a fuzzy approach for the MAritime RISK Assessment (MARISA) applied to safety at sea. The aim of his work was to define automatically an individual ship risk factor which could be used in a decision making system. Sahin and Kum [4] implemented risk assessment of arctic navigation by using improved fuzzy-AHP approach, to adapt to the fuzzy environment. Ozturk et al [5] evaluated navigational risk of port approach manoeuvrings with expert assessments and machine learning. Huang et al [6] built an evaluation and ranking model of navigation risk on basis of a comprehensive weighing method (CWM) and unascertained measurement theory, and the application results showed that the model may consider many kinds of uncertainty factors of navigation risk evaluation. Tian et al [7] proposed a risk cloud model (RCM) based on cloud model theory for evaluating risks in NNEt to adopt to uncertainty circumstances such as fuzziness or randomness. Fu et al [8] implemented identification of environmental risk influencing factors for ship operations in Arctic waters by using analytic hierarchy process (AHP) to overcome the existing uncertainty problems in identifying the risk influencing factors (RIFs). Mabrouki [9] proposed a specific methodology based on AHP multicriteria approach, to analyze and assess operational risk within the port terminals at the RO–RO activity, to identify the most critical risks and to establish preventive measures. Nie et al [10] carried our risk assessment of NNEt based on fuzzy comprehensive evaluation to overcome fuzziness. Weng and Wu [11], from three aspects of human, ship and environment, studied the risk level of WTS, summarized various methods to evaluate the risk level, and applied the method to perform safety analysis of the NNEt system for the port of Xiamen. Based on the comprehensive analysis of the influencing factors of safety, Jia [12] combined centralized statistical method, grey theory and fuzzy theory, to establish the safety evaluation model for the waterway navigation. Chen et al [13] systematically analyzed the key elements of navigation safety, determined risk assessment index system by combing experts' opinions, and established an evaluation model based on the abrupt progression method. Liu et al [14] presented comprehensive risk

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assessment of navigation safety in Shanghai inland water by means of multi-level fuzzy comprehensive evaluation based on AHP, due to the main consideration of fuzziness. Wang [15] made a review of risk assessment methods for maritime traffic. These scholars contributes a lot to risk control, and their positive results can provide reference for follow-up researches.

It is necessary to systematically and comprehensively identify the hazards, perform risk assessment by using scientific and reasonable evaluation methods that are with sufficient theoretical basis. Risk factors should be effectively warned based on the results of evaluation, so as to provide references for taking take targeted risk control measures. There is no fixed standard for classification of those elements. Evaluation on the constituent factors needs not only theoretical support, but also the customary practice and experience [10]. Therefore, the systematic and comprehensive identification and risk assessment of NNEt are still the focus of this field. This paper focuses on risk evaluation of NNEt under uncertainty. The approach is primarily based on the fuzzy theory to overcome uncertainty, in order to realize the quantitative evaluations of risk degree about the component elements of NNEt system. The approach process is applied to carry out risk evaluation analysis of Tiaozhoumen Waterway, Zhoushan Port. Specific work are as follows.

II. AREA OF INTEREST

The study object of this paper is the Tiaozhoumen Waterway of Zhoushan Port. The development and construction of Tiaozhoumen Waterway started on July 23, 2010, and was completed for use on December 2, 2011. On the whole, it is located on the southwest of the Zhoushan Island, between Xiazhi Island and Liuheng Island in Putuo District, Zhoushan City [16], as can be seen in Fig 1. It is a long and narrow waterway running from southeast to northwest, with about 22.5 nautical miles. In Fig 1, central line of the Tiaozhoumen Waterway is the serial connection of 4 way points (WPTs): from WPT 1 to WPT 4. In the southeast,WPT 1 is the intersection of Tiaozhoumen Waterway and Xiazhimen Waterway, while in the northwest, WPT 4 is the intersection of Tiaozhoumen Waterway and Fodu Waterway. Tiaozhoumen Waterway has an advantageous geographical location with good conditions for navigation use, such as deep water, small waves and stable seabed [17-18]. It is an ideal waterway for large ships.

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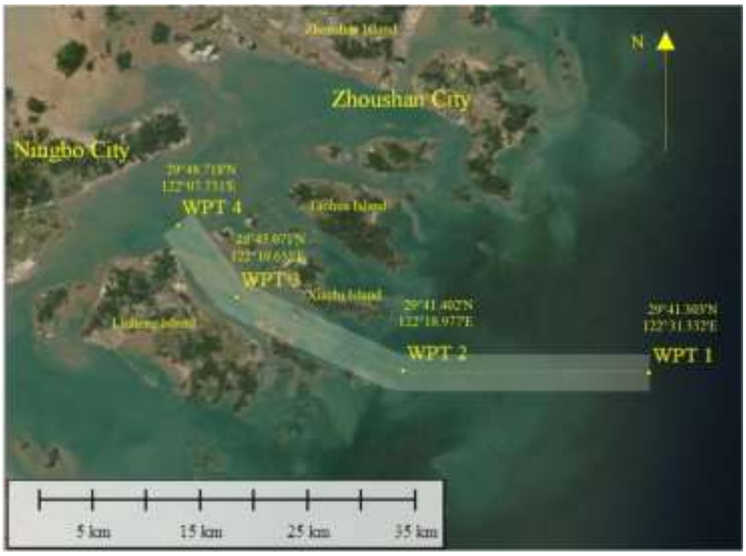

Fig 1: Area of interest: the geographical location of Tiaozhoumen Waterway

III. METHODS

Firstly, based on the viewpoint of systems engineering, a systematic and hierarchical analysis method is adopted to identify the risk factors in NNEt system. Secondly, the initial fuzzy evaluation is obtained based on expert's judgment by using questionnaire. Thirdly, the membership degree to any of the five fuzzy concepts (the linguistic terms for indicating risk level) is calculated based on fuzzy statistic method. Fourthly, based on the membership degree principle in fuzzy theory, the weighted average method is adopted to carry out defuzzification operation and get a clear quantitation on risk degree. Finally, evaluation and analysis are performed based on the quantitative result about risk degree. The overall technical route of risk evaluation analysis based on fuzzy theory is shown in Fig 2. Besides, in the application case, a comparative analysis is performed to show the advantages of the proposed method flow.

Fig 2: The overall technical route of risk evaluation analysis based on fuzzy theory

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3.1 Identification of Hazards

As mentioned above, NNEt [2] refers to the various external conditions necessary to the water activities of a ship or other type of facility. It is comprehended that NNEt is a general saying of all sorts of natural and social factors impacting on a ship's or facility's safety of activities. Simplely, NNEt consists of a number of factors [19], such as wind, wave and current, fog and visibility, channel length, channel width and channel water depth, channel bending, ship route cross, ship traffic flow volume, ship traffic flow diversity (such as the type of ship traffic flow composition, cargo type structure, scale structure, etc.), obstacles to navigation, navigational aids etc. Among them, some conventional factors have been considered in different literatures, such as wind, current, fog and visibility, channel water depth, ship traffic flow volume, etc [20-21]. Depending on time and space (such as water area), some personality factors are considered to be taken into account. If navigation safety in high temperature season is focused, the factor temperature then shall be considered. When paying attention to navigation safety in Arctic area, the factor sea ice then shall be payed attention to, etc. Zhao [22] identified the natural environment and traffic environment of the Yangtze River Bridge of Shanghai-Nantong railway separately, and took into account the bridge's conditions affecting safety. Li and Mei [23] identified seven factors including night background light, visibility, wind, current, channel width, traffic density, navigation aid conditions in the study of ship traffic safety evaluation in Jiaxing Port; Wen [24] determined the various factors affecting NNEt's safety in Meizhou Bay waterway based on a large number of investigation and research data. Based on the literatures, components of NNEt system are generally divided into three categories (the subsystems): natural environment, channel condition and traffic environment. It is concluded that the systematic and hierarchical analysis method and the existing research results can be used for reference in identifying risk factors in NNEt of Tiaozhoumen Waterway.

