Channel Safety Assessment in Ship Navigation Based on Fuzzy Logic Model

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Abstract

With the progress of economic globalization, international shipping trade is developing rapidly, resulting in a gradual rise in the volume of channel traffic. In turn, maritime affairs occur more frequently due to that than before, and the circumstance of transportation in channel is getting more and more complex. It has a great influence to the safety of ship navigation. This paper establishes a multilevel index system and constructs a fuzzy logic model based on fuzzy set to give an in-depth assessment on the channel safety. Previous researches show that fuzzy logic model can be used to manage multi-factor in safety assessment. However, the application for channel safety is an experiment and innovation. The model is applied to Yangtze Estuary deep water channel, and the output results are consistent with the practice. At the meantime, the assessment system has important value to make integrity planning of the channel.

Keywords: Channel; Safety; Fuzzy Logic; Assessment System; Model

1 Introduction

Nowadays, the integrative and comprehensive trend of world ports development, the large-scale and high-speed demand of ship and the increasing volume of cargo all bring more challenges for shipping safety which has a direct connection with the prospect of shipping and its surrounding industries. Meanwhile, it plays an important role in the protection of marine environment and the exploration of ocean resources.

Despite the remarkable effort performed at different levels to achieve a safe Maritime Transport System (MTS), the occurrence of accidents and incidents at sea is still increasing [1]. In the shipping field, with the growing emphasis on the safety management, the methodology of safety analysis and the research of safety assessment gain more and more attention, especially for the safety assessment which in recent years has been put at the top of the agenda. From the perspective of the safety management, safety assessment is not only of great academic and pragmatic importance, but is related to the future development of shipping industry.

As a hot topic in shipping field, safety assessment is also called risk assessment. Risk assessment is one method to determine the likelihood and severity of accidents and risk, using the principles and methods of the systems engineering to identify and analyse the hazard factors existing in the systems [2]. It aims to assess the security level of the overall system and provide preventive measures in accordance with scientific procedures and methods which need to do plenty of researches and analysis on the possibility of accidents and the extent of damage and injury.

Channel is the navigation passage providing safety for the ships in lakes, bays, ports and other waters. And channel safety is an important subsystem of maritime safety. Most sea traffic accidents are ship collision and grounding in port and channel. The safe navigation of ships, especially in narrow shipping waterways, is of the most concern to the maritime authorities [3]. At the same time, due to the changes of larger tonnage and faster speed of the modern ships, the increasingly heavy traffic density and the limitation of the fairways, the risk for navigating a ship in coastal waters is getting much higher than before [4].

The basic cause of the accidents is the manipulator’s negligence human error.. But the hidden reasons that is the imperfection of the management system of channel should not be neglected. To reduce the types of accidents, a number of navigation assistance systems capable of assisting mates have been introduced, and the proposed systems either use the accumulated actual accident data for simulation purposes or assume real-time vessel data using programming tools [5].

In order to improve the security situation of shipping transportation, especially for the cargo transportation, channel safety management needs to be taken into account seriously. And the first step is to have an accuracy understanding about the safety level. Channel around the port and lane in the open sea are both fundamental unit of the sea route. However, compared with sea lane, channel is more manageable and less uncertain. According to the result of channel safety assessment in ship navigation, the problems and potential safety hazard of the channel can be found in advance. To solve problems and eliminate hazard, relevant maintenance work and remedial work will be arrange which is of great significance in improving the level of shipping safety.

2 Literature review

Many researches of safety assessment have been done by lots of scholars of various countries who put forward some methodologies to study the topic in detail, such as the grey

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system theory, the Bayesian network, the artificial neural networks, the set pair analysis theory and fuzzy set theory.

Fuzzy set theory is appropriate for making decisions with complex situation when the context of the problem is usually unclear. Three most familiar models of fuzzy set are fuzzy synthetic evaluation model, fuzzy evidence theory and fuzzy logic model. Kyaw and Xiao developed a fuzzy synthetic evaluation method to assess the channel safety of the Yangon River [6]. Zhang et al. presented fuzzy synthetic evaluation method to find out the security status of the main channel navigation environmental of Lianyungang Port [7]. Yang et al. proposed a subjective security-based assessment and management framework using fuzzy evidential reasoning to deal with the security in situation of high-level uncertainty [8]. Markowskia and Mannanb explored the application of the fuzzy logic for risk assessment of major hazards connected with transportation of flammable substances in long pipelines [9].

