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Risk assessment of ship navigation in Bridge Areas

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RISK ASSESSMENT OF SHIP NAVIGATION IN BRIDGE AREAS

By

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DECLARATION

I certify that all the material in this research paper that is not my own work has been identified, and that no material is included for which a degree has previously been conferred on me.

The contents of this research paper reflect my own personal views, and are not necessarily endorsed by the University.

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ABSTRACT

Title of research paper: **Risk Assessment of Ship Navigation in Bridge Areas**

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Water transport promotes social and economic development. However, bridges on some channels deter navigation of ships sailing in such areas. Collision of ships and bridges poses threat to water transport. Systems to evaluate navigation safety in waters adjoining to bridges are sometimes not complete enough to cover main factors affecting navigation safety. This thesis firstly introduces previous researches in this area, taking fuzzy comprehensive assessment as an approach. Then, indexes affecting navigation safety in such waters are examined to establish an index system. According to the degree to which every index affects navigation safety and advice from experts, indictors of all indexes are formulated. Membership function is invented to put forward a comprehensive assessment model for risk assessment in such areas with the method of fuzzy comprehensive assessment. It is a model that not only provides effective assessment of current navigation situation in waters adjoining to bridges, but also sheds light on practical measures for choosing locations of bridges and discussions in this regard. Lelong Bridge is in this thesis an example to verify the model, whose results square with the fact. This research helps to cultivate a more comprehensive system and unified standards concerning risk assessment of navigation in bridge areas.

Key words: Navigation safety, waters adjoining to bridge areas, fuzzy assessment, membership

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LIST OF ABBREVIATIONS

AHP Analytic Hierarchy Process

AIS Automatic Identification System

DWT Dead Weight Tonnage

GT Gross Tonnage

IMO International Maritime Organization

MHF Medium High Frequency

PRC People's Republic of China

VHF Very High Frequency

VTS Vessel Traffic Service

COLREGs Convention on the International Regulations for Preventing Collisions at Sea, 1972

Chapter 1 Introduction

This chapter mainly covers background of the research, literature review and objective of the study.

1.1 Background

Waters boast economy and cultures in the surrounding areas. Waterborne transportation is essential for modern transportation. Without shipping, half of the world would starve and the other half would freeze. Channels have a due role to play in the shipping industry (Nie, 2013). Strait of Malacca makes Singapore a strong regional economy. Besides, Panama Canal and Suez Canal are indispensable to the world. The development of economy and society even highlights more the importance of water transport. China is not an exception. Along with the rapid growth of China's foreign trade, water transport in China booms. According to statistics from the Ministry of Transport of China, the total freight volume by waters amounts to 6.14 billion tons in 2015. By April, waterway cargo transport reaches 2.04 billion tons in 2017. In the government report, Premier Li reiterates that China will optimize original development distribution, in order to give a further push to the Belt and Road Initiative and make up a national marine strategy. Such initiatives require more promoted water transport (Ministry of Transport, 2017).

Water transport provides a strong and vital support to social and economic development. In 2016, the Pearl River system carries a freight volume of about 780 million tons. Freight turnover of freight reaches 163.3 billion ton-kilometers. The throughput of containers of main ports along the river is 14 million TEU. Passenger volume and passenger turnover are 16 million persons and 860 million person-kilometers.

Bridges across rivers and sea emerge one after another. By the end of 2014, the number of high way bridges amounts to 757100 with a total length of 43 million linear meters. Currently, the YellowRiver has 228 bridges built or being built. There are 162 bridges on the Yangtze River. Bridges in such areas contribute a great deal to the traffic and economic development therein.

However, due to the limited time and the large volume of work, designing and construction are to some extent problematic (Wang, 2012). Due to the Shortage of knowledge in hydrology, river beds or sea beds, location of the bridge, designing of spans and distribution of piers can be improper. All these factors may degrade navigational conditions in waters adjoining to bridges, adding risks of accidents. Severe accidents like high death tolls, destruction of ships and bridges are not rare (Wang, 2012). In 2007, Jiujiang Bridge in Foshan witnessed an accident in which a ship collides with the bridge and the bridge is broken with nine people dead. In the Yangtze River, the condition is no better. For example, sixteen accidents happened within 150 days in waters adjoining to Huangshi Bridge in Hubei Province, owing to the bad location. This bridge is built in the area where torrents are rapid and traffic is busy, causing the loss of millions of RMB (Mao, 2016). Globally, the navigation safety in bridge waters is threatened to a certain extent. On 9^{th}May, 1980, a cargo carrier crashed into the piers of Sunshine Skyway Bridge, causing 35 deaths and the southern part of the bridge collapsed (Sun, 2013). On 11^{th}, September, 2015, a ship carrying 180 passengers in Erlangen, Germany collides with a bridge across a canal as it is in Danube, when heading for a hotel. Two passengers died in this accident.

It can be concluded that the risk of collision between ships and bridges is rising. Bridges are bigger and longer; ship sizes are larger and the number of vessels goes up. Though ships are heavier, their speed is higher (Larsen, 1993). The volume of dangerous goods increases, too. Hence a systematic and comprehensive analysis, research and assessment on navigation safety in waters adjoining to bridges are necessary. Old regulations and standards may not square with the current situation. Domestic research in this regard mainly focuses on certain aspects concerning this subject, such as force from bridges on bridges, collision preventing measures (Liu, 2010). A comprehensive assessment method is needed. To improve navigation safety in such waters is of practical value. This thesis takes the navigational condition in Lelong Bridge in Shunde, Guangdong waters as an example, with a study on factors affecting navigation safety, which intends to formulate a model to assess safety conditions. Also, it is helpful to decide upon location of new bridges and discussions in this regard.

1.2 Literature review

Lokukaluge (2015) focuses on a collision detection methodology and collision risk assessment in an integrated system accounting for vessel state uncertainties in complex ship maneuvers. Technological measures to accommodate modern integrated bridge system are studied and navigation equipment in ships to detect collision dangers is illustrated. Kalman filter is applied to evaluate many vectors including course-speed vector and bearing vector. Potential approaches to detect dander of collision in e-navigation are discussed. Hu (2005) explores the force of collision between brides and ships and the corresponding evaluation approach. A simulation model is applied to figure out forces of ship-bridge collision with four ships whose tonnages are different. A curves set is set up based on data and curves gained to describe the maximum collision forces and deadweights of ships. Balmat (2011) conducts a study on real-life and simulated marine traffic flows for determining collision risks. Calle (2017) explores navigation of inland waterways at bridge crossings, effects of bridges on inland navigation of inland waterways and an approach to evaluate collision possibility of ships. Restricted clearance is considered, collision forces and possibility are calculated, and the forces of collision are figured out. Measures to reduce the risk are presented, too. The method is applied to some rivers. Wang (2017) researches the risk assessment of collision in complex channels, taking into consideration obstacles, water levels and other factors. Risk assessment model is formulated in this regard. Chen (2017) studies the possibility of collision between vessels in seas around UK and offshore infrastructures. Fuji (1974) focuses on the effect of ways of ship encountering, types of ships, weather condition and sailors' experience on accidents. How encounter is transformed into accidents is revealed with a model, which can be applied in other fields. Kim (2017) explores the key safety navigation factors in Taiwan harbors and surrounding waters. Such factors affecting navigation safety are reviewed with relevant literature and consultations on experts. Questionnaires are used to determine the value of importance of all factors. A systematic hierarchical structure is applied to assess factors like human, vessels, climate and environment. It highlights the role of sailors on board in preventing accidents. Van (2001) examines human factor in managing cargo operation. Human errors which can be disastrous to human life, cargo and environment are analyzed. A comprehensive assessment of human factors in ensuring marine safety is conducted, which is of help to human activities in offshore areas. Neumark (2010) assesses matters relating to navigation safety of navigation and predicts the future trend. Sutulo (2012) conducts safety assessment in an entrance channel, based on real experiments. Approaches to make clear width of channels and probability of a ship accident are discussed. Tracks of ships are taken into consideration. Ventikos (2017) assesses safety of ship's navigation in ice and operational effectiveness. Factors like ship operation and harbor management are considered. Autonomous navigation and sailing behind icebreakers are both discussed.

Domestic study is fruitful, yet most of which is qualitative. Wu (2001) comes up with an assessment method. The ratio of number of accidents to the number of vessels within a certain period is used to indicate navigation safety in an area. This method makes harbors comparable transversely. The concept of standard ship is put forward to replace different volumes of vessels with standardized volumes. Also, a diachronic comparison is conducted to replace the number of accidents of vessels with standardized number of accidents. This method is widely used in many ports of China.

Dai (1993) makes use of Fuzzy Inference System, comprehensively assessing factors like geographical condition, navigation environment, traffic situation, vessels and humans. Grey theory is applied to quantitatively analyze the risk degrees of channels in different ports.

Fan (2008) sets up an index set consisting of natural conditions, meteorology and traffic conditions, with a method of comprehensive fuzzy assessment. Huang (2013) comes up with a multi-level comprehensive assessment approach to evaluate traffic safety in different waters. On the basis on relevant data, this approach proves to be successful.

By utilizing these existing approaches and taking into account the status quo in Lelong Bridge, this article makes use of fuzzy comprehensive assessment of navigation safety in waters adjoining to bridges.

1.3 Research objective

Considering the fact that planning and construction of bridges do not take into account the environment in bridge areas, deteriorating navigation conditions and deterring development of water transport, this thesis intends to shed light on the method to assess navigation safety in waters adjoining to bridges, which could be helpful to optimize safety assessment in such areas.

1.4 Layout

This thesis is devided into six parts.
Chapter one covers research background, literature review, significanse of this study. Current situation of the risk assessment of navigation in waters adjoining to bridge

areas. Common reseach approaches are revealed.

Chapter two is dedicated to a systematic analysis of navigation environment in the aforementioned areas. Elements involved are presented.

Chapter three figures out indexes affecting navigation safety in bridge areas. Comprehensive assessment method is introdued. Risk degrees are set to assess the effects of every index on the navigation safety. Indicators of all indexes are made clear respectively. Also, various indexes are weighted for further calculation.

Chapter four sets up an index system. Risk degrees assessment sets are thereby established for fuzzy comprehensive assessment. Functions for the results are displayed.

Chapter five deals with risk assessment of navigation safety in Lelong bridge so as to evaluate validity of the ,model set up in former chapters. Natural conditions, traffic consitions, traffic governance and bridge conditions are analyzed. Relavant satatistics are input into the model to generate results.

Chapter six draws the conclusion that such a model is practicable and further study in this regard is proposed.