3.2 Fuzzy Evaluation on Risk Degree

Fuzzy evaluation by using linguistic terms (the qualitative concepts) is a very effective decision-making method in case of fuzziness [25-27]. The results of evaluation are usually expressed in a qualitative (fuzzy) form in practice, which can easily express the intuitive understanding of things [28]. Therefore, questionnaire using qualitative evaluation comment is designed to obtain qualitative evaluation of a concerned object based on the expert's judgment. The questionnaire (the core part) for fuzzy evaluation is shown in TABLE I.

This paper defines an index, risk degree (R), to reflect the risk level of the evaluation object. Usually, five words or phrases as used as benchmark linguistic terms (B) for qualitatively demarcating the risk level: Low (L), Moderately low (ML), Moderate (M), Moderately high (MH), and High (H); Besides, a numerical scale with the range [0 10] (or [0 1], [0 100], etc.) is often used for quantification of risk level. Thus, these five linguistic terms are adopted in this study to classify the risk levels. First, we define the five linguistic terms from the domain of discourse of the qualitative variable, namely the evaluation word/phrase (a). The domain of discourse of a includes all linguistic terms from L to H. Furthermore, the quantitative numerical variable called evaluation score (x) is used for quantitative evaluation. The domain

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of discourse of x is set to [0 10]. The mapping between a and x is established as indicated in TABLE I.

TABLE I. The mapping between variables a and x

Variable/Attribute	Domain of discourse/Value				
Evaluation word (a)	From L to H				
Benchmark five words (*B*)	L	ML	M	MH	H
Evaluation score (s)	$[s_{\min} \quad s_{\max}]=[0 \quad 10]$				
Benchmark five subintervals	[0, 2]	[2, 4]	[4, 6]	[6, 8]	[8, 10]

For concerned risk factors in Tiaozhoumen Waterway NNEt, using the five terms, the paper uses TABLE II to collect the initial fuzzy evaluations. An expert is asked to put a √ in the space to indicate his qualitative (fuzzy) evaluation of a risk factor. Multiple fuzzy evaluations can be achieved by consulting numbers of experts. Thus, the initial fuzzy evaluations based on experts' judgements can be received.

TABLE II. Questionnaire design (the core part) for fuzzy evaluation

Qualitative (fuzzy) evaluation		Benchmark five words				
		L	ML	M	MH	H
Risk factors	Risk factor 1					
	⋮					
	Risk factor i					

3.3 Calculation of Membership Degree

Membership and membership function are derived from the paper fuzzy sets, published by Professor Zadeh of University of California in 1965. If there is a number $A(x)\in[0,1]$ corresponding to any element in the universe (scope of study), then a is called a fuzzy set on U, and $A(x)$ is called the membership degree of x to a. When x changes in U, $A(x)$ is a function called the membership function of A. The membership degree $A(x)$ with the value of $[0,1]$ is used to represent the degree of x belonging to a. the closer the membership degree $A(x)$ to 1, the higher the degree of x belonging to a, and the closer $A(x)$ to 0, the lower the degree of x belonging to A.

It is a common method to get the membership of a fuzzy concept by membership function. But sometimes there are many difficulties in constructing membership function, such as no ready-made standard as the basis, lack of knowledge of participants. Or, due to the influence of experience knowledge, the membership function constructed does not meet actual requirements: not in line with general public perception. Therefore, in this paper, a reasonable and practical fuzzy statistical method is used to calculate

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the value of membership, instead of using the membership function based approach.

In view of the above analysis, in this paper, the fuzzy statistic method [29] is adopted to calculate membership degree (the value of membership function), since the method directly manifests the meaning of membership. It is an effective method and has been used by many scholars. Wang and Wang [30] calculated the membership degree of two stages at a certain time based on the fuzzy statistical principle, that is, to measure the membership degree of the time to flood season and non-flood season in the study of flood in Zhejiang Province; Zhang [31] calculated the membership degree of evaluation factor performance to fuzzy evaluation based on fuzzy statistical principle in the performance evaluation of eco industrial park. Chen et al [32-33] proposed to determine the relative membership function in flood season by using direct fuzzy statistical test. On the basis of stability demonstration, the relative membership function of flood season can be approximately used as absolute membership function when the data age is long enough.

The process of calculating membership degree based on fuzzy statistical method is as follows. First, the corresponding relationship between serial number (j) and linguistic term (LT) for fuzzy evaluation is established, as shown in TABLE III. Second, based on fuzzy statistic method, the membership degree to the j-th linguistic term (r_j) can be calculated.

TABLE III. Serial number & the corresponding linguistic term (LT)

Variable	**Value**				
Serial number (j)	1	2	3	4	5
Benchmark five words (B_j)	L	ML	M	MH	H

Based on fuzzy statistic, r_j can be obtained according to Formula (1):

$$r_j = \frac{n_j}{N} \tag{1}$$

where n_j represents the number of experts who use the j-th linguistic term to evaluate a factor; N represents the total number of consulted experts.

3.4 Quantification of Risk Degree

This step aims to get quantification of risk degree, so as to realize quantitative evaluation about a concerned object. With reference to AHP [34-35] method, five numbers (1, 3, 5, 7 and 9) are used as typical instantiation of S, s_j specifically, which means the fixed evaluation score corresponding to j-th

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linguistic term. The relationship between the benchmark linguistic terms (benchmark LTs) and s_j is shown in TABLE VI.

TABLE VI. The relationship between benchmark LTs and s_j

Variable	**Value**				
Serial number (j)	1	2	3	4	5
Benchmark five words (B_j)	L	ML	M	MH	H
Typical instantiation of s (s_j)	1	3	5	7	9

The weighted average method is used to perform defuzzification, using Formula (2):

$$s = \sum_{j=1}^{5} r_j s_j \tag{2}$$

where s represents the final quantitative evaluation result (the final evaluation score) after defuzzyfication operation; r_j represents the membership to the j-th linguistic term; and as the typical instantiation of s, s_j represents the fixed evaluation score corresponding to j-th linguistic term.

3.5 Analysis of Evaluation Results

The visual analysis of evaluation results tries to express the risk degree visually. This helps to show the results of the assessment, to aid analysis, and to make it easy for people to understand. Many scholars use visualization techniques to show their research results. Lei et al[36] put forward a navigation situation awareness system for VTS monitoring water area risk awareness. It monitors the safety risk of water area in a visual way, provides important reference for navigation decision-making, and it is able to provide technical support for the development of VTS intelligent system in the future; Xu [37] analyzed the research progress of the visualization technology of water traffic information, and demonstrated that the visualization of water traffic information can provide a new technical means for maritime supervisors to master the characteristics of the water traffic flow; Tian et al [38] directly displayed the evaluation level of risk factors under uncertainty by plotting cloud droplets of cloud model, to visually display the evaluation results; Shao [39] applied the grid visualization technology to quantitatively evaluate the safety risk of NNEt and determine the main high-risk areas, so as to provide intuitive decision-making information for safety management.

