Maritime Safety & Environment Management Dissertations

Maritime Safety & Environment Management

8-28-2016

Research on safety evaluation of navigation environment in Hangzhou Bay Bridge

Ning An

WORLD MARITIME UNIVERSITY

Dalian, China

RESEARCH ON SAFETY EVALUATION OF NAVIGATION ENVIRONMENT IN HANGZHOU BAY BRIDGE

By

An Ning

The People's Republic of China

A research paper submitted to the World Maritime University in partial fulfillment of the requirements for the award of the degree of

MASTER OF SCIENCE

(MARITIME SAFETY AND ENVIRONMENTAL MANAGEMENT)

2016

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.

(Signature):   An Ning

(Date):   Aug 3rd, 2016

Supervised by:

Fan Zhongzhou

Professor

Dalian Maritime University

Assessor:

Co-assessor:

I also expect to express my sincere thanks to my colleagues at Jiaxing MSA. My absence from work for MSEM program increased their workload and the research itself would not have been possible without their contribution.

Last but not the least, my deepest gratitude goes to my wife and mother for their encouragement and support throughout the study, and for inspiring me to complete this project.

ABSTRACT

Title of Research Paper: **Research on Safety Evaluation of Navigation Environment in Hangzhou Bay Bridge**

Degree: Msc

Hangzhou Bay Bridge is one of the important navigation elements in Jiaxing Port, especially facing Jiaxing Port Area of strong tidal and non-sheltered waters. Ship collision which may cause collapse of the bridge or other serious damages occurs frequently. The damage of the ship's collision with the bridge may be great; it will cause huge economic losses and casualties, and it could bring negative political influence and serious environmental damage. Therefore, it has important practical significance to study on the safety risk of navigation in the bridge area.

This dissertation will aim at the bridge area safety factor of the ship navigation to carry on the analysis, through the analysis of the surrounding traffic environment, for example: human factors, tidal factors, anchorage factors and bridge area navigation factors and so on. At the same time, this study will use the queuing theory to calculate the capability of ship navigation and FAHP method to get bridge area risk level by the numerical analysis, and will analyze the existing problems and put forward some suggestions for ship navigation safety management, so as to avoid the occurrence of accidents in the bridge area.

Keywords: Hangzhou Bay Bridge; Navigation safety factors; Collision avoidance; Queuing theory; FAHP;

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

AIS   Automatic Identification System

CCTV   Closed Circuit Television

ETA   Estimated Time of Arrival

FAHP   Fuzzy Analytical Hierarchy Process

HZ   Hangzhou

IMO   International Maritime Organization

JX   Jiaxing

MSA   Maritime Safety Administration

VTS   Vessel Traffic Service

SAR   Search and Rescue

1 Introduction

1.1 Research background

Jiaxing Port is located in the south wing of the Yangtze River Delta, north shore of Hangzhou Bay, which is one of the four major coastal ports in Zhejiang Province; it is also a first-class open port. Hangzhou Bay Bridge is now faced with safety pressure of potential accidents, the contradiction between navigation safety and maritime traffic safety risk becomes more and more obvious.

This paper aims to analyze main factors that affect navigation safety the water area around the Hangzhou Bay Bridge, and to study the basis of both safety and development, to put forward suggestions on risk prevention and control measures afterwards, in order to improve the navigation management level, to reduce the traffic safety risk, and to boost the development of the marine economy.

1.2 Current Situation of domestic and Foreign Research on Navigation Environment

On the environmental assessment of navigation, the experts have done a lot of theoretical research work at home and abroad. According to the region, they can be divided into three parts: research done by the European and American experts, Japanese experts, as well as domestic experts' research result. They are to be discussed as follows.：

1.2.1 Research on Navigation Environment in other countries

We find that the navigation environment safety evaluation work abroad,mainly included Europe and Britain,which are the representatives of tradonal shipping

powers. The Japanese scholars' study on marine traffic safety field is in a leading position in the world.

Britain's research focuses on the role of management. Vladimir M Trbojevic and Barryj Carry put forward the port navigation safety management system based on the risk degree. First of all, they make the ship traffic safety evaluation, and then they put forward the improvement project management.

In Japan's research，the Japanese experts mainly use simulation technology, the sea traffic flow and the operation of the ship environment simulation.