Chapter 2 A systematic Analysis of Navigation Environment in Adjoining Waters of Bridges

Navigation environment in waters adjacent to bridges generally indicates natural conditions, traffic conditions and bridge factors (Ma, 2006). It can also be generalized as meteorology, hydrology and geographical conditions, plus traffic conditions including traffic flow, vessel density, traffic orders and artificial facilities. Bridges have a due role to play in navigation in bridge waters.

2.1 Natural factors

Natural factors can be divided into three parts, namely meteorology, channels and water flows. Meteorology includes strong wind, poor visibility, etc (Pang, 2008). Navigation channels indicate turnings, depth of water and obstacles below waters.

2.1.1 Meteorology

Visibility exerts an influence on the speed of vessels, affecting waterborne transportation and efficiency. Collision, grounding and running on rocks easily happen to vessels with a poor visibility, posing threats to water transportation. Strong wind threatens navigation safety in bridge waters, too (Proske, 2005). Vessels gather or reduce speed in wind which also causes them to drift or turn sharply. Effects on vessels by wind are influenced by wind scale, chord angle of wind, freeboard, draft, wind-affected areas of vessels, and center of wind force, course and speed of ships.

The stronger a wind is, the more severe it is to lifting, trimming, drifting and turning of a vessel. In broad areas in Yangzte River, wind of four or five Beaufort scale are able to harm safety of a fleet, while wind of six Beaufort scale or higher adds difficulty to maneuvering ships or even threatens the bridges' safety.

2.1.2 Channels

Channel conditions means routes and navigation marks. Routes indicates what s ship goes through from the departure port to the destination port. Navigation marks concerns navigation aids functioning for positioning, danger avoiding and confirmation, so as to safeguard the safety of vessels (Youseff, 2017). Risks are mainly caused by rocks below water lines, shallow underwater banks, obstructions, torrents, sharp turns, narrow channels and displaced navigation marks. In shallow or narrow channels, depth of waters, speed and size of a ship exert influence on navigations, which mainly result from the resistance of waters. Engines in this regard are overloaded with low power. The ship sinks down more and is thus harder to handle.

2.1.3 Water flows

Depth, sectional shapes, bending, slope and piers location all have an influence on the speed of water flows in bridge waters which affects ship navigation. When the course of a ship is in a certain angle with torrents directions, the speed and track of a ship change. Consequently, complex water conditions in bridge water areas, to some extent, require broader channels (Zhang, 2011). Downstream sailing means more difficulty to maintain speed and more drifting. So it is with up streaming.

2.2 Traffic conditions

Traffic conditions include vessel density traffic orders and artificial facilities (Ma, 1998).

2.2.1 Vessel density

Vessel density refers to the number of vessels which go through the area within a certain period of time. Vessel density is one of the basic indicators to reveal what is actually happening concerning waterborne transportation in a region. It is connected with navigation safety in such areas.

2.2.2 Traffic order

Bridges are often built in economically advanced regions where water traffic is usually busy. Vessels with different courses and types when encountering are difficult to manage, especially in bridge waters (Zhao, 2010). A ship intending to avoid collision with another ship may crash with the others. Besides, fishing ships add more uncertainty to navigation in bridge waters.

2.2.3 Artificial fcilities

Artificial facilities can be categorized into three types. The first category refers to navigation aids including monitoring equipment, navigational devices and communication systems (Pang, 2008). The second category indicates preventative facilities for accidents. The last one deals mainly with equipment for emergencies.

Monitoring equipment is to supervise behaviors of ships and to provide modernized traffic services. Such equipment is currently divided roughly into two kinds, namely Vessel Traffic Services (VTS) and Automatic Identification System (AIS). Navigational devices are important artificial facilities to provide navigation aids to ships. Whether the number and distribution of such devices is sufficient or proper is of vital importance to navigation safety. So is efficient operation of them. Communication system refers to traditional Very High Frequency (VHF) and Medium High Frequency (MHF), mobile telephones and satellite communication in offshore water. Preventative system's function mainly covers a timely release of warnings and weather forecast (Zhang, 2004). To a certain degree, it reduces the risks of danger. Emergency responding equipment makes up for accidents, decreasing death tolls and property damage.

2.3 Bridge factors

Bridge factors mainly concern various kinds of parameters of bridges.

2.3.1 Navigation clearance

Navigation clearance and net breadth are two important parameters of a bridge. Navigation clearance combines the air draught of a ship and what is left between the top of the ship and the bridge. The highest water level allowing passage of a ship is where navigation clearance begins to be calculated.

2.3.2 Navigable bridge openings

The net breadth of navigable bridge openings confines the size of ships passing through a bridge. It is verified with the following formulas (Yan, 2004):

$$B_m = B_F + \Delta B_m + P_d$$
$$B_F = B_s + L \sin \beta \qquad (2.1)$$

In this formula, B_m stands for net breadth of a one-way navigable bridge opening; B_F is for track-width of ships; $\triangle B_m$ is spared breadth between ships with piers. For waterway of class one to five, $\triangle B_m$ can be 0.6 times that of B_F, in other words; $\triangle B_m = 0.6 * B_F$. P_d refers to cross track distance of ships. B_s in this case indicates the breadth of ships while L stands for length of ships. β is for drift angle which is generally 60 °in waterway of class one to five.

Chapter 3 An Assessment Index System of Navigation Safety in Bridge Waters

The construction of an assessment index system in bridge waters concerns principles, methods and choosing indexes.

3.1 Assessment principles

Assessment on navigation safety in bridge waters involves a comprehensive and complex system concerning many indexes. A single indicator is far from enough. Such system should be general so as to ensure objectivity. Different indexes interact with each other. Also, many indexes cannot be clearly classified. Consequently, fuzzy sets theory is applied to reveal how a certain index contributes to final results. Meanwhile, given standards are utilized to ensure comprehensive judgments with regard to various indexes (Xu, 2006). Fuzzy sets take into account every single indicator, via fuzzy transformation method and maximum membership grade law, which aims for a comprehensive assessment.

3.2 Fuzzy comprehensive assessment method

Fuzzy mathematics is widely used in fuzzy comprehensive assessment. Basic concepts in this regard goes as follows: firstly, a general overlook on the degree to which all indexes affect risks is required, then the importance of different indexes are quantified by making sure relevant weights of them; afterwards, mathematic models are needed to assess risks of all indexes.

Factors affecting navigation safety in bridge waters are overwhelming. It is a highly complicated system. For example, natural conditions can be divided into many sub-factors and indexes, most of which can be demonstrated by fuzzy approaches (Hu, 2005). It is difficult to have a precise quantitative analysis. Consequently, fuzzy sets theory is applied to quantitatively analyze the quality of different indexes.

3.2.1 Procedures

Firstly, it is essential to identify the ultimate aim which is placed at the highest level to have an assessment index system consisting of selected factors.

Secondly, the weights of all indexes ought to be figured out. A simplified binary comparative method is helpful, in which consensus ranking is conducted among all indexes (Woisin, 1979). Neighboring indexes are compared with mood operators to various degrees. According to the corresponding relation between mood operators and relative weights, the latter one can be calculated. Then identification approach is adopted to deal with relative weights of all indexes.

Thirdly, risk degrees assessment sets are set up, which are a collection of all potential assessment results. The results in this regard demonstrate the risk degrees of the system, in other words, the status quo of the situation.

Fourthly, membership function is utilized to indicate how indexes contribute to risk degrees assessment sets. Corresponding relations among indicator for every index and assessment sets are made in accordance with experience, as well as knowledge of judgers. Such corresponding relations are membership functions with the aim of assessing every single index. Assessment of a single index is fundamental to the overall assessment. In this regard, the initial issue concerning fuzzy mathematics is to ensure the membership functions.

Fifthly, membership functions are utilized to evaluate every single index, the results of which are collected in the set P_i. A matrix for fuzzy assessment is thus created, aiming for a fuzzy comprehensive assessment of the general aim.

3.2.2 Main contents of the method

A fuzzy comprehensive assessment method mainly concerns four aspects, index sets, Analytic Hierarchy Process (AHP), assessment sets and single index assessment.

3.2.2.1 Index sets

A certain thing, or the assessment object, is caused by multiple factors. Considerations concerning all indexes are hence indispensable for the evaluation of a certain thing. The index set U is a collection of all indexes that affect the evaluated object. It can be revealed as U= (u_1, u_2, u_3 … u_n). It is a set that includes many factors, which include the corresponding weights referred to as W_i (i= 1, 2,…, m). W_i to indicate how important an index is in the overall assessment. The set W is composed of W_i, in other words, W_i= (w_1, w_2, w_3,…,w_n). W is a fuzzy subset of U, revealing the portion of the contribution of every index to the causing of the assessment object.

$$\sum_{i=1}^{n} w_i = 1 \qquad w_i \geq 0 \tag{2.2}$$

3.2.2.2 Assessment sets

The set V is chosen to include the assessment results of the object. V= (v_1, v_2, v_3, …v_n), in which v_i may stand for many assessment results. The aim of fuzzy comprehensive assessment is to select a best result out of the assessment set after a consideration of the effects of all indexes upon the object (Zhang, 2010).

3.2.2.3 Single index evaluation

After a single index assessment of the indexes in the set U, the membership grade of u_i to v_i is decoded. Consequently, fuzzy subsets in terms of the set V are available, and the vector of single index assessment $R_i = (r_{i1}, r_{i2}, r_{i3}, \ldots r_{in})$. Through a thorough assessment of all elements in the set U, the single index assessment matrix is revealed as follows:

$$R = \begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1n} \\ r_{21} & r_{22} & \cdots & r_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ r_{m1} & r_{m2} & \cdots & r_{mn} \end{bmatrix} \quad (2.3)$$

For a project with a serial number of j and the index with a serial number of i in such a project, r_{ji} means the membership of the best project.

The membership fuzzy subset of the risk degrees assessment indicator of all indexes serves as a converter to quantitatively describe the location of the risk degrees of an index. Such a location is fuzzy, the whereabouts of which is between the neighboring two classes. Consequently, a single index assessment is achieved.