The research of channel safety assessment is not usual. And using fuzzy logic model to deal with channel safety is less common. Nevertheless, fuzzy logic method has many applications in relative fields. Sii et al. established the development of safety model using fuzzy logic for modelling various design variables for maritime and offshore safety [10]. Rainer focused on risk assessment in container security with fuzzy Logic model and showed that this method could help decision makers to response quickly [11]. Li et al. presented a dynamic fuzzy logic model (DFLM) which is able to improve the long-term safety management situation of marine crude oil transportation [12].

3 Fuzzy logic method

The concept of fuzzy set was proposed by L. A. Zadeh in 1964. Fuzzy logic theory is mainly used to study some ambiguous problems in practice and make them clear. The introduction of fuzzy logic can help complex system structure the mathematics model including subjective assessment and thought process. On the basis of L. A. Zadeh's famous "incompatible theorem", complexity and accuracy are mutually contradictory [13]. As the system complexity increases, people's ability of accurately description declines. Until it reaches such a limit, the accurate description finally loses its meaning. In this case, the "fuzzy" description is desirable and meaningful, because at least it provides a possible solution for some problem which cannot be analysed precisely. The biggest difference between fuzzy logic model and other expert system is that the former uses fuzzy interval to describe sociotechnical problem. It is totally different from classical probability theory, which also is exactly the greatest characteristic and advantage.

The channel security system is a complex system which is not able to be accurately described. Fuzzy set theory provides three useful tools to solve the problem, named the membership function, the linguistic variable and logical operator [14]. The description of the safety levels is presented by using membership function, which is more flexible than using traditional segmented function. The application of the linguistic variable makes the lexical expression of evaluation results more specific. Different fuzzy operators reflect different ways of thinking, and using different fuzzy operator can make an overall consideration of varieties of evaluation views.

In the classical set theory, the relationship between one element and one set only have two kinds which be represented as "belong to" and "not belong to". The description is defined, and ambiguity is absolutely not allowed. However, in the fuzzy logic theory, an element can belong to different sets with different membership degrees which determines the form of membership functions. The transition of element from one set to another is gradual rather than sudden. Fuzzy set can be entirely characterized by its membership functions, and the membership functions represent the degree of the elements belonging to fuzzy subsets. The value of the membership function is continuous in a range of 0 and 1. Moreover, fuzzy logic model generally has the following property, namely, the degree of membership for each element in all fuzzy subsets sum to 1[15-16].

4 Synthetic assessment system

During the navigation, there are a number of factors affecting safety directly or indirectly, and the final evaluation results depend on the combination of multiple impacts. According to different object of study, assessment systems focus on different research emphasis and analysis perspective. But overall, the factors can be summarized as three aspects: the human, the vessel and the environment. In order to make the assessment system become more simple and effective, it is of great importance to select the relational indicators and make a scientific assessment system which is the first step in the process of comprehensive evaluation in ship navigation.

In order to provide the evaluation standards for the safety assessment and analysis, the degree of safety need to be divided into several levels. As we all know, the more levels the division has, the more complex and accuracy the study is. However, this kind of practice should bring more workload. In current study, safely level is generally divided into 3-5 levels [17-18]. Combined with the former research experience, this paper has 5 safety levels: security, basic security, more insecurity, unsafe and very unsafe.

The research object of this paper is the channel, which means a universally applicable evaluation model should be put forward without the restriction of a specific port or particular sea area. So as to make the safety evaluation results more useful and provide more feasible suggestion, this article is based on a large number of predecessors' researches on this object and feedbacks from experts.

After being recombined of original and new factors, safety assessment index system for channel safety is composed of four sections: hydrometeorology, channel condition, traffic factor and management level. These four major factors can be divided into eleven sub-factors, such as wind, current, visibility, relative depth, relative width, angle of bend, traffic density, the rate of old ship, comprehensive quality of crews, navigational aids, management systems

[19]. The complete system is shown (Figure 1).

