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Real-time Risk Assessment for Aids to Navigation Using Fuzzy-FSA on Three-Dimensional Simulation System

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ABSTRACT: The risk level of the Aids to Navigation (AtoNs) can reflect the ship navigation safety level in the channel to some extent. In order to appreciate the risk level of the aids to navigation (AtoNs) in a navigation channel and to provide some decision-making suggestions for the AtoNs Maintenance and Management Department, the risk assessment index system of the AtoNs was built considering the advanced experience of IALA. Under the Formal Safety Assessment frame, taking the advantages of the fuzzy comprehensive evaluation method, the fuzzy-FSA model of risk assessment for aids to navigation was established. The model was implemented for the assessment of aids to navigation in Shanghai area based on the aids to navigation three-dimensional simulation system. The real-time data were extracted from the existing information system of aids to navigation, and the real-time risk assessment for aids to navigation of the chosen channel was performed on platform of the three-dimensional simulation system, with the risk assessment software. Specifically, the deep-water channel of the Yangtze River estuary was taken as an example to illustrate the general assessment procedure. The method proposed presents practical significance and application prospect on the maintenance and management of the aids to navigation.

1 INTRODUCTION

A marine aid to navigation is a device or system external to vessels that is designed and operated to enhance the safe and efficient navigation of vessels and /or vessel traffic (IALA, 2001).

The AtoNs system marks a navigational channel, so the risk level of the AtoNs not only reflects the navigation service level of this system also indicates the ship navigation safety level in this channel. After the real-time risk assessment of the AtoNs system, some suggestions can be given to the administrators to improve the navigation service level and guarantee the ship navigation safety.

During the whole lifecycle of an aid, the risk assessment for marine aids is always necessary. But, at present, the AtoNs risk assessment mainly depends on the subjective judgment of the administrators or experts, or relies on some indirect suggestions from related aids to navigation information systems. These methods can not produce real-time, accurate and systematic assessment results. So, making full use of the existing advanced information systems in the administration department, extracting real-time, accurate and comprehensive data from the systems, then carrying on real-time risk assessment for aids to navigation in chosen channel, is very significant to improve the service level of the AtoNs system. By this means, the risk assessment can run through the whole procedure of an aid including plan, placement, construction, operation, maintenance and management, and can decrease subjective judgments, which can provide more useful, comprehensive and real-time information and advices for the administrators.

The index system for AtoNs risk assessment was established by exploring experience from IALA and consulting many related experts. Then, under the framework of the Formal Safety Assessment (FSA) method, the fuzzy comprehensive assessment method was introduced into the work to build a Fuzzy-FSA model to realize the risk assessment for the AtoNs. Besides, the real-time risk assessment for aids to navigation of the chosen channel was performed on platform of the three-dimensional simulation system of aids to navigation, with the risk assessment software. Specifically, the deep-water channel of the Yangtze River estuary was taken as an example to illustrate the general assessment procedure.

2 INDEX SYSTEM FOR ATONS RISK ASSESSMENT

A marine aid to navigation, as an individual part in the channel, is very easily influenced by external environment, including the navigation vessel conditions, traffic conditions, channel conditions, hydrological conditions, meteorological conditions and so on. Frequent abnormal conditions happened to a marine aid maybe: damage, abnormal light, shifting, lost, etc. These all will have obvious harmful effects to the navigation service level for the ships and the navigation safety, even may lead to ship collision, ship grounding or collision between ships and buoys.

Therefore, the risk assessment for marine aids is necessary and covers so many factors, such as navigation ships, traffic, channel, environment, accidents history and so on. After drawing lessons from the <IALA Aids to Navigation Guide> and consulting some related experts on aids to navigation maintenance and management (from Aids to Navigation Administration Departments, Aids to Navigation Plan and Design Departments, Pilot Stations and Aids to Navigation Repair Stations), also, considering the operability of the real-time assessment on the aids to navigation three-dimensional simulation system, the index system for AtoNs risk assessment was established in Table 1.

Besides, some factors having relationships with the risk of AtoNs may be excluded from the index system because of their tiny and negligible effects comparing to other factors in the system, for example “channel length” in “waterway configuration”, or the meanings of them have been embodied into other factors in the system, for example “ship size” embodied into “traffic mix” via statistics. In a word, the built index system for AtoNs risk assessment is relatively complete and feasible.