3.2.2.4 Fuzzy comprehensive assessment

On the basis of single index assessment, assessment of multiple indexes is available (Ma, 2005). The set W, standing for weights of different indexes, along with fuzzy comprehensive assessment set of a single index, forms the matrix R. With a multiplication of a matrix, the matrix can be used for fuzzy comprehensive assessment subset for decision-making. The set B is as follows:

$$B = A \circ R = (a_1, a_2, \cdots, a_m) \circ \begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1m} \\ r_{21} & r_{22} & \cdots & r_{2m} \\ \cdots & \cdots & \cdots & \cdots \\ r_{m1} & r_{m2} & \cdots & r_{mn} \end{bmatrix} = (b_1, b_2, \cdots, b_n) \quad (2.4)$$

3.2.2.5 Results of assessment

Maximum membership grade law is applied in this thesis for further calculation. Maximum membership grade law can be detailed as follows: if A_1, $A_2 \ldots A_n$ are the subsets of the universe X, the membership function is μ, and if $x_0 \in X$(x_0 is to be identified), then there is an i(i= 1, 2, …, n) to conform to the following function:

$\mu_{Ai} = \max\{\mu_{A1}(x_0), \mu_{A2}(x_0), \ldots, \mu_{A3}(x_0)\}$ （2.4）

Then x_0 belongs to A_i.

3.3 Indexes

3.3.1 Establishment of indexes

There are many factors affecting navigation safety, some of which are independent and some are interactive. Their influences are of various degrees. A qualified comprehensive navigation safety assessment demands properly-chosen indexes (Xiong, 2011). Given that the navigation system is complex, the assessment system should be systematic, comprehensive, independent, simplified, practicable, comparable, representative, and up-to-date, combining qualitative and quantitative approached.

To select appropriate indexes and establish proper index system is the precondition of objective results. This thesis takes into account spatial restrictions on ships caused by bridges, as well as both subjective and objective factors that affect the normal sailing of ships. To grasp the main factor and avoid errors caused by complicated calculation processes, with regard to the analysis in chapter 2, this thesis generalizes the indexes into the following nine categories:

3.3.1.1 Wind

Channels in waters adjoining to bridges, though relatively small, still bear the influence of waves and wind. Ships in such areas usually have a light draft, thus the stability and resilience to wind are greatly reduced than in deep waters. Ship handling in turbulent weathers should be paid much attention. Wind will push away ships. Ships sway heavily because once the wind in such waters makes the ships yaw away, it could be extremely dangerous.

3.3.1.2 Visibility

The most important feature of visibility is the farthest horizontal distance human eyes could reach. In poor visibility or lightening, the visual range of sailors is shortened, which deteriorates navigation conditions, easily leading to yawing or collision (Chen, 2009).

3.3.1.3 Depth of water

The standard depth of waters adjoining to bridges indicates the minimum depth by which ships can pass the bridge in the lowest designed waterline. In shallow waters, the resilience of water amounts, the engine has poorer performance and is loaded more (Zhang, 2010). Ships could trim by stern or sink into waters more. Maneuvering ships is more difficult. The effects of waters on ships are also connected with the size of ships, depth of channels and the ship’s speed.

3.3.1.4 Torrents

In adjoining waters of bridges, torrent adds obstacles to ship handling. The relative speed of the hulk of a ship and surrounding waters is accelerated because of torrents. Restricted water in such condition is inclined to affect the ship. In downstream, slowing down and stopping the ship takes much time (Xu, 2006). Transverse torrents are able to push the ship away. The angle between the course of the ship and direction of torrents enlarges as the water flow is gaining speed. A slower ship bears more pressure. Drifting speed of a ship accelerates in downstream.

3.3.1.5 Bending of channels

Torrents in bending channels are complex. To locate the bridge in bending parts of a river adds difficulty in maintaining safe navigation. Bridges in such areas are more susceptible to collisions with ships. The bending of channels can be indicated by bending radius (Fan, 2010). The minimum bending radius allows the passage of the maximum size of a ship. The effect on ships can be revealed as follows:

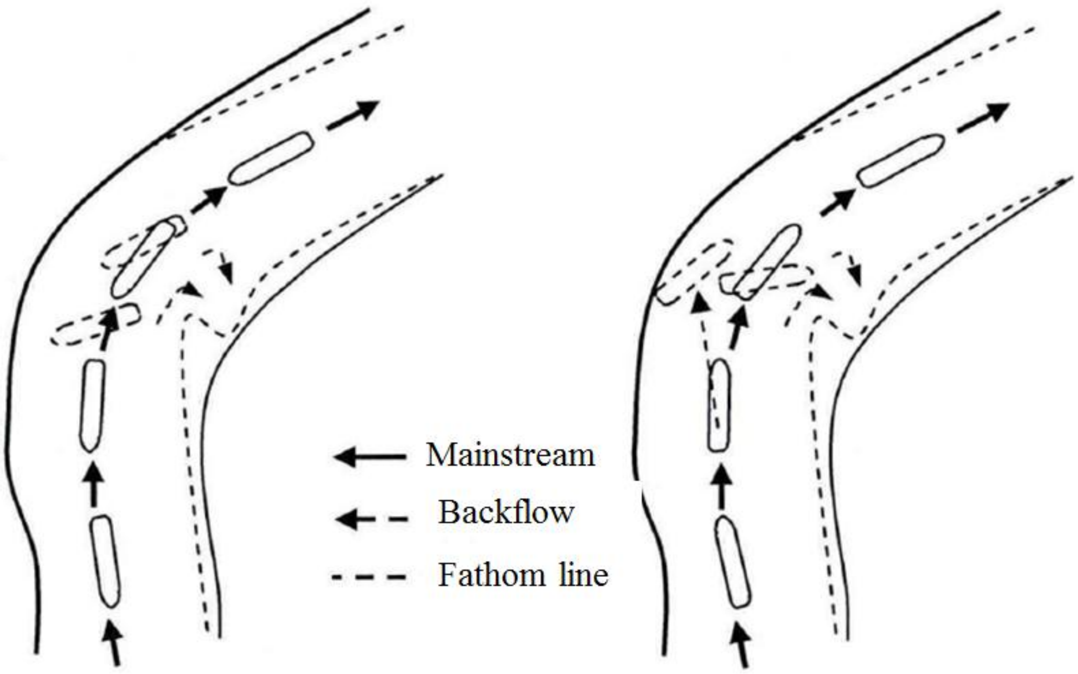

Fig 1The effect of bending channels on ships
Source: Zhang, 2011, p.23

3.3.1.6 Navigation aids

Accurate and reliable navigation marks safeguard ships passing waters adjoining to bridges (Xu, 2008). Signs of bridges and culverts help to protect both ships and bridges. For a bridge which restricts the passage of ships, navigation marks are indispensable. In accommodating bridges with navigation marks, traffic flows, possible sizes of ships should be taken into consideration.

3.3.1.7 Dimensions of navigation clearance

Navigation clearance and net breadth, as mentioned in chapter 2, limit the passage of ships of unfittingly big sizes.

3.3.1.8 Traffic density

Within a unit of period, the total number of vessels crossing the transverse section of waters is named as traffic density. Traffic density expresses traffic volumes (Zheng, 2010). It also to some extent reveals how crowded and dangerous the traffic is in an area. Normally, a more frequent traffic flow requires a higher standard of traffic management.

3.3.1.9 Traffic complexity

In waters adjoining to bridges, some factors including joining of main streams and branches makes traffic conditions more complicated. In fishing areas, some ships do not obey orders (Wen, 2017). Chaos of traffic poses great threat to navigation safety in such waters.

The index set U is defined as:

U= (u_1, u_2, u_3, u_4, u_5, u_6, u_7, u_8, u_9)

= (wind, visibility, depth of water, torrents, bending channels, navigation aids, dimensions of navigation clearance, traffic density, traffic complexity).

3.3.2 Risk degrees of indexes

Risk degrees of indexes makes clear dangerous or safe situation and depicts the degree of danger (Wang, 2006). With regard to relevant study concerning navigation risk degrees and on the spot navigation conditions, and the specialized analysis of scholars, risk degrees of navigation in waters adjoining to bridges are categorized into five classes, namely, safe, relatively safe, average, relatively dangerous, and dangerous. The set V consist of five classes of safety that is illustrated as follows:

$V = (v_1, v_2, v_3, v_4, v_5)$

$= (2, 1, 0, -1, -2)$

= (safe, relatively safe, average, relatively dangerous, and dangerous).

This set indicates possible assessment results, in which the element v_j (j= 1, 2, , n) is a potential one. Fuzzy comprehensive assessment is to identify the best result after a comprehensive assessment.

3.3.3 Indicator for risk degrees assessment of indexes

After indexes affecting navigation safety in waters adjoining to bridges are made clear, the assessment set is established. The effect of every index on navigation safety is to be analyzed and the corresponding indicator is to be figured out.

3.3.3.1 Indicator for wind

According to relevant research, the speed of wind has a linear relationship with the number of accidents in such areas, the latter one being represented by k_w (Dai, 2016). Such relation can be generalized as follows:

$k_w = 7.9v_w - 11.6 \quad k_w \geq 0$ (3.1)

in which v_w indicates the speed of wind.

With an analysis on accidents in waters adjoining to bridges, the frequency of accidents is in direct ratio to the speed of wind. Besides, ships bears the greatest danger when the wind is abeam. Dangers are less when ships are following or against the wind.

In order to better evalute the effect of wind, considering the risilience to wind of ships, channels condition, meteorology and regulations, in this regard, the standard force scale of wind in this article is set at fourth Beaufort scale, namely moderate breeze. Wind of other scales are standardized accordingly, so as to cipher out the annual average days with standard wind (Minorsky, 1959). The average days with standard wind within a year is taken to determine the indicator of wind. Wind is dealt in two categories, namely, wind of four to six Beaufort scale and wind larger than six Beaufort scale. Wind larger than six Beaufort scale are transformed into stardard wind. The coefficient is 1.5. Thus, the function to figre out annual days of standard wind is as follows:

Average annual days of standard wind= average annual days of wind of fourth to sixth Beaufort scale+ 1.5*(average annual days of wind more than sixth Beaufort scale).

In accordance with the aforementioned analysis, by questionnaire and consultation on experts, the indicator of wind speed is generalized in Table 3.1.

Tab 1The standard of an assessment about visibility wind

risk degrees / indicator	safe	relatively safe	average	relatively dangerous	dangerous
days of standard wind per year	<30	30-60	60-90	90-120	>120

Source: compiled by author based on statistics from Dai, 2016, p.74.