In this paper, the quantified value of risk degree can be obtained from Formula (2) directly. Further, based on the quantified value, the importance of factors in from perspective of risk can be ranked: the larger the quantified value is, the more important the factor is. Draw lessons from the references,

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visualization is used to display the evaluation results for analysis. In addition to the quantified value, plotting of quartiles, bar diagram, color gradation etc. are designed in this paper to visually display the questionnaire based initial fuzzy evaluations, the comprehensive evaluation results and the comparison of the importance of each factor under the risk significance, and make it easy to be understood.

VI. APPLICATION

4.1 Identification of Hazards

Based on the principle of systems engineering, risk factors of NNEt system of Tiaozhoumen Waterway are identified by systematic and hierarchical analysis. Thirteen risk factors (belongs to three categories) are identified for consideration, as shown in TABLE V.

TABLE V. Identification of risk factors in NNEt of Tiaozhoumen Waterway

The total system	Category	Risk factors
The NNEt of Tiaozhoumen Waterway	Natural environment	Wind
		Current
		Fog & Visibility
		Wave
		Tide
	Channel condition	Channel Length
		Channel Width
		Channel Water Depth
	Traffic environment	Channel Bending
		Ship Route Cross
		Ship Traffic Flow Volume
		Obstacles to Navigation
		Navigational Aids

4.2 Fuzzy Evaluation on Risk Degree

In this paper, we consulted 35 experts (issued and recycled 35 questionnaires). The experts gave their comments according to the experience of navigation practice and some evaluation standards [40-42]. Initial risk evaluation on NNEt of Tiaozhoumen Waterway is as TABLE VI.

TABLE VI. Initial risk evaluation on NNEt of Tiaozhoumen Waterway (statistical results)

Qualitative (fuzzy) evaluation	Risk level				
	L	ML	M	MH	H

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Risk factors	Wind	3	3	11	13	7
	Current	1	6	13	8	7
	Fog & Visibility	3	12	8	6	6
	Wave	3	6	9	13	4
	Tide	3	6	6	15	5
	Channel Length	5	13	10	5	2
	Channel Width	3	11	14	6	1
	Channel Water Depth	7	8	14	6	0
	Channel Bending	8	7	11	5	4
	Ship Route Cross	3	3	7	17	5
	Ship Traffic Flow Volume	1	2	10	16	8
	Obstacles to Navigation	0	3	13	15	4
	Navigational Aids	6	12	6	8	3

According to the results of expert evaluation, the coverage of experts' fuzzy evaluations on every factor can be graphically represented, as shown in Fig 3. In Fig 3, the quartiles are used to display the concentration or discrete degree of fuzzy evaluations on a factor. Taking 'Wind' as an example, after ranking the collected comments from the lowest to the highest, the comment in the first place is 'L', while the comment at the end is 'H'. The upper quartile is 'M', while the lower quartile is 'LH'. This distribution makes the general evaluation on the factor Wind is higher than 'M': the mean of evaluations is higher than 'M'.

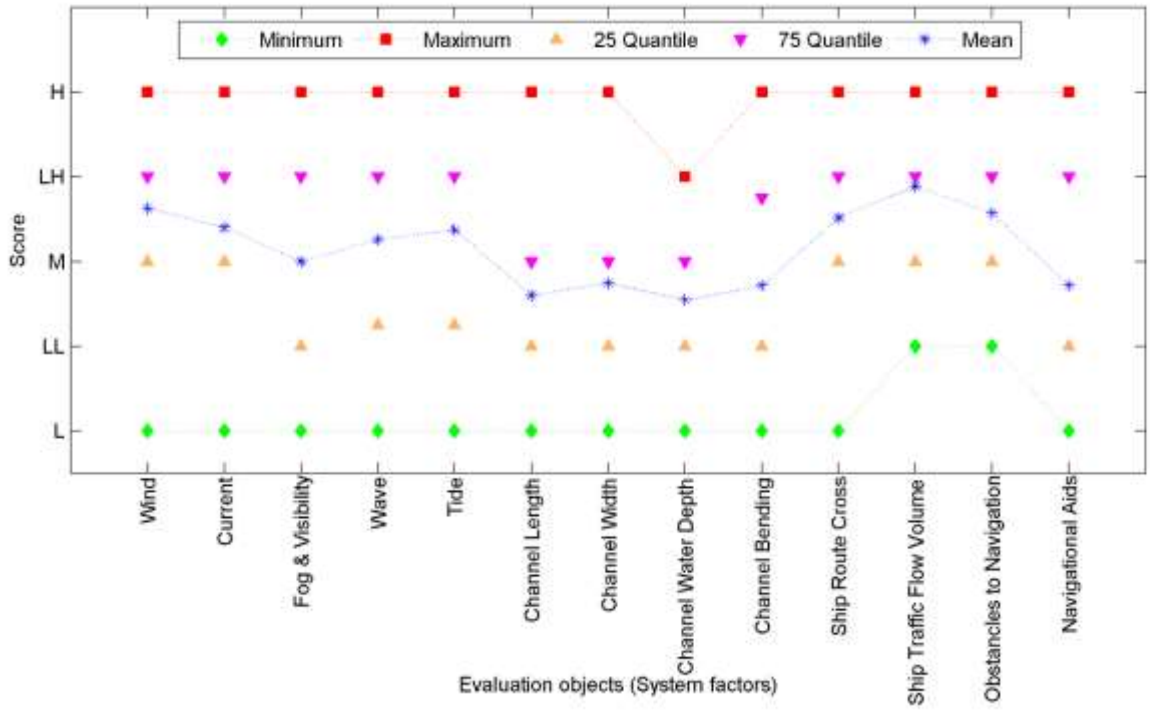

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Fig 3: The coverage of experts' fuzzy evaluations

4.3 Calculation of Membership Degree

According to the fuzzy statistics and Formula (1), the membership to benchmark five words (fuzzy concepts) about risk factors can be obtained, shown in TABLE VII.

TABLE VII. The membership to benchmark five words (fuzzy concepts)

Membership (r)		**Benchmark five words (fuzzy concepts) for evaluation use**				
		L	ML	M	MH	H
Risk Factors	Wind	0.09	0.03	0.31	0.37	0.20
	Current	0.09	0.34	0.23	0.17	0.17
	Fog & Visibility	0.03	0.17	0.37	0.23	0.20
	Wave	0.09	0.34	0.23	0.17	0.17
	Tide	0.09	0.17	0.26	0.37	0.11
	Channel Length	0.09	0.17	0.17	0.43	0.14
	Channel Width	0.09	0.31	0.40	0.17	0.03
	Channel Water Depth	0.20	0.23	0.40	0.17	0.00
	Channel Bending	0.23	0.20	0.31	0.14	0.11
	Ship Route Cross	0.09	0.09	0.20	0.49	0.14
	Ship Traffic Flow Volume	0.03	0.06	0.29	0.46	0.23
	Obstacles to Navigation	0.00	0.09	0.37	0.43	0.11
	Navigational Aids	0.17	0.34	0.17	0.23	0.09

In order to make the quantitative evaluation results of risk factors more intuitive and easy to understand, the quantitative evaluation results of 13 risk factors are visualized in the form of histogram. The abscissa involves of five linguistic terms: L, ML, M, MH and H. The left ordinate is number of experts while the right one is the proportion (membership degree based on the fuzzy statistics method) [28]. Visualization results are shown in Fig 4 ~ Fig 16. Taking 'Wind' as an example, it can be seen from Fig 4 that the number of experts using L, ML, M, MH and H to evaluate 'Wind' is respectively 3, 1, 11, 13 and 7, accounting for 0.09, 0.03, 0.31 0.37 and 0.20. According to Formula (1), this frequency or proportion is used as membership to a linguistic term-the fuzzy concept for quantitative evaluation.