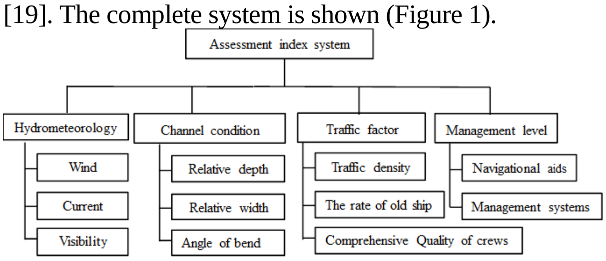

FIGURE 1. Safety assessment index system for channel safety

5 Application in channel safety assessment

Compared with other methods, especially for complex problem, fuzzy logic method has great advantages and the widespread application. And many researches show that fuzzy logic model is suitable for safety assessment.

5.1 WEIGHT PARAMETERS

In general, each element in safety assessment index system has the different status and importance for the evaluation. A weight in percentage represents the degree of impact. It is of great significance to take a scientific and effective way to get accurate weights, which are the necessary condition for establishing correct logic and producing reasonable results.

According to the content of our study, 50 experts who work in relative field were enrolled in the questionnaire investigation and 48 valid questionnaires were collected. The AHP method is used to analyse the research results and obtain the weight of each factor indicators. The weights of every index of the first level are showed in Table 1.

TABLE 1 Weights of every index of the first level

Index	Hydrometeorology	Channel condition	Traffic factor	Management level
Weight	0.289	0.267	0.331	0.113

5.2 THE MEMBERSHIP FUNCTION

In the process of safety assessment, the concept of membership degree is introduced to quantify the fuzzy information and to build a relatively simple mathematical model. Linguistic representation of parameters is listed (Table 2). Trapezoidal parameters of the membership function are expressed in a low-high-high-low (L, H, H, L) format, corresponding to four differentiable derivative points. Triangular parameters are expressed in a low-high-low (L, H, L) format. In the current work, input values were assumed to satisfy the trapezoidal curve, with output values assumed to occur on the triangular curve.

TABLE 2. Membership functions developed for employment in risk assessment of channel safety

Hydrometeorology	Range (0-10)	Channel condition	Range (0-10)
Linguistics representation	(L,H,H,L)	Linguistics representation	(L,H,H,L)
Good	(0,0,1,4)	Good	(0,0,1,4)
Normal	(1,4,6,9)	Normal	(1,4,6,9)
Poor	(6, 9, 10, 10)	Bad	(6, 9, 10, 10)
Traffic factor	Range (0-10)	Management level	Range (0-10)
Linguistics representation	(L,H,H,L)	Linguistics representation	(L,H,H,L)
Good	(0,0,1,4)	High	(0,0,1,4)
Normal	(1,4,6,9)	Medium	(1,4,6,9)
Bad	(6, 9, 10, 10)	Low	(6, 9, 10, 10)
Safety level	Range (0-10)		
Linguistics representation	(L, H, L)		
Security	(0, 0, 2)		
Basic security	(1, 3, 5)		
More insecurity	(3, 5, 7)		
Unsafe	(5, 7, 9)		
Very unsafe	(8,10,10)		

5.3 IF-THEN RULES

IF-then rules or logical operators which builds relationships between the input and the output parameters are the foundation of fuzzy logic model, which needs a lot of data and theoretical support. Based on the weights of influencing factors, the if-then rules used in this paper are showed as Table 3 .

No.	Hydrometeorology	Channel condition	Traffic factor	Management level	Safety Level
1	Good	Good	Good	High	Security
2	Good	Good	Good	Medium	Security
3	Good	Good	Good	Low	Basic security
4	Good	Good	Normal	High	Basic security
5	Good	Good	Normal	Medium	Basic security
6	Good	Good	Normal	Low	More insecurity
7	Good	Good	Bad	High	More insecurity
8	Good	Good	Bad	Medium	More insecurity
9	Good	Good	Bad	Low	Unsafe
10	Good	Normal	Good	High	Security
11	Good	Normal	Good	Medium	Basic security
12	Good	Normal	Good	Low	More insecurity
13	Good	Normal	Normal	High	Basic security
14	Good	Normal	Normal	Medium	More insecurity
15	Good	Normal	Normal	Low	Unsafe
16	Good	Normal	Bad	High	Unsafe
17	Good	Normal	Bad	Medium	Unsafe
18	Good	Normal	Bad	Low	Very unsafe
19	Good	Bad	Good	High	More insecurity
20	Good	Bad	Good	Medium	More insecurity
21	Good	Bad	Good	Low	More insecurity
22	Good	Bad	Normal	High	Unsafe
23	Good	Bad	Normal	Medium	Unsafe
24	Good	Bad	Normal	Low	Very unsafe