3.3.3.2 Indicator of visibility

Navigation safety in waters adjoining to bridges is severly affected by visibility, adding much difficulty to the passage of ships (Tang, 1996). To cite Yangtze River as an example, scholars in China records the number of accidents within 1,000 hours under a cerrtain degree of visibility, working out the ragular pattern govering the effect of visibility on navigation safety in the area. It is a pattern that can be revealed as follows:

$$k = 9.0 D_{B}^{-0.8} \quad (3.2)$$

K is the number of accidents in the visibility of D (km), within 1000 hours. It can be concluded that the poorer the visibility is, the higher the potential of accidents. Within a visibility of 1 km, vessels suffer from the most severe influence (Park, 2017). Consequently, 1 km is deemed as the dangerous degree of visibility. China's traffic governance system classifies visibility into many categories, in which poor visibility means less than two kilometers (Zhuang, 2007). 12 days a year with poor visibility is a classified as the first class. The second class is 22 days a year. The third class is 22 days a year. The highest level is 40 days a year. In accordance with navigation in bridge waters, to make the indicator square in conformity with the status quo, and also to ensure practicability in analyzing factors that affect the navigation safety in breach areas, this article, on the basis of study by relevant scholars, with questionnaires and consultation on experts, makes sure the indicator of factors affecting the navigation safety in bridge areas, in other words, the standard is annual days with the visibility of less than 2,000 meters.

Tab 2The standard of an assessment about visibility

risk degrees / indicator	safe	relatively safe	average	relatively dangerous	dangerous
days of poor visibility per year	<15	15-30	30-45	45-60	>60

Source: compiled by author based on statistics from Tang, 1996, p.64.

3.3.3.3 Indicator of depth of water

According to features of channels and ships in such regions, ships have more draft in shallow waters. The depth of water is represented by H and draft is d. The value of H/d has an influence on ships. When H/d= 4, the performance of a vessel is affected. When it is 1.2 to 1.5, and a ship goes at the speed of v= $\sqrt{gH}$ (g stands for acceleration of gravity), this ship is likely to be aground (Chen, 2008). The indicator for depth of water as an index is the value of H/d. Concerning the consultations on experts and questionnaires, the indicator is as follows:

Tab 3The standard of an assessment about the depth of water

risk degrees / indicator	safe	relatively safe	average	relatively dangerous	dangerous
depth of water/ draft	>4	2.0-4.0	1.6-2.0	1.3-1.6	<1.3

Source: compiled by author based on statistics from Chen, 2008, p.20.

3.3.3.4 Indicator of torrents

The effect of torrents concerns the direction and speed. Direction of water flow is complicated and intricate, yet water mainly goes at the same direction with the course of a ship (Consolazio, 2005). To simplify the calculation and convenient practice in real situation, this article takes the maximum speed as the main indicator. Taking into consideration the consultations on experts and questionnaires, the indicator of torrents is listed as follows:

Tab 4The standard of an assessment about torrents

risk degrees / indicator	safe	relatively safe	average	relatively dangerous	dangerous
Speed of torrens (m/s)	<1	1-2	2-3	3-4	>4

Source: compiled by author based on statistics from Consolazio, 2005, p.1259.

3.3.3.5 Indicator of bending channels

In order to ensure safety of bridges, this article takes a ship's required cumulative steering angle to pass a bridge as the indicator. Taking into consideration of consultations on experts and questionnaires, the indicator of bending channels is listed as follows:

Tab 5The standard of an assessment about bending channels

risk degrees / indicator	safe	relatively safe	average	relatively dangerous	dangerous
Cumulative steering angle (°)	<5	5-10	10-15	15-20	>20

Source: compiled by author based on statistics from Hu, 2005, p.168.

3.3.3.6 Indicator of navigation aids

In accordance with regulations issued by the government, i.e., *Aids to navigation on inland waterways* (GB 5863-1986), *The main dimensions of aids to navigation on inland waterways* (GB 5864-1986), and taking into consideration of consultations on experts and questionnaires, it is rational to take completion rate of navigation aids marks as the indicator. To convenient constructing functions, the completion rate of 100% is recorded as 100, and so forth. The indicator of navigation aids is listed as follows:

Tab 6The standard of a assessment about navigation aids

risk degrees / indicator	safe	relatively safe	average	relatively dangerous	dangerous
Completion rate of navigation marks(%)	95-100	90-95	80-90	70-80	<70

Source: compiled by author based on statistics from Ma, 2006, p.64.

3.3.3.7 Indicator of channel dimensions

Breadth and dimensions of navigation clearance of navigable bridge openings are important parameters affecting navigation safety. In real scenarios, what mostly affects navigation safety is the breadth of navigation openings. Tracks of ships in bending channels require more spare room than in direct channels (Yan, 2017).

Consequently, the breadth of navigable bridge openings should be verified according to the radius of bending channels, torrents, operation ability of ships, etc. This article makes use of the ratio of net breadth of navigable bridge channels to the breadth of ships as the indicator of dimensions of navigation clearance. Taking into consideration the consultations on experts and questionnaires, the indicator of bending channels is listed as follows:

Tab 7The standard of an assessment about bredth of navigable bridge openings

risk degrees / indicator	safe	relatively safe	average	relatively dangerous	dangerous
Bredth of bridge openings/bredth of ships	>8	5-8	3-5	2-3	<2

Source: compiled by author based on statistics from Pang, 2009, p.17.

3.3.3.8 Indicator of traffic density

Traffic density does not only pose spatial restrictions upon movements of ships, but also causing rising tensions psychologically to sailors. Traffic density indicates how busy or slack the water is and the safety degree in such area (Wang, 2010). By collecting and analyzing traffic volume in different bridges, taking into consideration of questionnaires and consultations on experts, this thesis takes the ratio of actual number of vessels passing through a bridge to the designed number within a certain period to represent the traffic condition in in such areas. The designed number of passing vessels is determined by the size of ships, depth of water, natural conditions and so on. It is represented as follows, in which μ stands for traffic density:

Tab 8The standard of an assessment about traffic density

risk degrees / indicator	safe	relatively safe	average	relatively dangerous	dangerous

Traffic density μ	<0.4	0.4-0.6	0.6-1.4	1.4-1.6	>1.6

Source: compiled by author based on statistics from Wang, 2010, p.42.

3.3.3.9 Traffic complexity

Traffic chaos is threatening to navigation safety (Chen, 2008). This article aims to make a qualitative description of traffic complexity. Risk degrees of traffic complexity are as follows:

Tab 9The standard of an assessment about traffic complexity

risk degrees / indicator	safe	relatively safe	average	relatively dangerous	dangerous
traffic complexity	simple	relatively simple	average	relatively complex	complex

Source: compiled by author based on statistics from Consolazio, 2008, p.17.

3.3.4 Weights of indexes

Weights are used to evaluate the degree to which a single index affects the overall assessment. Weight coefficient directly determines the evaluation results. There are many common ways to determine the weights, among which binary comparison is an effective one.

3.3.4.1 Importance comparison

Binary comparison is taken to invent a matrix covering all indexes (Zhang, 1999). It is in such matrix that the importance of every two indexes is compared and a certain value is attached to a certain index. According to the sum of value of each index, they are ordered with regard to their importance (Ji, 2010).

For comparing the importance of two indexes, value assignments are as follows:

Tab. 1Value assignment

index	u_{ij}	u_{ji}
u_i is more important than u_j	1	0
u_i and u_j are equally important	0.5	0.5
u_j is more important than u_i	0	1

Source: this paper

In this table, u_{ij} indicates the results of comparison, values of u_{ij} and u_{ji} lie among 0, 0.5, 1, the sum of both is 1. In other words, $u_{ij}+ u_{ji} = 1$. Thus the matrix n*n is available to make sure the importance of index sets.

$$U = \begin{bmatrix} u_{11} & u_{12} & \cdots & u_{19} \\ u_{21} & u_{22} & \cdots & u_{29} \\ \cdots & \cdots & \cdots & \cdots \\ u_{91} & u_{91} & \cdots & u_{99} \end{bmatrix} \quad (3.4)$$

Making $T_i = \sum_{j=1}^{9} u_{ij}$, i=1, 2, 3···9 .

In sequencing the indexes according to importance, the set U is to be evaluated. Taking into account the relevant articles and proposals of experts, the sequence of indexes and their corresponding importance are made clear, hence the matrix is available.

Tab 10Sequence of indexes by importance

indexes	wind	visibility	depth of water	torrents	bending channels	navigation aids	dimensions of navigation clearance	traffic density	traffic complexity	T
wind	0.5	1	1	1	1	1	1	1	1	8.5
visibility	0	0.5	0	0	1	1	0	1	1	4.5
depth of water	0	1	0.5	1	1	1	1	1	1	7.5
torrents	0	1	0	0.5	1	1	1	1	1	6.5
bending channels	0	0	0	0	0.5	1	0	0	1	2.5
navigation aids	0	0	0	0	0	0.5	0	0	1	1.5
dimensions of navigation clearance	0	1	0	0	1	1	0.5	1	1	5.5
traffic density	0	0	0	0	1	1	0	0.5	1	3.5
traffic complexity	0	0	0	0	0	0	0	0	0.5	0.5

Source: self-made table according to questionnaires filled by expert

According to the value of T, the sequencing of indexes is completed. Accordingly, the indexes in set U are reordered. Thus, a new index set is created according to the order of indexes.

U= (u_1, u_2, u_3, u_4, u_5, u_6, u_7, u_8, u_9)

= (wind, depth of water, torrents, dimensions of navigation clearance, visibility, traffic density, bending channels, navigation aids, traffic complexity).

3.3.4.2 Binary comparison and quantization

Successive binary comparison is conducted in the set U, and the importance of all indexes is quantized. In this regard, mood operators are introduced for comparison of importance. A mood operator is a tool to describe evaluation results of binary comparison in accordance with experience and knowledge (Jiang, 2011). They are categorized into eleven classes, namely, equally, slimly, slightly, relatively, obvious, significant, very, utterly, exceedingly, extremely, and incomparably. The gaps between them form another ten classes

Tab 11Corresponding Relations between Mood Operators and Relative Weights

Mood operators	equally		slimly		slightly		relatively		obvious		significant
Relative weights	1.0	0.90	0.82	0.74	0.667	0.60	0.54	0.48	0.43	0.38	0.33
Mood operators		very		utterly		exceedingly		extremely		incomparably	
Relative weights	0.29	0.25	0.21	0.18	0.14	0.111	0.08	0.05	0.03	0	

Source: this paper

The index in the first place is the standard, whose value is 1. Comparison between u_2 and u_1 is conducted; the results are described with fuzzy mood operators. Then the relative weights, w_1 and w_2 are available. Similarly, by comparing u_3 with u_4, relative weight of $u_3$to u_2 is available, which is represented by w_{23}. The function is as follows:

$w_{1i}= w_{1i-1}*w_{i-1i}$, $w_{13}= w_{12}*w_{23}$.

Accordingly, relative weights of all indexes are readily available.