Table 1. Index system for AtoNs risk assessment

Risk assessment for AtoNs	
1. Traffic Volume	Deep draught Shallow draught Commercial fishing vessels and other boats Hazard cargoes
2. Ship Traffic Conditions	Traffic mix Traffic density Ship speed
3. Navigational conditions	Visibility Wind Current and wave Obstructions condition Aids to navigation condition
4. Waterway configuration	Channel width Channel curvature Waterway complexity Channel depth Channel structure
5. Accident conditions	Accident frequency Injuries to people Property damage Hazardous material release Emergent rescue equipment condition Emergent rescue system level

3 FUZZY-FSA MODEL

3.1 *Introduction of Formal Safety Assessment (FSA)*

FSA is a structured and standardized safety assessment method. In the 20th century, for promoting and improving the maritime safety, the International Maritime Organization (IMO) encourages Member States to apply this advanced safety assessment to special research on the safety of vessels. So far, FSA has been widely applied into safety rule making, ship design and ship management and other related fields. It provides some decision-making proposals to improve the navigation safety level and reduce or avoid marine risk. FSA method has five formal steps shown in Fig 1, including identity risks/hazards, assess risks, specify risk control options, make a decision and take action.

Comparing to other methods, the steps in FSA are much more reasonable and comprehensive. Also, it can be integrated into some comprehensive evaluation methods to analyze the risk and influence. This method will propose corresponding decision-making suggestions from both the quantitative and qualitative angle. Then, the evaluation results will be much more scientific, making the suggestions on risk control more practical and feasible.

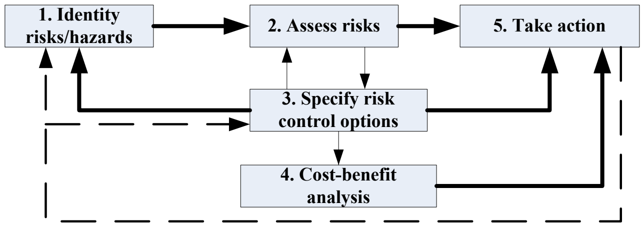

Figure 1. Steps of FSA method

3.2 *Introduction of Fuzzy-FSA model*

Fuzzy comprehensive evaluation method (Fuzzy) applies fuzzy transform principle and the maximum membership degree law, and considers factors associated with the target to make a comprehensive evaluation. The evaluation results can reflect the actual conditions of the evaluated target comprehensively after analyzing from multi-factor and multi-level. Now, Fuzzy method has been widely used in various fields.

The general steps of the Fuzzy comprehensive evaluation method are as follows:

- Building the risk evaluation index system with hierarchical structure based on the characteristics of the target to be evaluated;
- Determining of the weight set of the index system by expert consulting and AHP method;
- Building of the evaluation matrix of each factor according to the determined quantitative standard;
- Calculating the final fuzzy relation matrix for the target based on the weight set;
- Obtaining the quantitative and qualitative evaluation results through the defuzzification of the results.

Fuzzy-FSA model is built by introducing the Fuzzy comprehensive evaluation method under the framework of FSA method. The qualitative and quantitative risk level will be achieved by building the index system and fuzzy assessment. Fuzzy evaluation method is obvious in steps 1, 2, 3 and step 5 of FSA method. Because of considering too many economic and political factors, the step 4 of FSA, cost-benefit analysis is excluded here. FSA provides overall assessment ideas while the Fuzzy method provides evaluation technique and evaluation index. These two methods combined together to make the evaluation idea more clear and the evaluation results more persuasive and feasible. Fig 2 shows the general steps of Fuzzy-FSA method.