1.2.2 Current situation of domestic research on navigation environment

Compared with the developed countries, China started its research late both in terms of depth and breadth. But in recent years, there have been much research results in the field of ship navigation environment.

Professor Chen Weijiong has made a navigation tetrahedron structure model of environment as shown in Figure-1, which consists of interconnected "People-Ship-Navigation environment-Management" four factors, shipping and evaluation provide a framework support.
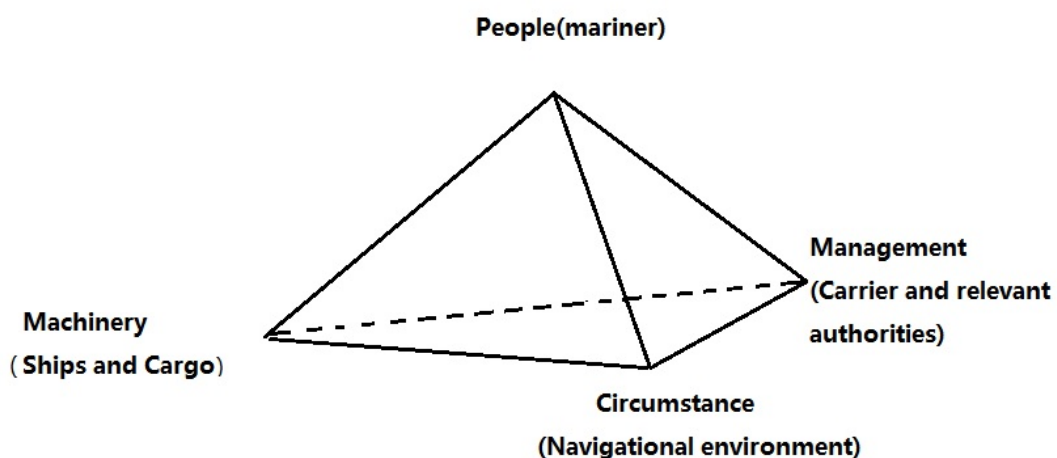
Figure1 System model of people-machinery-circumstance-management

Professor Wu Zhaolin proposes the use of "Safety Index Method" for safety evaluation; the method introduces the use of traffic accidents and we can use traffic volume ratio to measure the traffic safety situation, so as to increase the horizontal and vertical comparability. The introduction of the concept of integrated conversion accident number and standard provides a theoretical reference for the quantitative study of ship navigation safety.

He Huiguang proposes that the marine traffic environment includes three aspects: navigation area, the natural condition and the traffic condition. The risk classification of the maritime traffic environment includes the environmental factors, from "Very dangerous" to "almost no danger".

Professor Zheng Zhongyi applied factor analysis method based on environmental factors data of nine ports, integrated factor scores and port traffic accident number into linear regression. Regression equations were obtained, and the regression equation coefficients of each factor determine the effective degree of different environmental factors on port traffic accidents.

Shao Zheping proposes application way in simulation of control theory and method of fuzzy inference system based on established maritime traffic safety evaluation of FIS model in the doctoral thesis of the maritime traffic safety evaluation model, and this model provides a practical way for the realization of the maritime traffic safety dynamic assessment, his research has improved from static evaluation to dynamic evaluation process.