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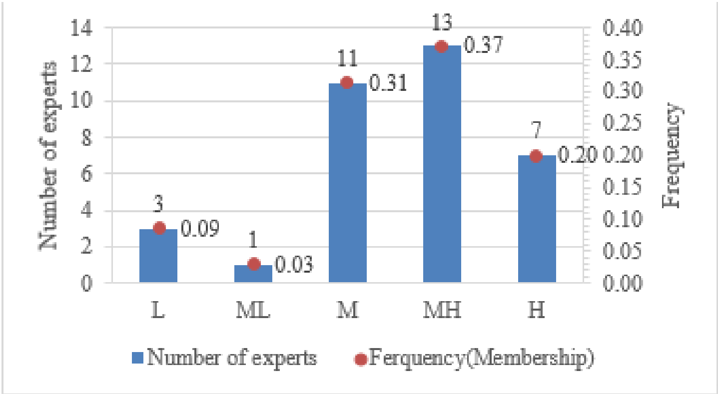

Fig 4: Fuzzy statistics of risk evaluation and membership about 'Wind'

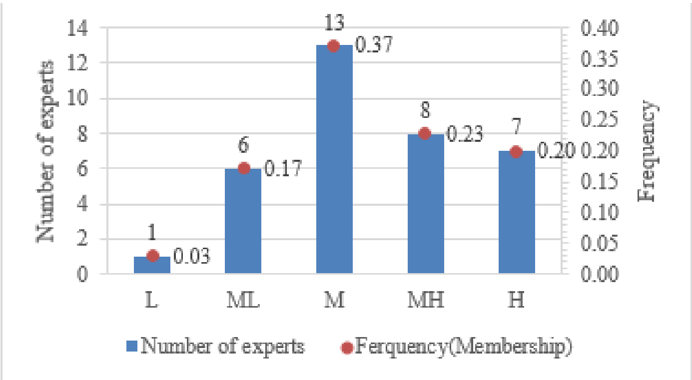

Fig 5: Fuzzy statistics of risk evaluation and membership about 'Current'

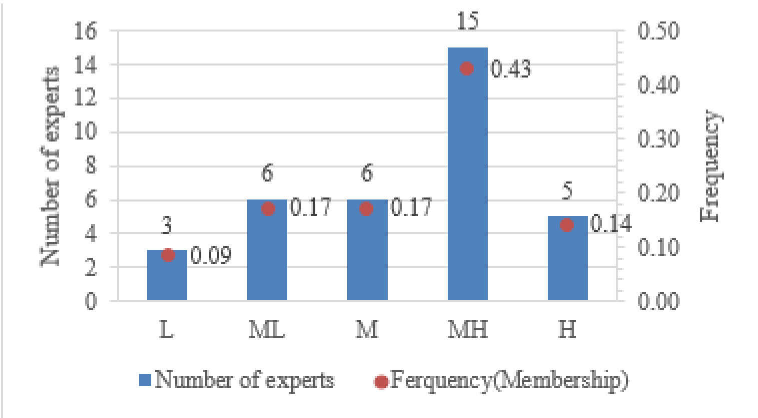

Fig 6: Fuzzy statistics of risk evaluation and membership about 'Fog & Visibility'

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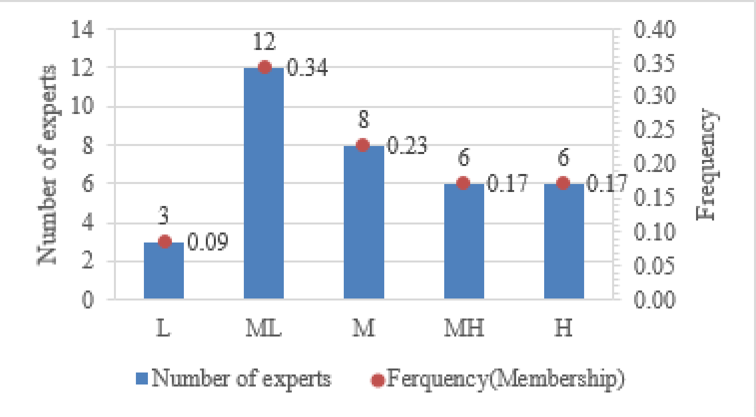

Fig 7: Fuzzy statistics of risk evaluation and membership about 'Wave'

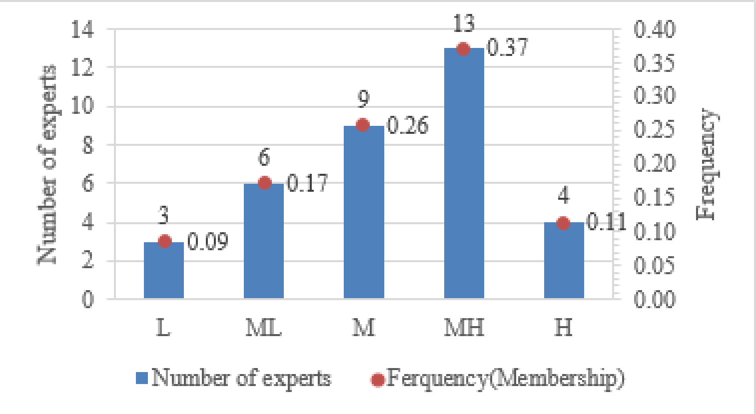

Fig 8: Fuzzy statistics of risk evaluation and membership about 'Tide'

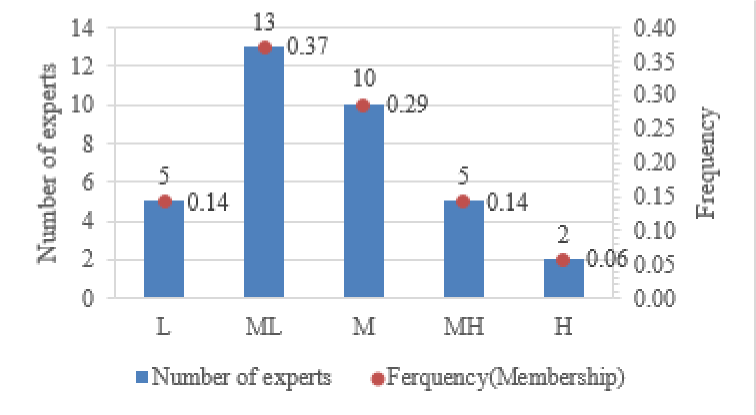

Fig 9: Fuzzy statistics of risk evaluation and membership about 'Channel Length'