Tab 12 Relative weights

Relative weights	wind	Depth of water	torrents	dimensions of navigation clearance	visibility	Traffic density	Bending of channels	Navigation aids	Traffic complexity
w_{i-1i}	1	0.82	0.90	0.82	0.82	0.90	0.67	0.90	0.90
w_{1i}	1	0.82	0.74	0.61	0.50	0.45	0.30	0.27	0.25

Source: this paper

Then the relative weight w_{1i} of every index is available. Normalization is then conducted to w_{1i} to work out the absolute weight:

$$w_i= \frac{w_{1i}}{\sum_{i=1}^{9} w_{1i}} \quad (3.5)$$

W= (w_1, w_2, w_3, w_4, w_5, w_6, w_7, w_8, w_9)

=(0.20, 0.17, 0.15, 0.12, 0.10, 0.09, 0.06, 0.06, 0.05)

Chapter 4 Fuzzy Comprehensive Assessment Model

4.1 Index system

The index system is made clear in chapter 3, and the index set, in accordance with indexes is designed as:

$U= (u_1, u_2, u_3, u_4, u_5, u_6, u_7, u_8, u_9)$

= (wind, visibility, depth of water, torrents, bending channels, navigation aids, dimensions of navigation clearance, traffic density, traffic complexity).

Also, in the last chapter, a simplified binary comparison is applied to quantitatively describe the importance of every index, namely, weights of all indexes. Normalized sequencing is conducted according to the importance of all indexes. Then the relative weight of every index w_{1i} is normalized. Absolute weight of every single index is thus achieved.

$U= (u_1, u_2, u_3, u_4, u_5, u_6, u_7, u_8, u_9)$

= (wind, depth of water, torrents, dimensions of navigation clearance, visibility, traffic density, bending channels, navigation aids, traffic complexity).

$W= (w_1, w_2, w_3, w_4, w_5, w_6, w_7, w_8, w_9)$

= (0.20, 0.17, 0.15, 0.12, 0.10, 0.09, 0.06, 0.06, 0.05).

4.2 Risk degrees assessment sets

Navigation safety in waters adjoining to bridge areas is classified into five levels, safe, relatively safe, average, relatively dangerous and dangerous. The set V representing risk degrees is as follows:

V= (v_1, v_2, v_3, v_4, v_5)

= (2, 1, 0, -1, -2)

= (safe, relatively safe, average, relatively dangerous, and dangerous).

4.3 Membership function and single index evaluation

Chapter 3 analyses the indicator of every index, both quantitatively and qualitatively, depicting to what extent every index can be defined by every level of risk degrees. Since the index and risk degrees are fuzzy, every level of risk degrees of each index lies between neighboring levels fuzzily. There is no clear boundary between different levels of risk degrees. It is difficult to assign the degree of a certain risk to a clear level.

Membership function indicates that deciders, in accordance with regular patterns and methods, as well as their own experience, uncover the corresponding relation between every index and five levels of risk degree (Hu, 2004). Hence a comprehensive assessment of risk degrees of a single index is finished.

In comprehensively evaluating a system or other objects, membership functions corresponding to levels of risk degrees of every index serve as converters, in which after the input of an index, the membership grade of this index to the levels of risk degrees is figured out (Fan, 2008). That is basically the process of a comprehensive assessment. The membership function of every index to risk degrees is defined as follows:

1. Wind

According to indicator of the assessment of wind, the speed of wind is the indicator. In constructing membership function of wind, the membership grade of wind to five levels of risk degrees is thus available so as to achieve a comprehensive assessment.

$$p_1^1 = \begin{cases} 0, & x \ge 40 \\ \frac{40-x}{20}, & 20 \le x \le 40 \\ 1, & x \le 20 \end{cases} \quad (4.1)$$

$$p_1^2 = \begin{cases} 0, & x \le 20 \text{ or } x \ge 70 \\ \frac{x-20}{20}, & 20 \le x \le 40 \\ 1, & 40 \le x \le 50 \\ \frac{70-x}{20}, & 50 \le x \le 70 \end{cases} \quad (4.2)$$

$$p_1^3 = \begin{cases} 0, & x \le 50 \text{ or } x \ge 100 \\ \frac{x-50}{20}, & 50 \le x \le 70 \\ 1, & 70 \le x \le 80 \\ \frac{100-x}{20}, & 80 \le x \le 100 \end{cases} \quad (4.3)$$

$$p_1^4 = \begin{cases} 0, & x \le 80 \text{ or } x \ge 140 \\ \frac{x-80}{20}, & 80 \le x \le 100 \\ 1, & 100 \le x \le 120 \\ \frac{140-x}{20}, & 120 \le x \le 140 \end{cases} \quad (4.4)$$

$$p_1^5 \begin{cases} 0, & x \le 120 \\ \frac{x-120}{20}, & 120 \le x \le 140 \\ 1, & x \ge 140 \end{cases} \quad (4.5)$$

The set of single index assessment of wind is: $P_1 = (p_1^1, p_1^2, p_1^3, p_1^4, p_1^5)$.

2. Depth of water

In constructing membership function of depth of water, the membership grade of depth of water to five levels of risk degrees are thus available so as to achieve a comprehensive assessment.

$$p_2^1=\begin{cases}0, & x\geq 3.8\\ \dfrac{x-3.8}{0.4}, & 3.8\leq x\leq 4.2\\ 1, & x\geq 4.2\end{cases} \quad (4.6)$$

$$p_2^2=\begin{cases}0, \ x\leq 1.8\ or\ x\geq 4.2\\ \frac{x-1.8}{0.4}, \ 1.8\leq x\leq 2.2\\ 1, \ 2.2\leq x\leq 3.8\\ \frac{4.2-x}{0.4}, \ 3.8\leq x\leq 4.2\end{cases} \quad (4.7)$$

$$p_2^3=\begin{cases}0, \ x\leq 1.5\ or\ x\geq 2.2\\ \frac{x-1.8}{0.4}, \ 1.5\leq x\leq 1.7\\ 1, \ 1.7\leq x\leq 1.8\\ \frac{2.2-x}{0.4}, \ 1.8\leq x\leq 2.2\end{cases} \quad (4.8)$$

$$p_2^4=\begin{cases}0, \ x\leq 1.2\ or\ x\geq 1.7\\ \frac{x-1.2}{0.2}, \ 1.2\leq x\leq 1.4\\ 1, \ 1.4\leq x\leq 1.5\\ \frac{1.7-x}{0.2}, \ 1.5\leq x\leq 1.7\end{cases} \quad (4.9)$$

$$p_2^5\begin{cases}0, \ x\geq 1.4\\ \frac{x-120}{20}, \ 1.2\leq x\leq 1.4\\ 1, \ x\leq 1.2\end{cases} \quad (4.10)$$

The set of single index assessment of depth of water is: $P_2=(p_2^1, p_2^2, p_2^3, p_2^4, p_2^5)$.

3. Torrents

According to indicator of torrents, the speed of water should be regarded as the specific indicator. In constructing membership function of torrents, the membership grade of torrents to five levels of risk degrees is thus available so as to achieve a comprehensive assessment.

$$p_3^1=\begin{cases}0, & x\geq 1.2\\ \dfrac{1.2-x}{0.4}, & 0.8\leq x\leq 1.2\\ 1, & x\leq 0.8\end{cases} \quad (4.11)$$

$$p_3^2 = \begin{cases} 0, & x \le 0.8 \ or \ x \ge 2.2 \\ \frac{x-0.8}{0.4}, & 0.8 \le x \le 1.2 \\ 1, & 1.2 \le x \le 1.8 \\ \frac{2.2-x}{0.4}, & 1.8 \le x \le 2.2 \end{cases} \quad (4.12)$$

$$p_3^2 = \begin{cases} 0, & x \le 1.8 \ or \ x \ge 3.2 \\ \frac{x-1.8}{0.4}, & 1.8 \le x \le 2.2 \\ 1, & 2.2 \le x \le 2.8 \\ \frac{3.2-x}{0.4}, & 2.8 \le x \le 3.2 \end{cases} \quad (4.13)$$

$$p_3^2 = \begin{cases} 0, & x \le 2.8 \ or \ x \ge 4.2 \\ \frac{x-2.8}{0.4}, & 2.8 \le x \le 3.2 \\ 1, & 3.2 \le x \le 3.8 \\ \frac{4.2-x}{0.4}, & 3.8 \le x \le 4.2 \end{cases} \quad (4.14)$$

$$p_3^5 = \begin{cases} 0, & x \le 3.8 \\ \frac{4.2-x}{0.4}, & 3.8 \le x \le 4.2 \\ 1, & x \ge 4.2 \end{cases} \quad (4.15)$$

The set of single index assessment of torrents is: $P_3=(p_3^1, p_3^2, p_3^3, p_3^4, p_3^5)$.

4. Dimensions of navigation clearance

According to indicator of dimensions of navigation clearance, the ratio of the breadth of navigable bridge openings to the breadth of ships is the specific indicator. In constructing membership function of the depth of water, the membership grade of new sizes of navigable bridge openings to five levels of risk degrees is thus available so as to achieve a comprehensive assessment.

$$p_4^1 = \begin{cases} 0, & x \le 6.5 \\ \frac{9.5-x}{3}, & 6.5 \le x \le 9.5 \\ 1, & x \ge 9.5 \end{cases} \quad (4.16)$$

$$p_4^2 = \begin{cases} 0, & x \le 4 \ or \ x \ge 9.5 \\ \frac{x-6.5}{3}, & 6.5 \le x \le 9.5 \\ 1, & 6 \le x \le 6.5 \\ \frac{6-x}{4}, & 4 \le x \le 6 \end{cases} \quad (4.17)$$

$$p_4^3 = \begin{cases} 0, & x \le 2.5 \ or \ x \ge 5 \\ \frac{6-x}{2}, & 4 \le x \le 6 \\ 1, & 3.5 \le x \le 4 \\ \frac{x-2.5}{1}, & 2.5 \le x \le 3.5 \end{cases} \quad (4.18)$$

$$p_4^4 = \begin{cases} 0, & x \le 1.7 \ or \ x \ge 3.5 \\ \frac{3.5-x}{2}, & 2.5 \le x \le 3.5 \\ 1, & 2.3 \le x \le 2.5 \\ \frac{x-1.7}{1}, & 1.7 \le x \le 2.5 \end{cases} \quad (4.19)$$

$$p_4^5 = \begin{cases} 0, & x \ge 2.3 \\ \frac{2.3-x}{0.6}, & 1.7 \le x \le 2.3 \\ 1, & x \le 1.7 \end{cases} \quad (4.20)$$

The set of single index assessment of dimensions of navigation clearance is: P_4=（p_4^1, p_4^2, p_4^3, p_4^4, p_4^5）.