1.3 Research methods and technical routes

This dissertation is mainly about the Hangzhou bay bridge waters. By using VTS monitoring system data and analyzes relevant information,this article will explore the current Jiaxing Port area traffic conditions,and do some research on the accident statistics analysis, and analyzes the main safety risk. The data about port planning and related requirements were collected from the terminal companies, shipping companies and the bridge owners. The collected data were analyzed. It has made a study on the port development planning, and makes predictions on infrastructure needs. It will analyse problems and put forward countermeasures. The technical route of the research subject is shown in Figure-2.
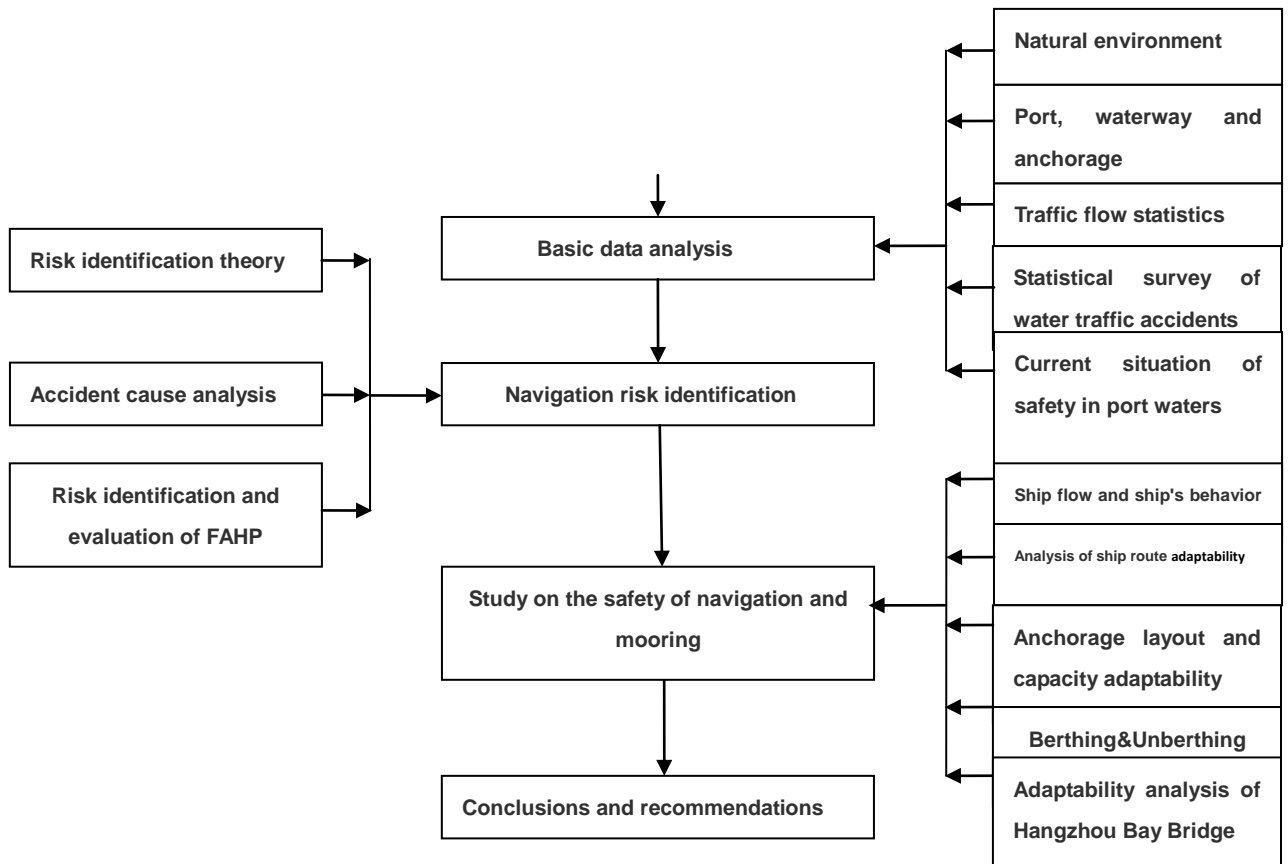
Figure-2 Technology Roadmap

1.4 The organization of this paper

1.4.1 An introduction to the basic situation of safety evaluation theory and evaluation system in Jiaxing Port waters.

1.4.2 We sent questionnaires to experts in the shipping industry and collected the results of questionnaire statistics. We determine the effect of the evaluation index system and the index important degree, The queuing theory was used to calculate the capability of bridge navigation and risk level was determined on the basis of the weights which was figure out using the Fuzzy Analytical Hierarchy Process (FAHP) method.

1.4.3 For safety problems of the bridge, this study will put forward some suggestions for ship navigation safety management, so as to avoid the occurrence of safety accidents in the bridge area.