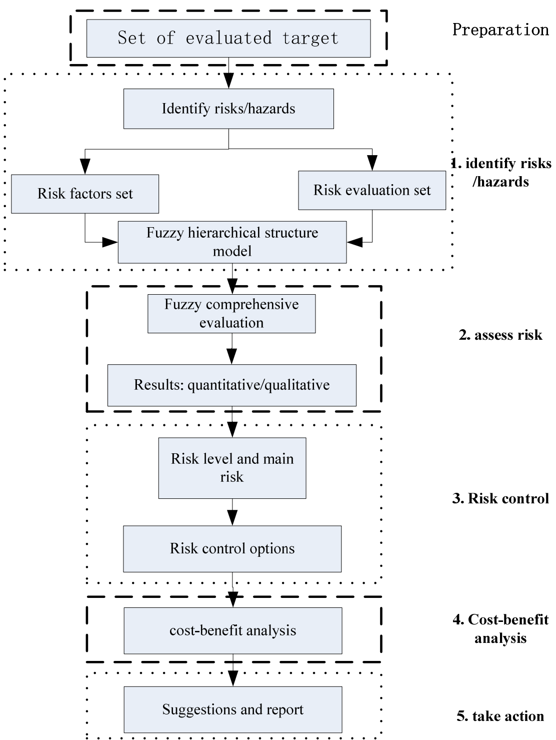

Figure 2. General steps of Fuzzy-FSA method

3.3 *Quantitative Standard of Each Factor*

In order to realize the real-time risk assessment of the AtoNs, each factor in the index system should be analyzed to determine one corresponding quantitative standard. The standard must be so accurate as much as possible that can represent the actual meaning of the factor, and also should be feasible making sure the value of the factor is easy to get.

- The meanings of some factors in Table 1 are obvious and clear, so the quantitative standards of them can be determined easily according to their literal meanings, for example, "traffic mix", "current and wave", "channel depth" and "accident frequency".
- While some factors can be quantified into a percentage, for example, using "the proportion of large ships per day (%)" to indicate the "Deep Draught", using "the proportion of over-speeding ships per day (%)" to indicate the "Ship Speed", the same to the other three factors: "Shallow draught", "Commercial fishing vessels and other boats", "Hazard cargoes".
- While some factors are qualitative, such as, "channel structure", "aids to navigation condition", "hazardous material release", "emergent rescue equipment condition" and "emergent rescue system level". These factors can be quantified by means of a score (from 0~10) determined by the administrators or investigation results.
- Then, "Injuries to people" and "property damage" can be quantified by straight data, which are "the number of people injured" and "the economic lost" respectively.
- Because of lacking of intuitive and appropriate judgment criteria, or no direct data, the other factors (visibility, wind, channel width, channel curvature, obstructions condition, waterway complexity) can not be quantified according to the superficial meanings, needs further analysis. Taking the "visibility" as an example, even one channel may have different visibilities every day, so it is very inconvenient to collect the data and unsuitable to compare between different channels if just using the "the distance of the visibility" to qualify it. Therefore, after further analyzing the factor and making reference to related research, "the days per year with the visibility less than 1km" is determined as the quantitative standard for "visibility". Also, the quantitative standards of "wind", "channel depth", "channel curvature" and "waterway complexity" all have been determined by this means.

The quantitative standard of every factor is shown in Table 2.

Table 2. Quantitative standard of each factor and the weight index

Risk assessment for AtoNs		Quantitative Standard	Weight
1. Traffic Volume	Deep draught	The proportion of large ships per day (%)	0.055
	Shallow draught	The proportion of small ships per day (%)	0.037
	Commercial fishing vessels and other boats	The proportion of Commercial fishing vessels and other boats per day (%)	0.037
	Hazard cargoes	The proportion of ships with hazard cargoes per day (%)	0.055
2. Ship Traffic Conditions	Traffic mix	Average ship numbers per day	0.102
	Traffic density	Smoothness level: Score (0~10)	0.077
	Ship speed	The proportion of over-speeding ships per day (%)	0.077
3. Navigational conditions	Visibility	The days per year with the visibility less than 1km	0.021
	Wind	The days per year with wind stronger than 6 grade	0.038
	Current and wave	Speed of cross current(m/s)	0.034
	Obstructions condition	Distance to the channel centerline (m)	0.021
	Aids to navigation condition	Score (0~10)	0.034
4. Waterway configuration	Channel width	The length of the largest ship/ the most narrow width of the channel	0.097
	Channel curvature	The largest turning angle of the channel (Deg)	0.049
	Waterway complexity	Numbers of traffic special points in the channel /channel length	0.025
	Channel depth	Channel depth (m)	0.021
	Channel structure	Score (0~10)	0.021
5. Accident conditions	Accident frequency	Average Accident frequency per year	0.034
	Injuries to people	The numbers of people injured	0.033
	Property damage	The economic lost	0.033
	Hazardous material release	Pollution degree: score (0~10)	0.033
	Emergent rescue equipment condition	score (0~10)	0.033
	Emergent rescue system level	score (0~10)	0.033