25	Good	Bad	Bad	High	Very unsafe
26	Good	Bad	Bad	Medium	Very unsafe
27	Good	Bad	Bad	Low	Very unsafe
28	Normal	Good	Good	High	Basic security
29	Normal	Good	Good	Medium	Basic security
30	Normal	Good	Good	Low	More insecurity
31	Normal	Good	Normal	High	Basic security
32	Normal	Good	Normal	Medium	More insecurity
33	Normal	Good	Normal	Low	Unsafe
34	Normal	Good	Bad	High	Unsafe
35	Normal	Good	Bad	Medium	Unsafe
36	Normal	Good	Bad	Low	Very unsafe
37	Normal	Normal	Good	High	Basic security
38	Normal	Normal	Good	Medium	Basic security
39	Normal	Normal	Good	Low	More insecurity
40	Normal	Normal	Normal	High	More insecurity
41	Normal	Normal	Normal	Medium	More insecurity
42	Normal	Normal	Normal	Low	Unsafe
43	Normal	Normal	Bad	High	Unsafe
44	Normal	Normal	Bad	Medium	Very unsafe
45	Normal	Normal	Bad	Low	Very unsafe
46	Normal	Bad	Good	High	Unsafe

TABLE 3. If-then rules

No.	Hydrometeorology	Channel condition	Traffic factor	Management level	Safety Level
47	Normal	Bad	Good	Medium	Unsafe
48	Normal	Bad	Good	Low	Very unsafe
49	Normal	Bad	Normal	High	Very unsafe
50	Normal	Bad	Normal	Medium	Unsafe
51	Normal	Bad	Normal	Low	Very unsafe
52	Normal	Bad	Bad	High	Very unsafe
53	Normal	Bad	Bad	Medium	Very unsafe
54	Normal	Bad	Bad	Low	Very unsafe
55	Poor	Good	Good	High	More insecurity
56	Poor	Good	Good	Medium	More insecurity
57	Poor	Good	Good	Low	Unsafe
58	Poor	Good	Normal	High	Unsafe
59	Poor	Good	Normal	Medium	Unsafe
60	Poor	Good	Normal	Low	Very unsafe
61	Poor	Good	Bad	High	Very unsafe
62	Poor	Good	Bad	Medium	Very unsafe
63	Poor	Good	Bad	Low	Very unsafe
64	Poor	Normal	Good	High	Unsafe
65	Poor	Normal	Good	Medium	Unsafe
66	Poor	Normal	Good	Low	Very unsafe
67	Poor	Normal	Normal	High	Unsafe
68	Poor	Normal	Normal	Medium	Very unsafe
69	Poor	Normal	Normal	Low	Very unsafe
70	Poor	Normal	Bad	High	Very unsafe
71	Poor	Normal	Bad	Medium	Very unsafe
72	Poor	Normal	Bad	Low	Very unsafe
73	Poor	Bad	Good	High	Very unsafe
74	Poor	Bad	Good	Medium	Very unsafe
75	Poor	Bad	Good	Low	Very unsafe
76	Poor	Bad	Normal	High	Very unsafe
77	Poor	Bad	Normal	Medium	Very unsafe
78	Poor	Bad	Normal	Low	Very unsafe
79	Poor	Bad	Bad	High	Very unsafe
80	Poor	Bad	Bad	Medium	Very unsafe
81	Poor	Bad	Bad	Low	Very unsafe

5.4 RESULTS OUTPUT

On the basis of If-then rules and defuzzification method, the surface viewers can be got which reflect the relationship among two inputs and the outputs. For example, one of the inputs is fixed as Hydrometeorology, and then three figures can be showed as Figure 2.