Chapter 2 Analyses of navigation environment and traffic conditions of Hangzhou Bay Bridge

2.1 Analysis of the Bridge condition

Hangzhou Bay Bridge begins from Haiyan ZhengJiaDai to Cixi Water Bay, its total length is 36 km, the bridge has north and south navigable holes, and the expected highest water level is 5.19 m (1985 National elevation datum); North Main Navigable holes clearance height is 47 m, navigable clear width is 325 m and the designed navigable ship is GT 35,000. The south navigable hole clearance height is 28 m, navigable clear width is 110 m; South navigable hole clearance height is 31 m, navigable clear width is 250 m and the designed Navigable Ship is GT 3000. (China route guide, 2008)Temporary anchorage of Zhapu Port Area and the bridge distance is very close; the nearest distance is only 0.8nm.
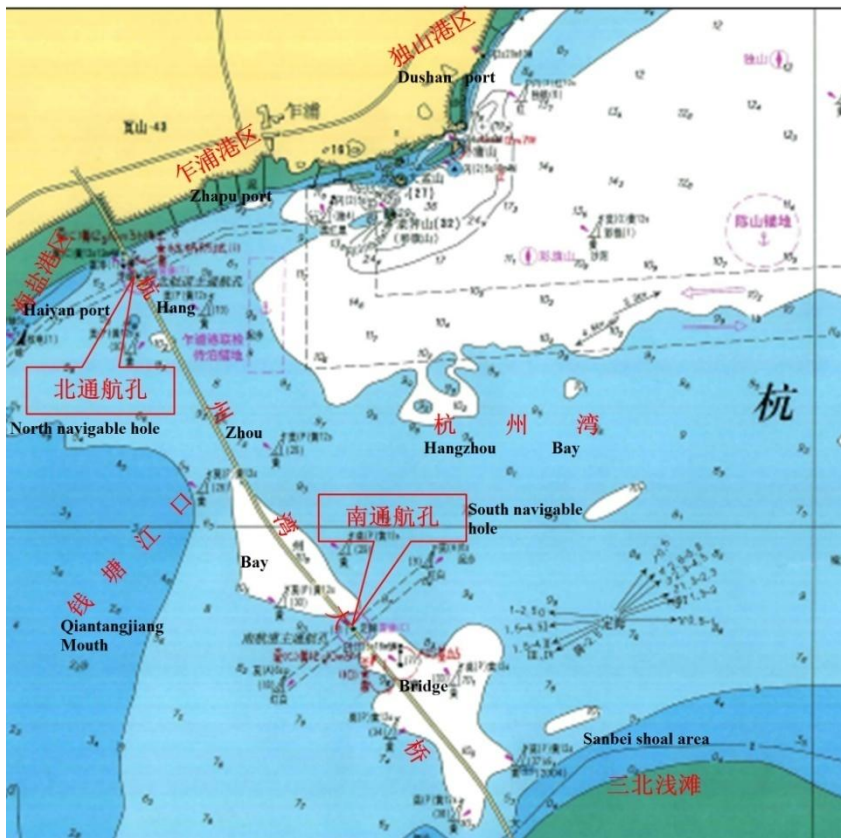
Figure-3 Hangzhou Bay cross-sea bridge map (China route guide, 2008)

2.2 Statistics and analysis of Traffic flow

2.2.1 Analysis of current ship flow in Jiaxing port area

Table-1 Statistics on the number of ships arriving at the port

Year	Ships numbers	Cargo throughput (million ton)
2010	8112	44.33
2011	9498	52.58
2012	12922	60.04