3.4 *Weight of Each Factor*

The weight of each factor is also very important to the risk assessment results. For making sure of the accuracy and acceptability of the assessment results, on the basis of the related project from Shanghai Aids to Navigation Administration Department, the weight index was acquired by integrating Delphi method and Analytic Hierarchy Process (AHP) method. During the project, the expert questionnaire was complied and sent to 48 experts from Aids to Navigation Administration Departments, Aids to Navigation Plan and Design Departments, Pilot Stations and Aids to Navigation Repair Stations and some related departments. The questionnaires were all replied back. Fully considering all the experts' comments and suggestions, the judgment matrix based on AHP method was established. The weight of each factor was calculated by square root rule, and passed the consistency check. The detailed calculation procedure will not be repeated here.

Besides, the weight index should also be dynamic and adjustable in coincidence with the changes in channel or port or government policy. Because with the development of port and channel and the continuous construction of AtoNs, the risk may face will also be changed. The weight index is also shown in Table 2.

Owning to limited time and resources, the number of the sent questionnaires may be not enough. But the experts chosen are all very experienced and representative in the field in China. Their persuasive comments and suggestions can generally guarantee the objectivity and accuracy of the assessment results.

4 REAL-TIME RISK ASSESSMENT FOR ATONS USING FUZZY-FSA ON THE PLATFOM OF AIDS TO NAVIGATION THREE-DIMENSIONAL SIMULATION SYSTEM

Till now, the AtoNs administrators mastering and assessing the AtoNs risk mainly resorts to measurements by practical ship trail. It is time-consuming and cost expensive. The most important is that the results by technical measurements only can reflect the conditions of the aids observed under the environment condition at that time, but not comprehensive and real-time. Besides, the results measured are easily affected by the technical level, the distance from the target, the testers and the environment conditions and some other factors.

Now, China Aids to Navigation Administration Departments have been equipped many useful AtoNs information system to help mastering the real-time conditions of the AtoNs in the water areas under the jurisdiction, such as AIS AtoNs system, Aids to Navigation Three-dimensional Simulation System, Aids to Navigation Telemeter and Telecontrol System, and so on. Especially, the Aids to Navigation Three-dimensional Simulation System is a comprehensive system, integrating with other information systems, which can display the surrounding conditions in real time, including the aids to navigation and nearby ships' information under the pre-set environment conditions. So, it is an optimal platform to realize the real-time risk assessment for aids to navigation.

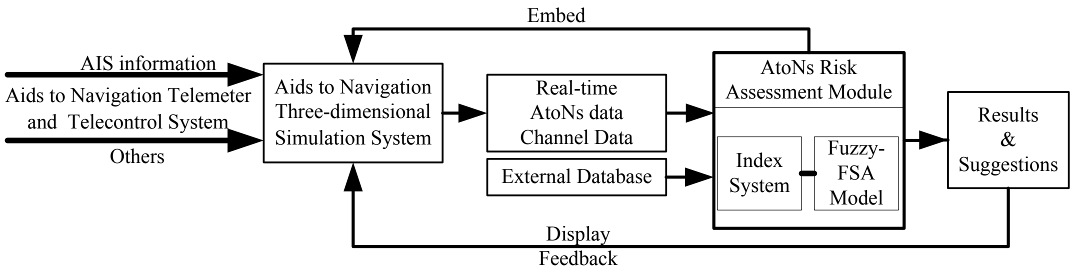

Figure 3. General Procedure of the real-time risk assessment for aids to navigation

Table 3. Data classification and data source

Classification	Data needed	Data source
Basic fact data	Navigational conditions Channel Conditions	Statistics Material, such as sailing guidelines Channel database and the supplement in the simulation system
Real-time data	Traffic Volume conditions Ship traffic conditions Accident frequency; Injuries to people; Property damage; Hazardous material release	AIS data in three-dimensional simulation system AIS data in three-dimensional simulation system Accident statistics materials
External data	Aids to navigation condition Emergent rescue equipment conditions; Emergent rescue system level	Evaluation results form the administrators Actual conditions and expert judgments

4.1 *General Procedure of the real-time risk assessment for aids to navigation*

If all the values of the influencing factors of aids to navigation risk were input or determined manually, the risk assessment system would be meaningless. So, an AtoNs risk assessment module was developed on the platform of the Aids to Navigation Three-dimensional Simulation System. It was embedded into the simulation system, also, can run independently.