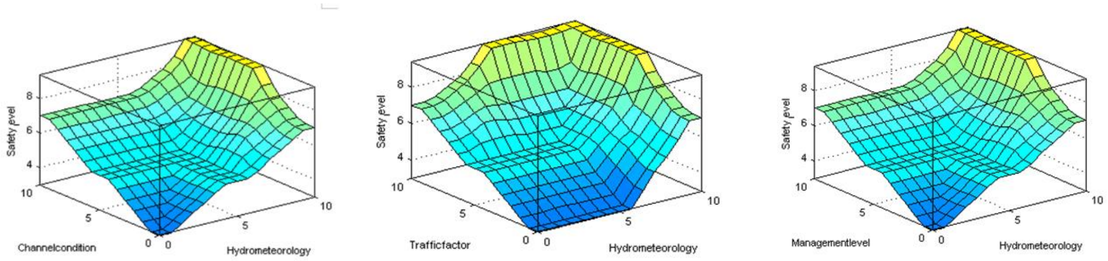

FIGURE 2. Surface viewers

6 Case study

The Yangtze estuary deep water Channel, as an integral part of the Yangtze River waterway, is the main channel of this waterway. With the increase of the traffic in the river, accidents such as collisions, groundings, overturns, oil-spills and fires occur repeatedly, causing serious consequences to the sustainable development of Yangtze River [20]. Besides, the depth in some part of the channel was only about 6 meters, which became a bottleneck and restricted the further development of Shanghai's economy, as well as the area of Yangtze Basin.

Since 1998, the depth of the Yangtze estuary deep water channel has continuously been increased to 8.5 m, 10 m and 12.5 m after three great dredging project. And the length for bidirectional channels is 92.2 km. The scale and intensity of the Yangtze Estuary deep channel dredging project is the largest one in water transportation engineering history of China.

Nowadays, the deep water channel can not only meet two-way navigation need of the third and the fourth generation of container ship, and also satisfy one-way navigation requirement of the fifth and the sixth generation of container ship.

The safety situation of Yangtze estuary deep water channel affects the amount of cargoes and containers in Shanghai port which is a huge support for the construction of international shipping centre. In addition, the channel safety also impacts the port throughput of Jiangsu province and other regions. The sustainable safety situation of the Yangtze River can propel the Chinese economy development to a new level.

Before the dredging project for the Yangtze deep water channel, the channel condition and the traffic factor had an adverse impact both on safety level and economic benefit. The old scores of hydrometeorology, channel condition, traffic factor, management level are 3, 4, 4 and 2, and the output is 4.27 which means that there is a potential danger in the channel safety.

According to the latest data of Yangtze Estuary deep water Channel in 2012, the scores of the channel are 3, 2.5, 2.5 and 1, respectively, and the final output is 3.49.

We can see that because of the bad situation of hydrometeorology and traffic factor, the safety level is not good enough and it still can be improved. If the traffic factor and the channel condition can be improve to 1.5, and the output should be 2.95. All above is showed as Table 4.

TABLE 4. Safety assessment process based on fuzzy logic theory

	Hydrometeorology	Channel condition	Traffic factor	Management level	Safety Level
Old Data	3	4	4	2	Basic Security（4.27）
Present Data	3	2.5	2.5	1	Basic security（3.49）
Improved Data	3	1.5	1.5	1	Security（2.95）

7 Conclusions

In this paper, a fuzzy logic model aimed at channel safety assessment is put forward to appraise safety level of the channel and provide data support for the channel construction and maintenance. In addition, a summary of the safety factors that influence the channel is also carried out. This is the basis of the fuzzy logic model. Clear evaluation results and intuitive graphs can be gain after determining the corresponding input variable. In the case analysis, it can be seen that the results are similar to the research results of former scholars.

Compared with the traditional certainty probability model, fuzzy logic method is more of an advantage. Nowadays it is essential to achieve sustainable economic growth. However, the protection of original environment and the exploitation of modern channel are sometimes contradictory. There is not obvious boundary so that fuzzy logic can do a lot of help. Besides, it is relatively more accurate to evaluate the safety level through membership function discussed by experts and summarized from related data.

The fuzzy logic model is also easy to be applied. After the channel safety index system is established and the weight of each factor is determined, the construction of the model is finished. When changing the inputs, the outputs have a correspondingly change. According to the differences between the results, the defects and problems can be found which can impact negative influences on the performance and the efficiency of channel service.

In the future study, we still need to revise the if-then rules and the weight of factors. The procedure of ship navigation in the channel can be divided into more detail process. If the most risky process is known, then the safety assessment is more targeted.

In conclusion, the introduction of fuzzy logic model can take into consideration the influences of various factors and yield objective and accurate evaluation result, and fuzzy logic model of the channel safety assessment in ship navigation is reasonable and feasible.

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