5. Visibility

According to indicator of visibility, the annual days of visibility of less than 2000m are the indicator. In constructing membership function of visibility, membership grade of visibility to five levels of risk degrees are thus available so as to achieve a comprehensive assessment.

$$p_5^1 = \begin{cases} 0, & x \ge 20 \\ \frac{20-x}{10}, & 10 \le x \le 20 \\ 1, & x \le 10 \end{cases} \quad (4.21)$$

$$p_5^2=\begin{cases}0, & x\le 10 \text{ or } x\ge 35\\ \frac{x-10}{10}, & 10\le x\le 20\\ 1, & 20\le x\le 25\\ \frac{35-x}{10}, & 25\le x\le 35\end{cases} \quad (4.22)$$

$$p_5^3=\begin{cases}0, & x\le 25 \text{ or } x\ge 50\\ \frac{x-25}{10}, & 25\le x\le 35\\ 1, & 35\le x\le 40\\ \frac{50-x}{10}, & 40\le x\le 50\end{cases} \quad (4.23)$$

$$p_5^4=\begin{cases}0, & x\le 40 \text{ or } x\ge 65\\ \frac{x-40}{10}, & 40\le x\le 50\\ 1, & 50\le x\le 55\\ \frac{65-x}{10}, & 55\le x\le 65\end{cases} \quad (4.24)$$

$$p_5^5=\begin{cases}0, & x\le 55\\ \frac{x-55}{10}, & 55\le x\le 65\\ 1, & x\ge 65\end{cases} \quad (4.25)$$

The set of single index assessment of visibility is: $P_5=(p_5^1, p_5^2, p_5^3, p_5^4, p_5^5)$.

6. Traffic density

According to the indicator of traffic density, the ratio of actual vessel volume to the designed vessel volume is the specific indicator. In constructing membership function of traffic density, the membership grade of traffic density to five levels of risk degrees is thus available so as to achieve a comprehensive assessment.

$$p_6^1=\begin{cases}0, & x\ge 0.45\\ \frac{0.45-x}{0.1}, & 0.35\le x\le 0.45\\ 1, & x\le 0.35\end{cases} \quad (4.26)$$

$$p_6^2=\begin{cases}0,\ x\le 0.35\ or\ x\ge 0.7\\ \frac{x-0.35}{0.1},\ 0.35\le x\le 0.45\\ 1,\ 0.45\le x\le 0.5\\ \frac{0.7-x}{0.2},\ 0.5\le x\le 0.7\end{cases}\quad (4.27)$$

$$p_6^3=\begin{cases}0,\ x\le 0.5\ or\ x\ge 1.5\\ \frac{x-0.5}{0.2},\ 0.5\le x\le 0.7\\ 1,\ 0.7\le x\le 1.3\\ \frac{1.5-x}{0.2},\ 1.3\le x\le 1.5\end{cases}\quad (4.28)$$

$$p_6^3=\begin{cases}0,\ x\le 1.3\ or\ x\ge 1.65\\ \frac{x-1.3}{0.2},\ 1.3\le x\le 1.5\\ 1,\ 1.5\le x\le 1.55\\ \frac{1.65-x}{0.1},\ 1.55\le x\le 1.65\end{cases}\quad (4.29)$$

$$p_6^5=\begin{cases}0, & x\le 1.55\\ \frac{x-1.55}{0.1}, & 1.55\le x\le 1.65\\ 1, & x\ge 1.65\end{cases}\quad (4.30)$$

The set of single index assessment of traffic density is: P_6=（p_6^1, p_6^2, p_6^3, p_6^4, p_6^5）.

7. Bending of channels

According to the indicator of bending of channels, the cumulative steering angle of a ship to pass bridges is the specific indicator. In constructing membership function of bending of channels, the membership grade of bending of channels to five levels of risk degrees is thus available, so as to achieve a comprehensive assessment.

$$p_7^1=\begin{cases}0, & x\ge 7\\ \frac{7-x}{4}, & 3\le x\le 7\\ 1, & x\le 3\end{cases}\quad (4.31)$$

$$p_7^2=\begin{cases}0, & x\le 3\ or\ x\ge 12\\ \frac{x-3}{4}, & 3\le x\le 7\\ 1, & 7\le x\le 8\\ \frac{12-x}{4}, & 8\le x\le 12\end{cases} \quad (4.32)$$

$$p_7^3=\begin{cases}0, & x\le 8\ or\ x\ge 17\\ \frac{x-8}{4}, & 8\le x\le 12\\ 1, & 12\le x\le 13\\ \frac{17-x}{4}, & 13\le x\le 17\end{cases} \quad (4.33)$$

$$p_7^4=\begin{cases}0, & x\le 13\ or\ x\ge 22\\ \frac{x-13}{4}, & 13\le x\le 17\\ 1, & 17\le x\le 18\\ \frac{22-x}{4}, & 18\le x\le 22\end{cases} \quad (4.34)$$

$$p_7^5=\begin{cases}0, & x\le 18\\ \frac{x-18}{4}, & 18\le x\le 22\\ 1, & x\ge 22\end{cases} \quad (4.35)$$

The set of single index assessment of bending of channels is: P_7=（p_7^1, p_7^2, p_7^3, p_7^4, p_7^5）.

8. Navigation aids

According to the indicator of navigation aids, the complexion rate of navigation marks is the specific indicator. In constructing membership function of navigation aids, the membership grade of navigation aids to five levels of risk degrees is thus available, so as to achieve a comprehensive assessment.

$$p_8^1=\begin{cases}0, & x\le 93\\ \frac{x-93}{4}, & 93\le x\le 97\\ 1, & x\ge 97\end{cases} \quad (4.36)$$

$$p_8^2=\begin{cases}0, & x\le 88\ or\ x\ge 97\\ \frac{97-x}{4}, & 93\le x\le 97\\ 1, & 92\le x\le 93\\ \frac{x-88}{4}, & 88\le x\le 92\end{cases} \quad (4.37)$$

$$p_8^3=\begin{cases}0, & x\le 76\ or\ x\ge 92\\ \frac{x-88}{4}, & 88\le x\le 92\\ 1, & 84\le x\le 88\\ \frac{84-x}{8}, & 76\le x\le 84\end{cases} \quad (4.38)$$

$$p_8^4=\begin{cases}0, & x\le 66\ or\ x\ge 84\\ \frac{84-x}{8}, & 76\le x\le 84\\ 1, & 74\le x\le 76\\ \frac{x-66}{8}, & 66\le x\le 74\end{cases} \quad (4.39)$$

$$p_8^5=\begin{cases}0, & x\ge 74\\ \frac{74-x}{8}, & 66\le x\le 74\\ 1, & x\le 66\end{cases} \quad (4.40)$$

The set of single index assessment of navigation aids is: P_7=（p_7^1, p_7^2, p_7^3, p_7^4, p_7^5）.

9. Traffic complexity

It is hard to quantitatively describe traffic complexity. Fuzzy mood operators are applied in this regard. According to the indicator of traffic complexity, subsets of membership grade of risk degrees of traffic complexity are applied as the single index assessment matrix.

Tab 13 Membership Grade

	V_1	V_2	V_3	V_4	V_5
Simple	0.8	0.2	0	0	0
Relatively simple	0.2	0.6	0.2	0	0
Average	0	0.2	0.6	0.2	0
Complex	0	0	0.2	0.6	0.2
Relatively complex	0	0	0	0.2	0.8

Source: this paper

4.4 Fuzzy Comprehensive assessment

In previous parts of this chapter, single index assessment is conducted. Membership functions are made among nine indexes and five levels of risk degrees. According to the values of indicators of different indexes, the membership grade vector (single index assessment sets) P_i (i=1, 2, 3, 4, 5) is calculated. P_i of every index forms a matrix for fuzzy assessment.

$$P = \begin{bmatrix} p_1^1 & p_1^2 & p_1^3 & p_1^4 & p_1^5 \\ p_2^1 & p_2^2 & p_2^3 & p_2^4 & p_2^5 \\ p_3^1 & p_3^2 & p_3^3 & p_3^4 & p_3^5 \\ p_4^1 & p_4^2 & p_4^3 & p_4^4 & p_4^5 \\ p_5^1 & p_5^2 & p_5^3 & p_5^4 & p_5^5 \\ p_6^1 & p_6^2 & p_6^3 & p_6^4 & p_6^5 \\ p_7^1 & p_7^2 & p_7^3 & p_7^4 & p_7^5 \\ p_8^1 & p_8^2 & p_8^3 & p_8^4 & p_8^5 \\ p_9^1 & p_9^2 & p_9^3 & p_9^4 & p_9^5 \end{bmatrix}$$

The set P represents the fuzzy relationship between the indexes set U and risk levels set V. The membership grade of the index u_i to the level of risk degrees v_j is represented by p_i^j. When the fuzzy weight vector *w* and assessment matrix *p* are known, according to multiplication in a fuzzy matrix, fuzzy mapping is conducted. The fuzzy comprehensive assessment matrix M is available. M is calculated in the following way:

M= W*P

$$= (w_1, \quad w_2, \quad w_3, \quad w_4, \quad w_5, \quad w_6, \quad w_7, \quad w_8, \quad w_9) \bullet \begin{bmatrix} p_1^1 & p_1^2 & p_1^3 & p_1^4 & p_1^5 \\ p_2^1 & p_2^2 & p_2^3 & p_2^4 & p_2^5 \\ p_3^1 & p_3^2 & p_3^3 & p_3^4 & p_3^5 \\ p_4^1 & p_4^2 & p_4^3 & p_4^4 & p_4^5 \\ p_5^1 & p_5^2 & p_5^3 & p_5^4 & p_5^5 \\ p_6^1 & p_6^2 & p_6^3 & p_6^4 & p_6^5 \\ p_7^1 & p_7^2 & p_7^3 & p_7^4 & p_7^5 \\ p_8^1 & p_8^2 & p_8^3 & p_8^4 & p_8^5 \\ p_9^1 & p_9^2 & p_9^3 & p_9^4 & p_9^5 \end{bmatrix}$$

$= (m_1, m_2, m_3, m_4, m_5)$

in which m_j is an indicator for fuzzy comprehensive assessment.

Also,

$m_j = \sum_{i=1}^{9} w_i * p_i^j$ (j= 1, 2, 3, 4, 5).

m_j represents the membership of assessment object to levels of risk degrees.