The real-time risk assessment for aids to navigation is realized by extracting the needed real-time data from the aids to navigation three-dimensional simulation system. And also, some additional external database and expert experience knowledge will be supplemented to the system. The data can be updated real-timely according to the chosen targets and assessment conditions. In this module, the important real-time information was extracted to determine the value of the factors in the built index system, then, activating the fuzzy-FSA model to carry out the risk assessment for chosen aid or channel. The results can reflect the real time risk level of the aids to navigation in the channel, which can provide more helps for the aids to navigation administrators and be useful for improving the navigation service level and ship navigation safety level. And, the results can be displayed on the three-dimensional simulation system, also can be saved as an excel table to be printed, which is very convenient to compare and analyze in future.

The general procedure of the assessment is shown in Fig. 3.

4.2 *Preparation of data*

The data needed in the assessment includes the values of the factors and their weights. Then, according to the built risk assessment index system and the quantitative standards, the value of each factor can be classified into three types, which are basic fact data, real-time data and external data (Table 3). It is obvious that the navigational conditions and the channel conditions of one channel are often constant in a long time, while the ship conditions, ship traffic conditions and the accidents conditions are mainly dynamic. Besides, some other data, such as the aids to navigation service, emergent rescue equipment conditions and emergent rescue system level, rely on external input or judgment. This classification is helpful to the data preparation before risk assessment.

Different types of data are from different sources, shown in Table 3. The Aids to Navigation Three-dimensional simulation system, as the foundation platform, is certainly the first data source. Particularly, its bottom aids to navigation database and channel database will provide some precious data for the risk assessment. Meanwhile, the database can be supplemented and perfect according to requirements. Besides, the basic fact data and the real-time data can be complied into a database for the direct use in the three-dimensional simulation system. And, this is helpful to data modification and update, guaranteeing the timeliness and accuracy of the evaluation result.

4.3 *Design Results of the Real-time risk assessment module*

Based on the ECDIS, using Visual C++ and Database Management technology, the real-time risk assessment system for aids to navigation on Three-dimensional simulation system was achieved and taken into actual use in Shanghai Aids to Navigation Department. This module can run with the simulation platform, or, run independently. When choosing one evaluated aid or channel on the ECDIS of the three-dimensional simulation system, the "Aids to Navigation Risk Assessment" module is activated to realize the risk evaluation for the chosen target (Fig.4). All the indexes and their values are all displayed in the evaluation window. And the evaluation results displayed in the window includes risk value of each aspect and the value and level of the total risk, also some risk control suggestions (Fig.5).

The evaluation process and the final results can be saved into a database called "Assessment Record" for future study or comparisons between different targets or assessment conditions.

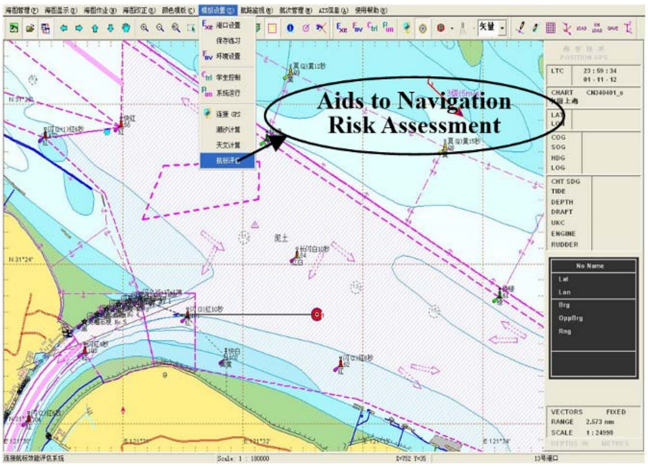

Figure 4. Activating the "Aids to Navigation Risk Assessment" module on Three-dimensional system