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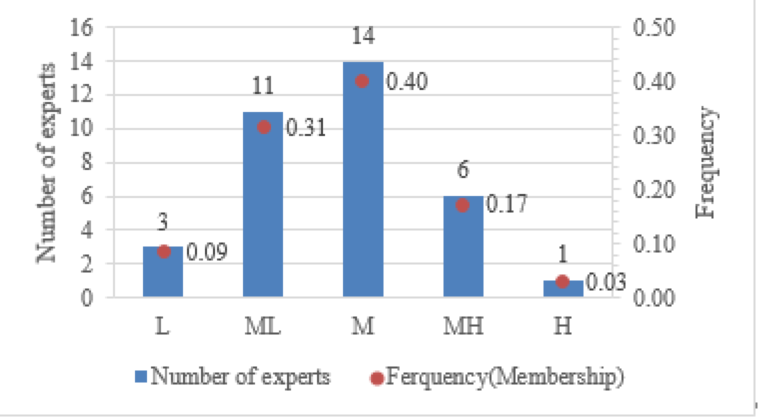

Fig 10: Fuzzy statistics of risk evaluation and membership about 'Channel Width'

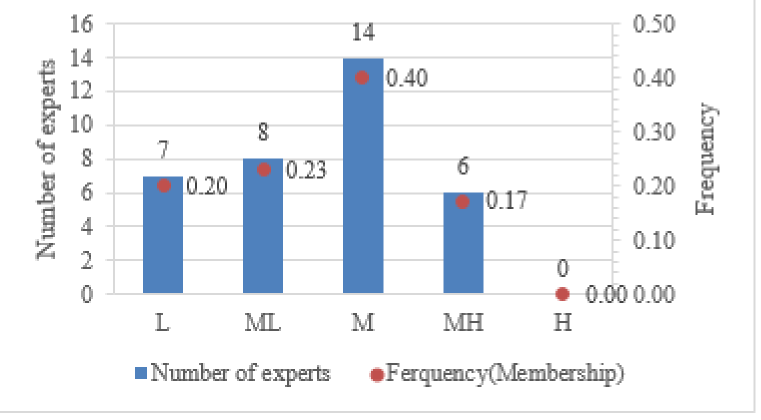

Fig 11: Fuzzy statistics of risk evaluation and membership about 'Channel Water Depth'

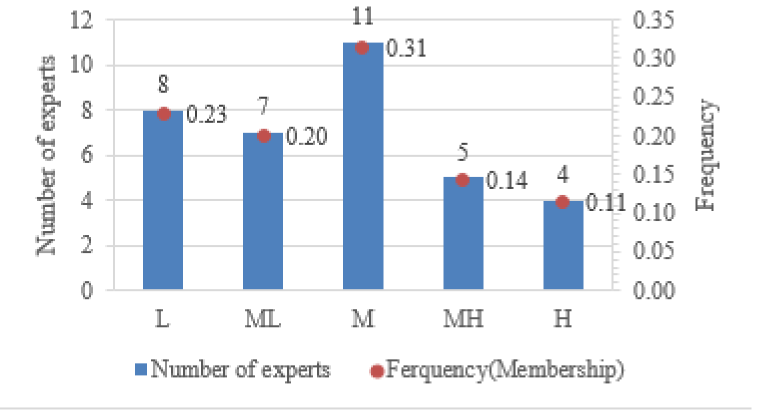

Fig 12: Fuzzy statistics of risk evaluation and membership about 'Channel Bending'

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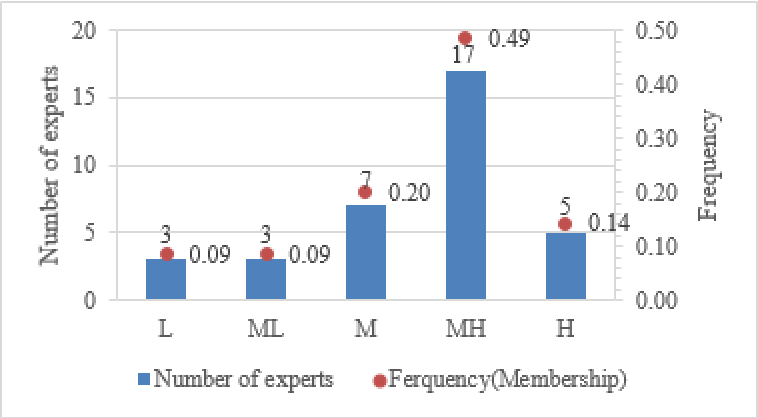

Fig 13: Fuzzy statistics of risk evaluation and membership about 'Ship Route Cross'

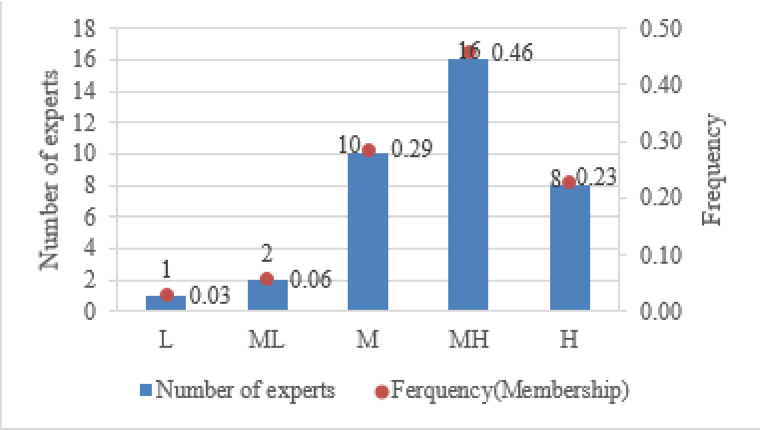

Fig 14: Fuzzy statistics of risk evaluation and membership about 'Ship Traffic Flow Volume'

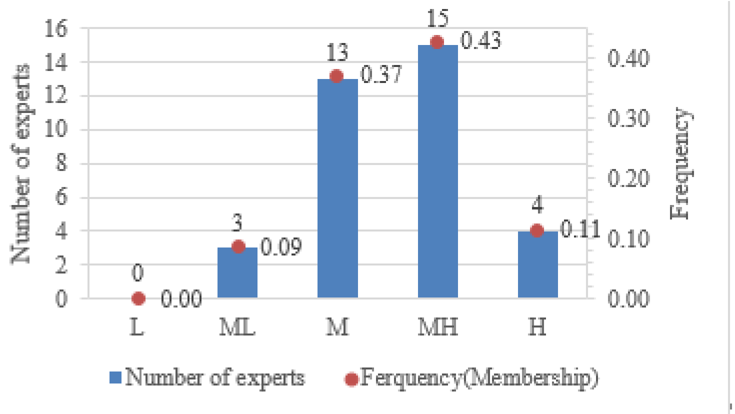

Fig 15: Fuzzy statistics of risk evaluation and membership about 'Obstacles to Navigation'

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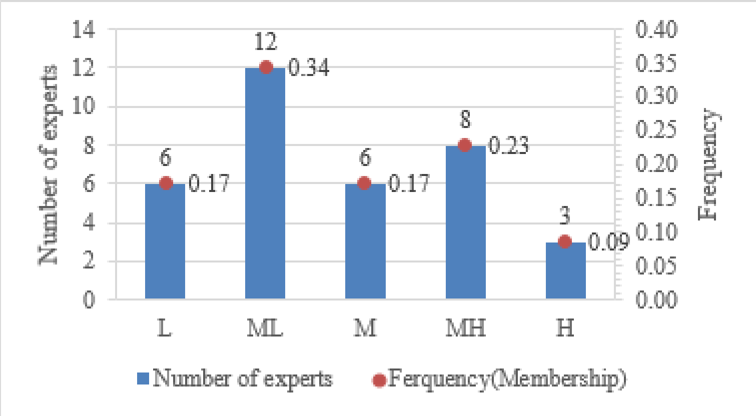