2.2.2 Statistical analysis of ship traffic flow

According to Jiaxing VTS center statistics show, from Jan 1st - Dec 31st 2012, there are 12,922 ships through the east line, through which 1455 ships carry dangerous goods.
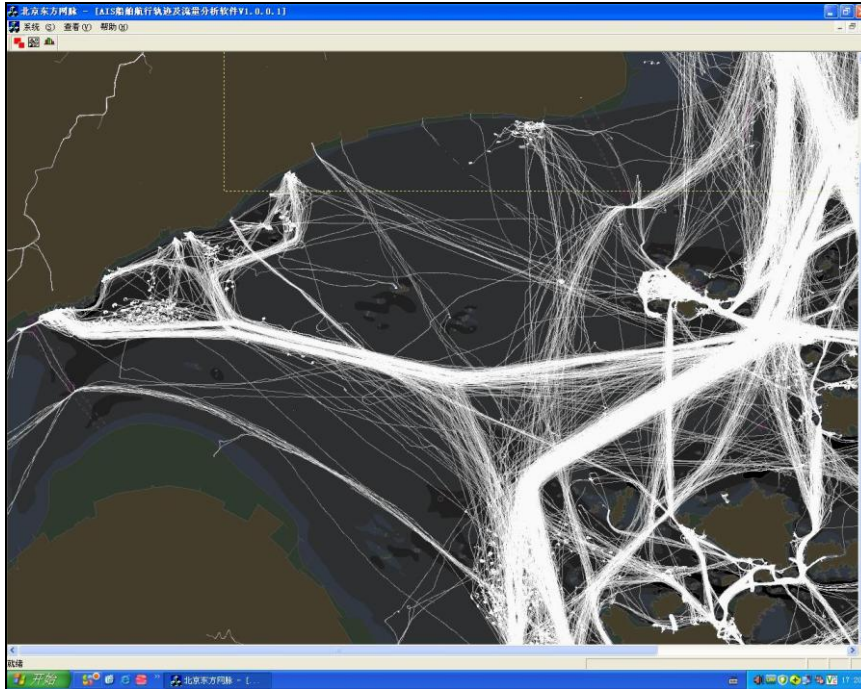
Figure-4 AIS track diagram of the ship in jiaxing area in June 2013
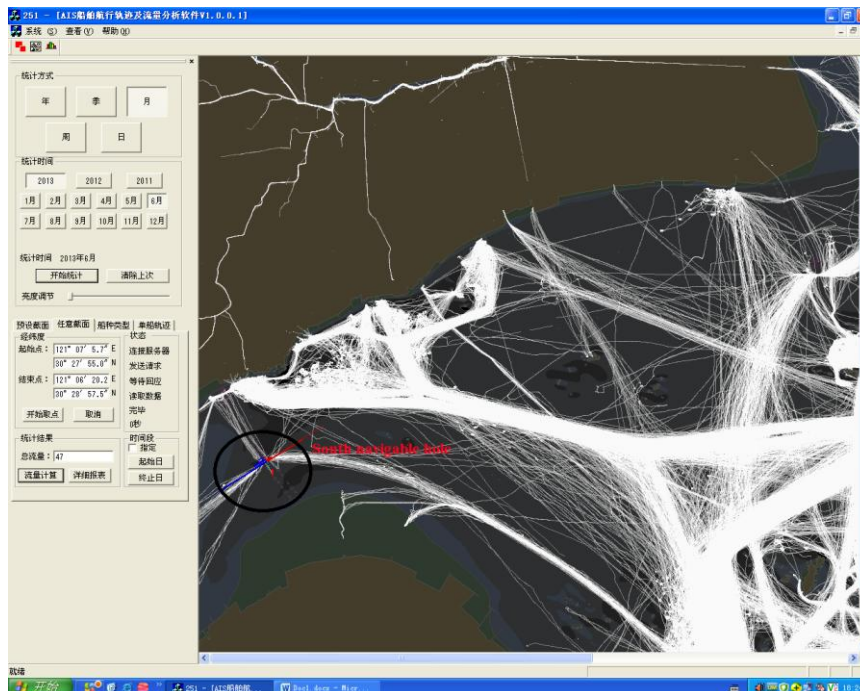
Figure-5 Hangzhou Bay Bridge, The south navigable hole track diagram of the ship

Table-2 The navigation data near the Hangzhou bay bridge (2013.06)

Channel	Date	ships	Entering ships	Depature ships	Passenger ships	Tankers ships	Dangerous Goods ships
Jinshan	2013.6	1242	623	619	0	546	4
Hangzhou bay Bridge		19	10	9	0	0	0
South		47	20	27	0	0	0

navigation hole						

2.3 Safety analysis of Port waters

2.3.1 Pilot

Jiaxing port pilot station has the registered pilots eight, unberthing is responsible for navigation in the waters and the foreign ships need to compulsory pilotage, and they accept Chinese ship pilotage application, and they can provide pilotage service.

2.3.2 Tug

There are 9 tugs in Jiaxing port.