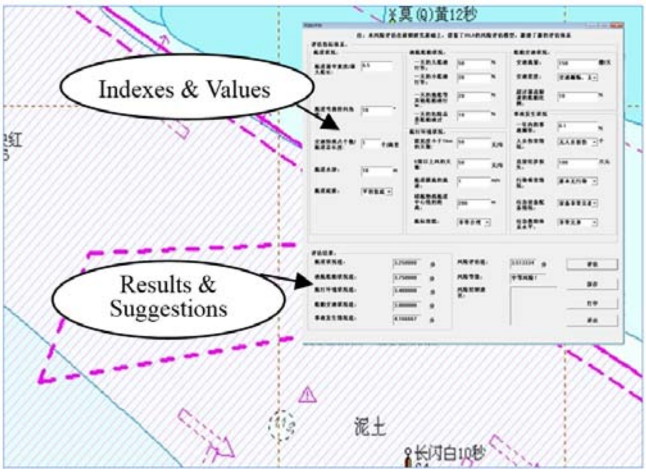

Figure 5. Evaluation effects of the chosen channel

5 REAL-TIME RISK ASSESSMENT FOR AIDS TO NAVIGATION IN YANGTZE ESTUARY DEEP-WATER CHANNEL

Taking the deep-water channel of the Yangtze River estuary as an example to illustrate the general assessment procedure, then, related risk assessment results and risk control suggestions will be given at last.

5.1 *General conditions of the deep-water channel*

After the third-phase project, the depth of the deep-water channel is kept at 12.5m, and the ship flux increased steadily. But the navigation environment of the deep-water channel is very complicated. Many heavy wind days occur and last a long time. And the days with poor visibility may account for 5% of the total year. With the development of Shanghai International Shipping Center, much larger numbers of ships with various types navigate in this water area. Even the maximum speed limitation is set to be 15kn, still many large ships navigate beyond it, bringing higher risks to the whole navigation safety. Fig.6 shows the average speed distribution condition in this channel in 2013. Almost 29.1% ships are over-speeding.

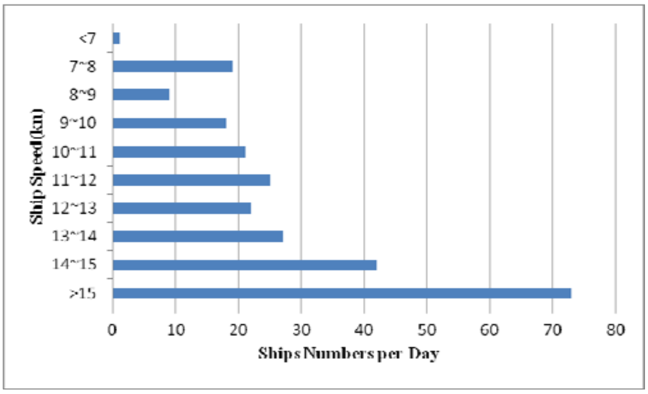

Figure 6. Ship speed distribution condition in deep-water channel

Analyzing the AIS data in the three-dimensional system, it is found that the average ship flux in the deep-water channel is 251 per day in recent years, in which, large ships (draft>10m) account for 10.3%, while the small ships account for about 31.9%. Most of the ships are commercial ships and other boats, occupying 57.8% of the total numbers. And 15.8% ships carry hazardous cargoes.

5.2 *Risk assessment for AtoNs in deep-water channel*

After activating the "Aids to Navigation Risk Assessment" module on Three-dimensional system, then choosing the deep-water channel in the ECDIS, the window of the real-time risk assessment for AtoNs in the deep-water channel will be appeared, like Fig.5. The blanks in the window are filled with the values of each index as in Table 4. The meanings of each data were illustrated in Table 2, and also the weight of each index.

Certainly, if the chosen targets or the assessment environments were changed, the values of each index would be changed correspondingly and real-timely. That is how the real-time assessment be achieved.

Table 4. The values of each index for deep-water channel

Risk assessment for AtoNs in deep-water channel		Index values
1. Traffic Volume	Deep draught	10.3%
	Shallow draught	31.9%
	Commercial fishing vessels and other boats	57.8%
	Hazard cargoes	15.8%
2. Ship Traffic Conditions	Traffic mix	251
	Traffic density	8(0~10)
	Ship speed	29.1%
3. Navigational conditions	Visibility	18.25
	Wind	31
	Current and wave	0.7
	Obstructions condition	570
	Aids to navigation condition	9(0~10)
4. Waterway configuration	Channel width	0.914
	Channel curvature	12
	Waterway complexity	0.08
	Channel depth	12.5
	Channel structure	8(0~10)
5. Accident conditions	Accident frequency	0.02%
	Injuries to people	0
	Property damage	15
	Hazardous material release	8(0~10)
	Emergent rescue equipment condition	8(0~10)
	Emergent rescue system level	8(0~10)

Click the "Assessment" in the window, the results will be displayed in the window (Fig.5). It was illustrated in Fig.7.