Fig 16: Fuzzy statistics of risk evaluation and membership about 'Navigational Aids'

4.4 Quantification of Risk Degree

In 4.3, the membership to linguistic terms about risk factors is obtained. According to Formula (2), quantitative results about risk degree are reached by using the weighted average method. Then the quantitative risk evaluations of concerned risk factors are shown in TABLLE VIII (column 2). According to TABLE I, it is able to find a fuzzy evaluation corresponding to the quantitative evaluation s, and this evaluation is treated as the qualitative evaluation on a concerned factor. The qualitative risk evaluations of concerned risk factors are also shown in TABLE VIII (column 3). Taking Wind as an example, the quantitative result on risk degree is 6.12 ($R(\text{Wind}) = s(\text{Wind}) = 6.12$) by using the 'Weighted Average' method, which gives the evaluation result in a quantitative way. And, the qualitative evaluation corresponding to $s(\text{Wind})$ is 'MH'.

TABLE VIII. Evaluation on NNEt of Tiaozhoumen Waterway based on the 'Weighted Average' defuzzication process

Risk factors	**The quantitative evaluation: evaluation score (s) about risk degree**	**The qualitative evaluation corresponding to score (s)**
Wind	6.12	MH
Current	4.98	M
Fog & Visibility	5.8	M
Wave	4.98	M
Tide	5.48	M
Channel Length	5.72	M
Channel Width	4.48	M
Channel Water Depth	4.08	M
Channel Bending	4.35	M

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Ship Route Cross	6.05	MH
Ship Traffic Flow Volume	6.95	MH
Obstacles to Navigation	6.12	MH
Navigational Aids	4.46	M

4.5 Analysis of Evaluation Results

TABLE VIII gives the quantification on risk degree by using the weighted average defuzzyfication method. Based on the quantitative results, the risk degree of factors can be understood and mastered quantitatively. Visualizing evaluation results is used to facilitate analysis. Ranking of risk and comparison of relative importance is shown in Fig 17. The height of each bar reflects the risk degree and relative importance of a concerned factor.

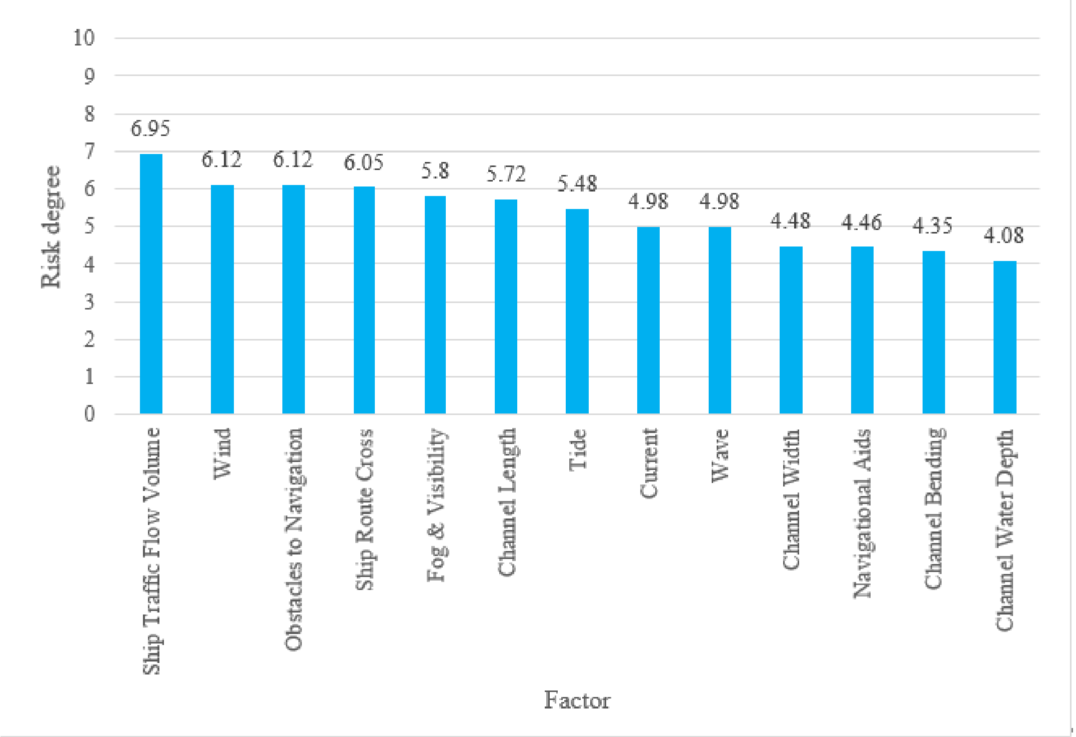

Fig 17: Ranking of risk and comparison of relative importance based on the 'Weighted Average' defuzzication process

The ranking of risk levels and the priority of taking preventive measures can be determined based on the quantitative results about risk degree. For example, quantitative evaluation of Ship Traffic Flow Volume is 6.95 and it’s bigger than that of others,which means it foremost catches people's attention due to the high risk level and should be considered first when taking risk control measures.

From the results, risk degrees/bubble diameters about Ship Traffic Flow Volume, Wind, Obstacles to Navigation, Ship Route Cross, Fog & Visibility, Channel Length and Tide are much higher than those of

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others, the failure probability of ship navigation safety in Tiaozhoumen Waterway are much closer with those factors. Thus, for ship navigation safety, more attention should be paid to such factors and priority should be given to taking measures to avoid risks caused by such factors. In the meantime, it is suggested to take safety measures, such as strengthening hydrometeorological monitoring, establishing alert system for severe hydrometeorological conditions, monitoring dense traffic area round-the-clock, and organizing traffic flow, to improve the efficiency of traffic management and ensure safety as far as possible.

4.6 Comparison Analysis

According to fuzzy theory, the 'Maximum Membership Degree' principle is one of the approaches to get a clear conclusion. Quantitative results about risk degree are reached by using the 'Maximum Membership Degree' principle to make comparison analysis. According to the principle, a fuzzy evaluation corresponding to the maximum membership is treated as the qualitative evaluation. Thus, the qualitative risk evaluations of concerned risk factors based on the principle are shown in TABLE IX (column 3). According to TABLE III, as the typical instantiation of S, s_j is used as the fixed evaluation score corresponding to j-th term, that is used for fuzzy evaluation. Thus, quantitative risk evaluations of concerned risk factors by using the 'Maximum Membership Degree' principle are also shown in TABLE IX (column 2). Taking Wind as an example, based on the 'Maximum Membership Degree' principle, the qualitative evaluation is 'MH'. And s_j corresponding 'MH' is 7 ($j=4$, since that 'MH' is the forth element in the set of benchmark five words). Thus, the quantitative result on risk degree is 7 ($R_j(\text{Wind}) = s_j(\text{Wind}) = 7$, $j=4$), which gives the evaluation result in a quantitative way.