4.5 Results of assessment

The results gained in 4.2 is a fuzzy vector, reflecting the vague distribution of risk of navigation in waters adjoining to bridges in the set V. weighted means are adopted to abtain final results of assessment. Then, the assessment set V_j is subject to the method of weighted means, which is

$$v = \frac{\sum_{j=1}^{5} m_j \times v_j}{\sum_{j=1}^{5} m_j}$$

Applying all weighted means to assessment set V, the navigation safety in waters adjoining to bridges is hence able to be depicted.

Chapter 5 Assessment of Navigation Safety in Waters Adjoining to Lelong Bridge

5.1 Analysis on navigation environment in the area

5.1.1 Natural conditions

Lelong bridge lies in Shunde, Guangdong. It is in the Pearl River Delta area, south of the Tropic of Cancer. Subtropical climate, combined with moonson climate and maritime climate endowed this region with long time of sun light, richful rain and moisture. It is a region of spring all the year round. Regular wind in winter mainly comes from the north. Strong wind mainly comes from the southeast. Coueses, speed and frequencies of winds are generalized as follows:

Tab 14 Statistics about wind course/speed/frequency

Course Speed	N	NNE	NE	ENE	E	ESE	SE	SSE
Maximum(m/s)	11	12	11	9	12	8	24	7
Average(m/s)	2.9	2.9	2.3	2.7	2.4	2.3	2.6	2.7
Frequency(%)	16	7	3	4	5	6	9	10

Course Speed	S	SSW	SW	WSW	W	WNW	NW	NNW	C

Maximum(m/s)	10	8	5	5	5	10	7	10	
Average(m/s)	2.7	2.7	2.2	2.3	2.1	2.1	2.3	2.7	
Frequency(%)	4	1	1	1	1	1	3	12	15

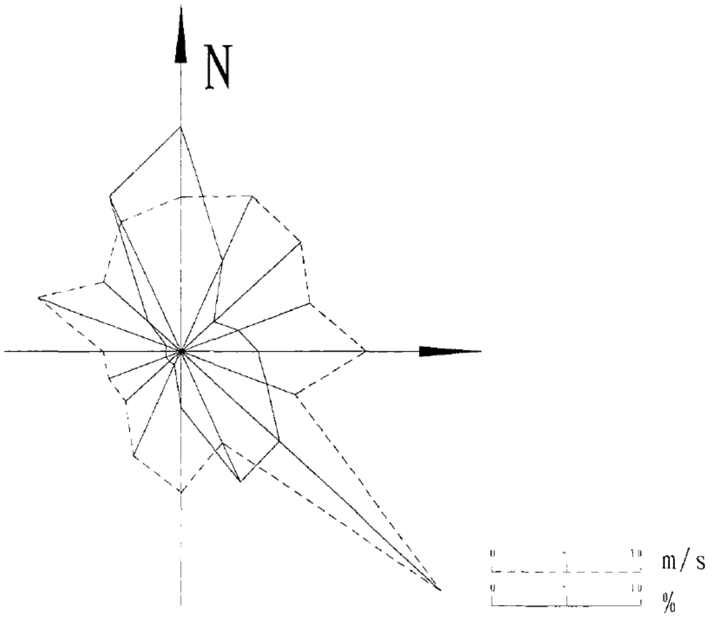

Fig 2 Schematic diagram about the wind course/speed/frequency
Source: selp-made table with statistics from https://www.gdmsa.gov.cn/

In Fig 2, thick lines indicate the frequency of winds and dash lines indicate the speed of wind.

Historically, the average wind speed in a month is 2.3 m/s. The maximum speed in a month is 24 m/s (on 6th, October, 2016). The strongest wind is more than twelve Beaufort scale, equally 33 m/s (on 5th, September, 2010). Courses of wind change significantly in summer and winter. Southern wind prevails from spring to early autumn while north and east wind take the lead from autumn to the end of winter. This region is affected by tsunamis with an average annual frequency of ten times. The maximum wind speed is about 17.2 to 24 m/s.

Fog is a mian factor in Guangdong to have a significant effect on ships. Especially, thick fog greatly reduces visibility. In some cases, going off course, agrounding and collision still happen even though the navigation equipment such as radar is applied. Recent statistics show a trend that fog mainly appears from November to May in the next year, January to April. The average number of days with fog is 9. The average number of days with visibility of less than 1,000m is 38.

Hydrology mostly affects navigation safety by torrents which severely deter the passage of ships sometimes. When there is an angle of a certain degree between longitudinal axis of a ship and the course of torrents, the speed and track of a ship are subject to the effects of torrents.

The speed of a vessel is related with the speed and direction of waters, as well as the course of this vessel. The faster the transverse water flow is, the broader the track of a vessel is. In handling a ship, the best corrected angle should be adopted to offset the effect of water flow. Also, the vessel ought to go at a proper speed to ensure that it sails at the designed course.

5.1.2 Traffic condition

Shunde Channel is located in Foshan, Guangdong Province. The up river is connected with the main stream of Yangtze River and the down part of the river is connected with Hongqili Channel. The navigation condition is fine and traffic is busy. Shunde Channel lies in the Pearl River Delta which is abundant in rivers. It is the artery channel of Nansha Port, trasporting cargoes in large volumes. Also, it is a convenient waterway for the region to be connected to Hong Kong. In a broader sense, it plays an important role in the container transportation in Pearl River. Consequently, the traffic density is significant. According to statistics on traffic density issued by maritme authorities, the overall deadweight of vessels loading or uloading cargoes in Shunde Channel is 23,171,907 deadweight tons in 2016. The volume of passenger traffic in the same year is 3,400,000. Also in 2016, the average number of vessels passing through the channel is 452 per day for inland vessels and 25 per day for seagoing vessels (Kao, 2017). In accordance with the traffic conditions in Shunde Channel and statistics in recent years, the average number of vessels passing through Shunde Channel is about 500 per day. Following figures indicate traffic density arround Lelong Bridge.

Fig 3 Traffic flow of vessels at ebb tide
Source: Chuanxun APP

Types of vessels going through this channel is complicated. In particular, seagoing vessels, ships carrying sands and passenger carriers, due to large tonnage and horse power, are easy to cause accidents. Meawhile, some sailors are not familiar with the channels in this region, which can be disastrous sometimes. Overloading is a severe yet usual phenomenon in such a region, reducing the reserved buoyancy of vessels and hence posing great threats. Vessels without liencenses are usually fragile, vulnerable to wind and S-waves. Devices and wires in such vessels are obselete or overused, leading to poor performance. Consequretnly, mechanic malfunction that happened in such inqualified vessels are frequent, which is harmful to other ships, too. The following figure reveals traffic density in Shunde channel.

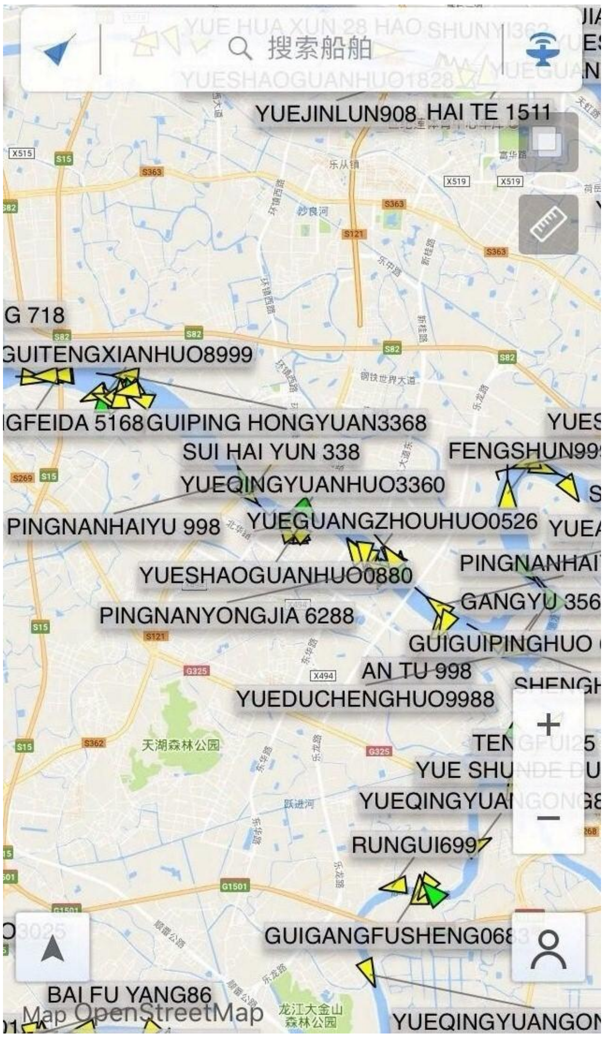

Fig 4 Traffic flow of vessels at high tide
Source: Chuanxun APP

5.1.3 Traffic governance

To ensure waterway safety, traffic governance in waters adjoining to Lelong Bridge is a key responsibility for maritime authorities. Taking into consideration the complicated and busy traffic in water areas, maritime authorities should optimize relevant governance measures. Such areas should be equipped with supervision facilities, in order to guarantee safety. When the bridge is under repairing, warning ships should be placed to meet the requirements of such areas for safety demands (Chen, 2006). Timely monitoring waters adjoining to bridges are another effective approach to safeguard navigation safety.