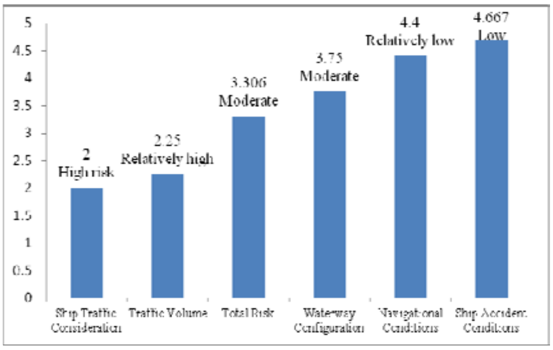

Figure 7. Risk condition of the AtoNs in deep-water channel (**Attention:** 0~2, High Risk; 2~3, Relatively High Risk; 3~4, Moderate Risk; 4~4.5, Relatively Low Risk; 4.5~5, Low Risk**)**

Fig.7 shows that the overall risk level of the AtoNs in Yangtze estuary deep-water channel is moderate (score: 3.306). The main risks are caused by ships conditions and the traffic conditions with high risk level, with the score of 2 and 2.25 respectively. In the deep-water channel, the types of the ships are various, with many small ships and commercial fishing vessels or boats. And, many over-speeding ships and ships with hazardous cargoes navigate in the channel. These all lead to high risk level. However, the channel conditions, aids to navigation conditions and the navigational environment are all very good to the ship navigation, which can reduce the navigation risk to some extent. In conclusion, the overall risk level of the channel is moderate.

To the Yangtze estuary deep-water channel, some risk control suggestions were proposed based on the above evaluation results:

- Standardizing the ship navigation orders, warning and guiding the small ships and commercial fishing vessels to obey the rules; Warning the over speeding ships timely to keep safety speed;
- Placing safe water markings or leading lines in the water area with big ship flux to guide the ships past this area quickly and safely;
- Making full use of the visual aids and radio aids to build one comprehensive navigation aid system to provide accurate and timely navigation information and warnings for the ships;

The results were reviewed and approved by the administrators and experts from Shanghai Aids to Navigation Department. And, the risk assessment can be real-timely changed in coincidence with the chosen targets and the assessment environments.

6 CONCLUSIONS

In order to improve the risk assessment level for AtoNs, one real-time risk assessment module was completed based on built index system and fuzzy-FSA model. Comparing to the traditional AtoNs risk assessment method, the real-time risk assessment for aids to navigation using fuzzy-FSA on the platform of aids to navigation three-dimensional simulation system can provide real-time, more scientific and comprehensive results for the chosen targets. And the risk assessment results would be changed real-timely if the targets and the assessment environments were changed. Besides, after practical using in the Yangtze estuary deep-water channel in Shanghai, the assessment results were approved by the administrators and experts from Shanghai Aids to Navigation Department. The method proposed presents practical significance and application prospect on the maintenance and management of the aids to navigation.

REFERENCES

[1] IALA and AISM(2001): IALA AIDS TO NAVIGATION GUIDE

[2] WANG Ruzheng. (2011): Quantitative evaluation method for the efficacy of aids to navigation. *Journal of Dalian Maritime University*. 37, 39-42

[3] QIU Yunming, JI Yongqing, Pan Jinwen. (2007): Quantitative analysis on influential factors of navigational aids with disorder operation in lower reaches of Yangtze River. *Journal of Shanghai Maritime University*, 28, 57-61

[4] DU Dong, PANG Qinghua, WU Yan. (2008): Modern comprehensive evaluation method and case study (Second Edition). Beijing: Tsinghua University Press

[5] D.Zhang, X.P.Yan, Z.L.Yang, etc. (2013): Incorporation of formal safety assessment and Bayesian network in navigational risk estimation of the Yangtze River. *Reliability Engineering & System Safety*, 118, 93-105

[6] CHEN Guowei. (2010): Application of three-dimensional simulation system to the placement and management of aids to navigation. *Proceedings,17th Conference of the International Association of Marine Aids to Navigation and Lighthouse Authorities (IALA-AISM)*. Cape Town-South Africa. 2010, 50-60