TABLE IX. Evaluation on NNEt of Tiaozhoumen Waterway based on the 'Maximum Membership Degree' principle

Risk factors	The quantitative evaluation: s_j corresponding the qualitative evaluation	The qualitative evaluation
Wind	7	MH
Current	5	M
Fog & Visibility	3	ML
Wave	7	MH
Tide	7	MH
Channel Length	3	ML
Channel Width	5	M
Channel Water Depth	5	M
Channel Bending	5	M
Ship Route Cross	7	MH
Ship Traffic Flow Volume	7	MH
Obstacles to Navigation	7	MH
Navigational Aids	3	ML

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TABLE IX gives the quantification on risk degree about the factors by using the 'Maximum Membership Degree' principle. Based on the quantitative results, the ranking of risk and comparison of relative importance is shown in Fig 18.

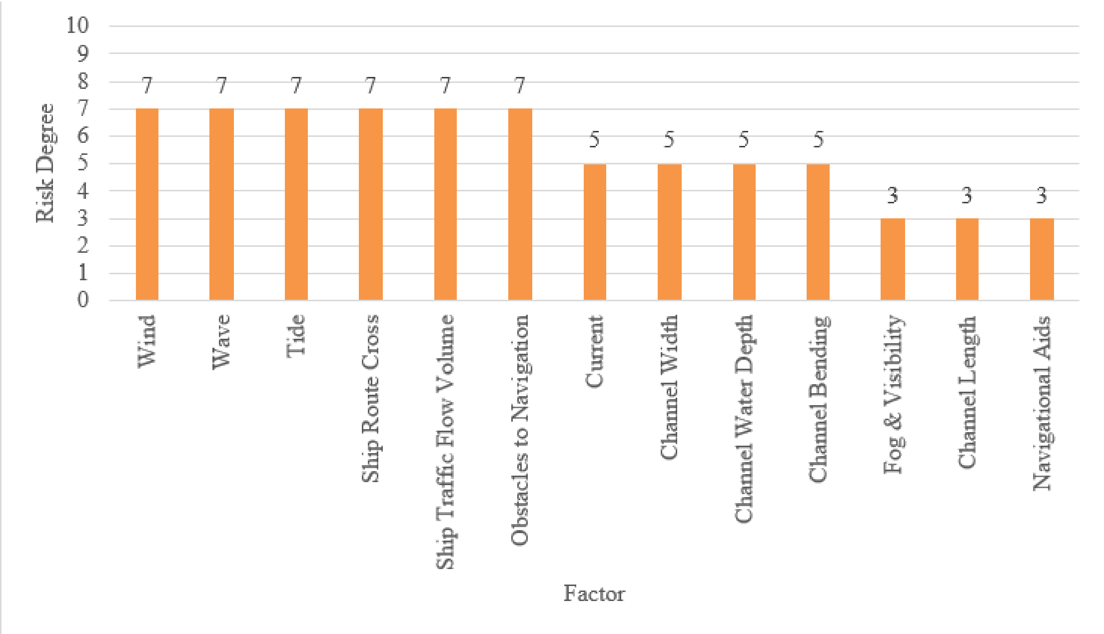

Fig 18: Ranking of risk and comparison of relative importance based on the 'Maximum Membership Degree' principle

The ranking of risk levels and the priority of taking preventive measures can be determined based on the quantitative results about risk degree. For example, seven factors are given a same score 7 as quantitative evaluation. These factors are considered "the most important and equally important", which means those 7 factors foremost catches people's attention due to the high risk level and should be considered first when taking risk control measures.

In terms of quantitative evaluation, the method based on weighted average has a better sensitivity: there are obvious differences on the index score for qualitative evaluation. However, the 'Maximum Membership Degree' principle based method only gives limited types of numerical value. What is more, there are obvious differences on both the ranking of risk and comparison of relative importance, as can be seen in Fig 17 and Fig 18. In terms of qualitative evaluation, due to considering other experts' comments, the weighted average method gives moderate results: when the numerical results is similar, the qualitative assessment is same. However, the 'Maximum Membership Degree' principle based method only draws conclusions based on the opinions of the majority, making the evaluation results have obvious different: more personalized results.

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V. CONCLUSION

The NNEt of water area is one of the important factors that affect the safety of navigation. Scientific and reasonable risk analysis of NNEt will provide important reference for taking risk prevention measures, guarding navigation safety of ships and supporting the shipping development.

This paper focuses on risk evaluation of NNEt system under uncertainty. And a case study with Tiaozhoumen Waterway, Zhoushan Port is carried out. Based on the principle of safety related systems engineering, the systematic and hierarchical analysis method is used to identify the risk factors in NNEt of Tiaozhoumen Waterway. The fuzzy evaluation results of risk factors are obtained by issuing expert questionnaires and using fuzzy statistics. The membership degree of risk factors are obtained based on fuzzy statistical method. The weighted average method is adopted to carry out the defuzzification and obtain the quantitative evaluation of risk factors. Based on the quantitative evaluation results, the relative importance of risk factors are obtained and compared. A comparison analysis is performed to show the sensitivity and advantages of the used weighted average method and 'Maximum Membership Degree' principle based method respectively. The research results of risk identification and evaluation can provide basis or reference for taking different and targeted risk prevention measures to ensure navigation safety.

CONFLICT OF INTERESTS

The authors declare no conflict of interests regarding the publication of this paper.

AUTHOR CONTRIBUTIONS

Methodology: Y.F.-T; Field investigation, data collection, expert consultation: Y.F.-T, X.W.-Z; Data statistic: Y.F.-T, X.W.-Z; Junior analysis: Y.F.-T; Visualization and analysis: Y.F.-T; Writing—original draft preparation: Y.F.-T, X.W.-Z; Writing—review and editing: Y.F.-T; Supervision: Y.F.-T, W.Z.-A, X.F.-W; Project administration: Y.F.-T, W.Z.-A, X.F.-W; Funding acquisition: Y.F.-T, W.Z.-A, X.F.-W. All authors have read and agreed to the published version of the manuscript.