5.1.4 Bridge conditions

(1) Location of the Bridge

Datum levels of different elements around Lelong Bridges are as follows:

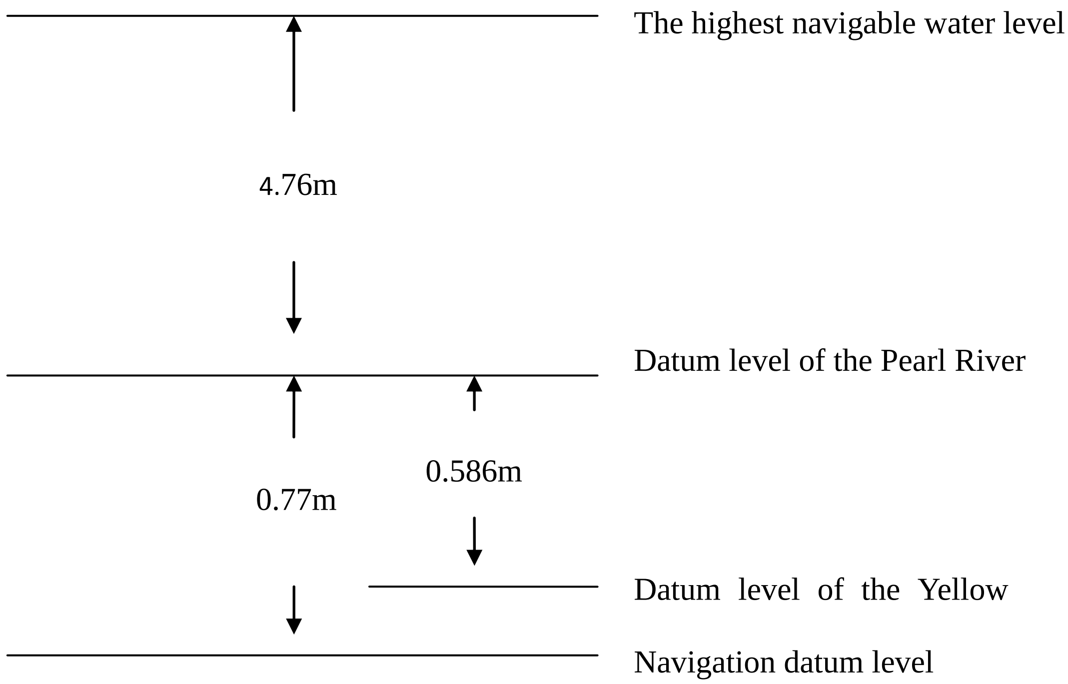

Fig 5 Schematic diagram of datum levels

Source: selp-made table with statistics from https://www.gdmsa.gov.cn/

The highest navigable water level is made according to floods that happened once in twenty years, which in this article is 4.76 m above the datum level of the Pearl River.

Lelong Bridge is located in Shunde Channel, which is classified as the third class according to domestic regulations. The channel is slightly bending and the water flows smoothly and slowly. The river bed is about 530 meters broad. The breadth of the river is about 470m normally. The average depth of the channel is 15m. The breadth of 4m depth contour is 384m. Scouring can be found in 500 meters up the river, and in the bridge location, scour depth is about 1 to 2 meters. In 500 meters down the river, scouring is not severe, with a depth of 0.5 meters (Zheng, 2017). In general, apart from human activities, the river in which the bridge is located has a balanced scouring and sedimentation.

Surrounding areas of Lelong Bridge are mainly aqua farms, planned as lands for agriculture. Some parts are residential areas. On the left bank, about 700 meters upriver, there lies a simple dock for loading sands. On the left bank, about 3,000 meters upriver, there lies Lecong Dock.

On the right bank about 570 meters upriver locates Geluo Water lock. On the left bank about 877 meters downstream is Shengyuan Water lock and 500 meters lays Dongfeng Water lock. Flood discharges in the aforementioned dams have little effect on navigation in this area.

There are 1.8 bridges in every 10 km in Shunde Channel. Longjiang Bridge is located in 4.5 km upstream and 0.6 further in the same direction lays Longjiang Second Bridge.

(2) Arrangement of the Bridge

The bridge is placed in plateau sediment by the Pearl River. The land is flat. The bridge belongs to part of Shunde Channel, which is slightly bending. The breadth of the river is 470 m, and the depth of water is 15 m. The angle between the longitudinal axis of the bridge and course of torrents is about 6° . There are two navigable openings. The span combination is (3*30) + (4*30) + (40+50+40+40) + (60+2*100+60) + (40+50+50+40) + 2*(3*30). The net height of navigable openings is 10m and the net breath is 75m. The upper breadth of the top is 56m and the side height is 6 m. The highest navigable water level designed is 4.76m (datum level of the Pearl River). Main types that can pass through Lelong Bridge are as follows:

Tab 15 Typical vessels passing the bridge

serial	Tonnage of ships	Sizes(L*B*D)

number		
1	Normal inland cargo ship of 1000 MT	58*12.6*2.6
2	Containerships of 1000 MT	49.9*15.6*2.8
3	Bulk cargo carrier of 1000 MT	49.9*12.8*3.0
4	Liquefied cargo carrier of 1000 MT	49.9*13.2*3.2
5	Sand carrier of 1000 MT	58*12.8*3.2

Source: selp-made table with statistics from https://www.gdmsa.gov.cn/

According to *Inland Navigation Standard*, the navigation requirements of inland vessels of 1,000 MT (L*B*D=49.9m*15.6m*2.8m) are calculated as follows:

$$B_{m1} = B_F + \Delta B_m + P_d$$

$$B_F = B_s + L\sin\beta$$

The required net breadth for navigation of vessels is figured out as follows:

$$B_F = B_s + L\sin\beta$$

$$= 15.6 + 58 \times \sin 6°$$

$$= 21.67 \text{ (m)}$$

$$B_{m1} = B_F + \Delta B_m + P_d$$

$$= B_F + 0.6B_F + P_d$$

$$= 1.6 \times 20.82 + 15$$

$$= 48.31 \text{ (m)}$$

There are two openings in the bridge with a net breadth of 75m, in order to meet the demand of inland vessels passing through bridges with two one-way openings.

5.2 Assessment system of navigation safety in waters adjoining to Lelong Bridge

Taking into account what is discussed previously, on the basis of data collection and consultations on experts, the values of indicator of every index are revealed as follows:

Tab 16 Assessment systems in the area

index	indicator	value
Wind u_1	Days with standard wind per year	80

Depth of water u_2	H/d	4.0
Torrents u_3	Speed of torrents	2.0
Dimensions of navigation clearance u_4	Ratio of net breadth of bridge openings to breadth of vessels	4.2
Visibility u_5	Days with poor visibility per year	54
Traffic density u_6	Ratio of actual traffic density to designed density	0.95
Bending of channels u_7	Cumulative steering angle	10
Navigation aids u_8	Completion rate of navigation marks	90
Traffic complexity u_9	Fuzzy assessment	Average

Source: selp-made table with statistics from https://www.gdmsa.gov.cn/

Risk degrees of indicators are represented in 3.2.2 as safe, relatively safe, average, relatively dangerous, and dangerous respectively. The set V is composed as:

V= (v_1, v_2, v_3, v_4, v_5).

Weights of indicators are ciphered out in 3.2.3 as:

$$W = (w_1, w_2, w_3, w_4, w_5, w_6, w_7, w_8, w_9) \\ = (0.20, 0.17, 0.15, 0.12, 0.10, 0.09, 0.06, 0.06, 0.05)$$

5.3 Assessment of navigation safety in waters adjoining to Lelong Bridge

According to the value of indicators put forward before, taking into account membership grade function or fuzzy membership subset in 4.1, a single index assessment is conducted. Single index assessment of the previous eight indexes is as follows：

According to the membership grade vector of indicator of index, the matrix of fuzzy relation is listed as follows:

$$P = \begin{bmatrix} P_1 \\ P_2 \\ P_3 \\ P_4 \\ P_5 \\ P_6 \\ P_7 \\ P_8 \\ P_9 \end{bmatrix} = \begin{bmatrix} 0 & 0 & 1 & 0 & 0 \\ 0.5 & 0.5 & 0 & 0 & 0 \\ 0 & 0.5 & 0.5 & 0 & 0 \\ 0 & 0.1 & 0.9 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 1 & 0 & 0 \\ 0 & 0.5 & 0.5 & 0 & 0 \\ 0 & 0.5 & 0.5 & 0 & 0 \\ 0 & 0.2 & 0.6 & 0.2 & 0 \end{bmatrix} =$$

P1= (0, 0, 1, 0, 0)

P2= (0.5, 0.5, 0, 0, 0)

P3= (0, 0.5, 0.5, 0, 0)

P4= (0, 0.1, 0.9, 0, 0)

P5= (0, 0, 0, 1, 0)

P6= (0, 0, 1, 0, 0)

P7= (0, 0.5, 0.5, 0, 0)

P8= (0, 0.5, 0.5, 0, 0)

P9= （0,0.2,0.6,0.2,0）

Multiplication is conducted in the matrix, which is a converter for a fuzzy comprehensive assessment:

$$M = W \bullet P$$
$$= (0.166, 0.2, 0.5, 0.2, 0)$$

According to maximum membership grade law, the risk degree of navigation in waters adjoining to Lelong Bridge is “average”.

Chapter 6 Conclusion

This article notes that the construction and designing of bridges do not take into account features of navigation in waters adjoining to bridges though the economy and society are developing. Such conditions in return deteriorate navigation environment in such kind of areas, deterring navigational advancement herein. This thesis hence investigates navigation safety in such areas. Firstly, the development in the academic arena is overviewed, in which research method is chosen. After that, analysis on indexes affecting navigation safety in this regard is checked, and a system of indicators for the assessment of risk degrees is set up. Then, in accordance with the importance of every index in affecting navigation safety is made clear, with introduction of consultations on experts, fuzzy membership function is formulated, which is afterwards used in fuzzy comprehensive assessment to set up a model, in order to evaluate the risk degrees of navigation in bridge waters. This model can be utilized to analyze the navigation conditions in such areas, so as to have a fair command of safety conditions in such areas. It sheds light on the choice of locations of new bridges and relevant discussions on navigation.

The model in this article is formulated in accordance with researches and studies of many scholars and experts, containing as large as possible indexes that affect navigation safety in such waters. Nevertheless, with the aim to simplify and make convenient calculations, indexes of wind and torrents are concerned only from the perspective of speed, ignoring wind courses and water directions. The result hence may be affected in this regard. In other conditions, indicators of wind and torrents can be enriched for more precise results.

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APPENDIX: A

Tab. 2 Questionnaire for advice of experts

To whom it may concern:

In order to have an objective and comprehensive evaluation on the importance of factors affecting navigation safety in waters adjoining to bridges, we invented this table. In accord with your rich experience and knowledge, please finish the below table. If you think the two factors are equally important, then please fill in the numeral “0.5”, “1” for more important and “0” for less important.

Thanks for your taking time.

indexes	wind	visibility	depth of water	torrents	bending channels	navigation aids	dimensions of navigation clearance	traffic density	traffic complexity	T
wind	0.5	1	1	1	1	1	1	1	1	8.5
visibility	0	0.5	0	0	1	1	0	1	1	4.5
depth of water	0	1	0.5	1	1	1	1	1	1	7.5
torrents	0	1	0	0.5	1	1	1	1	1	6.5
bending channels	0	0	0	0	0.5	1	0	0	1	2.5
navigation aids	0	0	0	0	0	0.5	0	0	1	1.5

dimensions of navigation clearance	0	1	0	0	1	1	0.5	1	1	5.5
traffic density	0	0	0	0	1	1	0	0.5	1	3.5
traffic complexity	0	0	0	0	0	0	0	0	0.5	0.5