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REFERENCE

[1] Shao L, Li N, Tang Q, et al. Impact of Manufacturing Offshoring and Reshoring on Development of Chinese Ports. Journal of Transportation Systems Engineering and Information Technology. 2020, 20(6): 47-56.
[2] Tian Y F, Sun X C, Chen L J, et al. Risk Assessment of Nautical Navigation Environment Based on Grey Fixed Weight Cluster. Promet-Traffic & Transportation. 2017, 29(3): 331-342.
[3] Balmat J F, Lafont F, Maifret R, et al. MAritime RISk Assessment (MARISA), a fuzzy approach to define an individual ship risk factor. OCEAN ENGINEERING. 2009, 36(15): 1278-1286.
[4] Sahin B, Kum S. Risk Assessment of Arctic Navigation by Using Improved Fuzzy-AHP Approach. International Journal of Maritime Engineering. 2015, 157(4): 241-250.
[5] Ozturk U, Birbil S I, Cicek K. Evaluating navigational risk of port approach manoeuvrings with expert assessments and machine learning. Ocean Engineering. 2019, 192: 1-21.
[6] Huang C H, Xiao Y J, Gao D Y, et al. Evaluation model of navigation risk in routeing waters and its application. China Safety Science Journal. 2014, 24(2): 93-99.
[7] Tian Y, Chen L, Huang L, et al. Featured risk evaluation of nautical navigational environment using a risk cloud model. Journal of Marine Engineering & Technology. 2020, 19(3): 115-129.
[8] Fu S S, Zhang D, Zhang M Y, et al. Identification of environmental risk influencing factors for ship operations in Arctic waters. Journal of Harbin Engineering University. 2017(11): 1-10.
[9] Mabrouki C, Bentaleb F, Mousrij A. A decision support methodology for risk management within a port terminal. SAFETY SCIENCE. 2014, 63: 124-132.
[10] Nie X L, Ran D, Yue X W. Risk assessment of navigation environment based on fuzzy comprehensive evaluation. Journal of Dalian Maritime University. 2013, 39(1): 27-30.
[11] Weng Y Z, Wu Z L. Safety analysis of the navigation environment system for the port of Xiamen. Journal of Dalian Maritime University. 2001(1): 1-4.
[12] Jia M M, Xiong X L, Huang L W, et al. Safety evaluation model for the waterway navigation based on the centralized statistical method-grey fuzzy. Journal of Safety and Environment. 2017, 17(1): 41-45.
[13] Chen W, Zhang P, Jiang S, et al. Navigation environment risk assessment of the channels based on the improved catastrophe progression method. Journal of Safety and Environment. 2020, 20(5): 1617-1623.
[14] Liu W, Sun L, Chen F, et al. Risk assessment and control of inland ships navigation safety − A case study of Shanghai inland waters. Sydney, NSW, Australia: 20161-8.
[15] Wang Z. A Review of Risk Assessment Methods for Maritime Traffic. International Core Journal of Engineering. 2021, 7(6).
[16] Zhao Z P. Discussion and research on berthing departure of Wugang Wharf in Ningbo-Zhoushan port. China Water Transport. 2019, 58(8): 85-86.
[17] Wang Y B, Wang J, Wang Z J. The navigation method of Tiaozhoumen channel of Ningbo−Zhoushan por. Marine Technology. 2014(3): 11-13.
[18] Liu D, Hou Y J. Design of wharf approach channel under deep water route alignment system in core port area of Ningbo Zhoushan Port. China Water Transport. 2018, 18(5): 126.

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www.forestchemicalsreview.com
ISSN: 1520-0191
September-October 2022 Page No. 970-992
Article History: Received: 06 April 2022, Revised: 28 April 2022, Accepted: 04 May 2022, Publication: 15 May 2022

[19] Li Z R, Zhu J S, Zhu J L, et al. Post-evaluation of Navigation Safety with the Implementation of Ship Routing Based on Matter Element Method. Safety and Environmental Engineering. 2019, 26(5): 181-186.
[20] Li W, Ma X, Cheng H, et al. Research on the Safety Management of Water Traffic Based on the Statistical Analysis of Accidents. Safety and Environmental Engineering. 2013, 20(1): 132-137.
[21] Liu T, Li Z, Liang S. Research on Safety Status of Arctic Route Based on System Dynamics Model. Safety and Environmental Engineering. 2019, 26(3): 193-202.
[22] Zhao C L. On risk assessment of navigation environment of Shanghai-Nantong railway Yangtze River Bridge Waters. Port & Waterway Engineering. 2014, 8(494): 122-128.
[23] Li M J, Mei C W. On Assessment of Marine Traffic Safety of Jiaxing Port Based on Fuzzy Comprehensive Evaluation. Science & Technology Vision. 2012(34): 43-45.
[24] Wen Q H. Safety Evaluation of Navigation Environment in Channel Waters of Meizhou Bay. JOURNAL OF GUANGZHOU MARITIME INSTITUTE. 2017, 25(2): 21-23.
[25] Gao F C. Study on navigation environment risk index of Tsuen Wan Channel of Huizhou Port. Pearl River Water Transport. 2016(20): 56-57.
[26] Zhang Z Y. Digitalization evaluation system for shipbuilding industry based on Delphi methord. Defense Manufacturing Technology. 2009(6): 50-52.
[27] Deng X, Zhu Y, Dong H. Design of ship navigation risk assessment system based on fuzzy analytic hierarchy process. Ship Science and Technology. 2017, 39(24): 46-48.
[28] Zhang Y. Application of fuzzy comprehensive evaluation mathematical model in risk management of waterway regulation project. Scientific and Technological Innovation. 2019(6): 105-106.
[29] Tang D, Han Y. Seafarer Ability Evaluation Model Based on Analytic Hierarchy Process and Fuzzy Comprehensive Evaluation. Journal of Shanghai Ship and Shipping Research Institute. 2020, 43(1): 65-70.
[30] Wang H, Wang S. Transitional Period of Flood Season Staged in Zhejiang Province and Its Spatial Distribution Pattern Based on Fuzzy Statistical Method. Water Resources and Power. 2014, 32(5): 36-39.
[31] Zhang Y. Construction of fuzzy statistic clustering model of eco industrial parks. Engineering Journal of Wuhan University. 2011, 44(1): 104-106.
[32] Chen S, Wang S, Wang Y, et al. Study on the determination of relative membership function in flood season by direct fuzzy statistical test. ADVANCES IN SCIENCE AND TECHNOIOGY OF WATER RESOURCES. 2003(1): 5-7.
[33] Chen S, Zhang W. Test of direct fuzzy statistics and stability analysis of absolute membership degree in flooding season. Journal of Dalian University of Technology. 2000(2): 233-235.
[34] Ma C, Zuo L, Lu Y, et al. Study on the indexes and evaluation method of carrying capacity of the navigation channel in the lower Yangtze River. Hydro-Science and Engineering. 2019(1): 85-93.
[35] Sun W, Zhang Q. Navigation Safety Evaluation of Funan Waterway Based on AHP. Journal of Shanghai Ship and Shipping Research Institute. 2014, 37(4): 28-32.
[36] Lei J, Chu X, Jiang Z, et al. Situation Awareness System for Vessel Navigation Based on Visual Analytics. NAVIGATION OF CHINA. 2018, 41(3): 47-52.
[37] Xu W, Chu X, Liu X. Advances of Maritime Traffic Information Visualization Techniques. NAVIGATION OF CHINA. 2015, 38(1): 34-38.
[38] Tian Y, Run Y, Zhang D, et al. Risk Evaluation of Navigation Environment Based on Cloud Model and Monte Carlo Method. TRANSPORT RESEARCH. 2016, 2(6): 38-46.
[39] Shao M, Wu Z, Song Y, et al. Grid-Enabled Visualization of Risk on Maritime Navigation Environments with Entropy Weight - Atribute Mathematics Method. NAVIGATION OF CHINA. 2018, 41(2): 46-51.
[40] Zhu J, Lan P, Xu S. Comprehensive Port Navigation Safety Evaluation. Navigation of China. 2015, 38(4): 79-82.

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ISSN: 1520-0191
September-October 2022 Page No. 970-992
Article History: Received: 06 April 2022, Revised: 28 April 2022, Accepted: 04 May 2022, Publication: 15 May 2022

[41] Chen B, Sha Z, Wu J, et al. Navigation risk assessment of Pearl River Estuary based on ship domain. Journal of Dalian Maritime University. 2020, 46(1): 29-38.
[42] Gang L, Zhong Z, Qi L. Research on ship domain model based on fuzzy theory. Chinese Science and Technology Paper. 2017, 12(19): 2241-2244.