2.3.3 AIDS to navigation
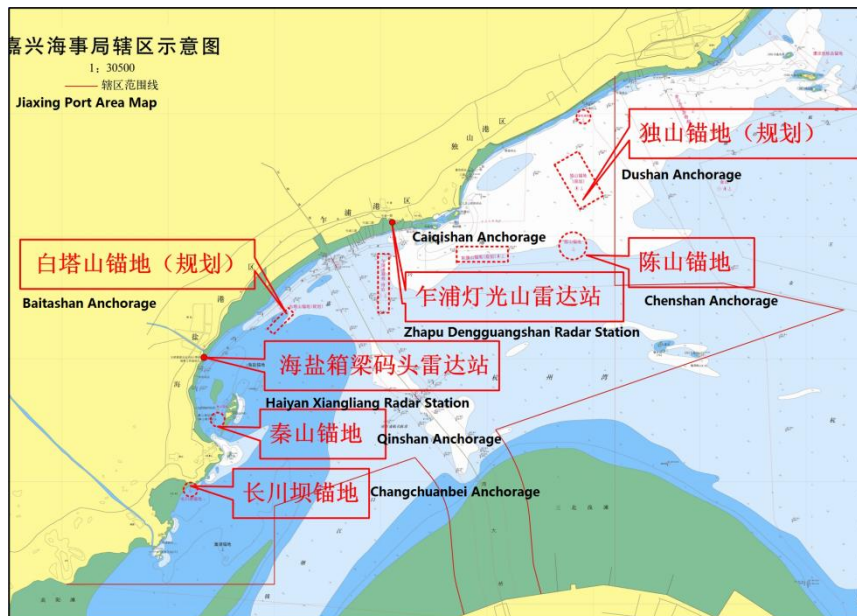
Figure-6 Jiaxing port radar station (China route guide, 2008)

2.3.4 Traffic safety management situation

Jiaxing Port is managed by Jiaxing MSA in implementing maritime supervision and service, which is a competent authority for safety surveillance and pollution control, ships and offshore facility inspection, maritime security management and maritime search and rescue mission.

Charpter 3 Accident statistics

3.1 Risk identification theory

The risk identification of Jiaxing Port is a complex system composed of many factors, which is organic combination of "the people - ship - environment – management". Risk identification is the basis of risk aversion, and based on qualitative analysis of various risk factors and experience judgment, we can evaluate object hazards or accident source, type, and degree of possible danger. In this way we can find out its main hazards.

Each link of the shipping process is affected by various objective factors and restrictions. Through analyzing natural factor, navigation factor, ship factor, personnel factor, we could get insight of traffic management of Jiaxing Port.

3.2 Based on the risk identification and analysis of the accident

3.2.1 Accident of Hangzhou Bay Bridge

Since the construction of Hangzhou Bay Bridge in 2003, three accidents have occurred. Details are as follows:

a．Accident-1: Around 12 April 2005, "Zhepu 8208" round in the construction of Hangzhou Bay Bridge waters crashed C22 pier of Hangzhou Bay Bridge, which resulted in severe inclining of ship. Ships capsized, four crew members swam onto the raft, a crew member jumped onto the pier. After the rescuing of all crew members, this accident had led to economic losses of nearly 27.5 million RMB.

b. Accident-2: Aug 11,2006, Singaporean "asphalt express" vessel anchored in

temporary anchorage of Zhapu Port, the ship was out of control and crashed into Hangzhou Bay Bridge, damaging a bridge prestress, replacement of the beam and slab, direct economic losses amounted for more than 9.80 million RMB, which became a serious water traffic accident.

Figure-7 Accident photo-1

Figure-8 Accident photo-2

c. Accident-3: Around 12 Sep 2010, "ZheSheng 89003" crashed into loading and unloading points of downstream bridge 500 meters in the process of touch of Hangzhou Bay Bridge F04-Pier (30°25′.241N/121°09′.580E), no casualties, no serious damage, which became an accident of the general level.

In recent five years, there are 13 water traffic accidents, including 2 ship sinkings cases, no mortality. Direct economic losses of the four accidents are shown in the table-3 in 2008-2012. The type of accident as detailed in table-4 in 2008-2012, and the type of accident distribution diagram detailed in 2008-2012 figure-7.

Table-3 Accident four indicators in 2008-2012

Index year	The number of accidents	Wreck Number of ships	Number of deaths and missing	Direct economic loss (Ten thousand RMB)
2008	0	0	0	0
2009	4	1	0	394.1
2010	3	1	0	325.2
2011	5	0	0	596
2012	1	0	0	293
Total	13	2	0	1,608.3

Table-4 The distribution of accident types in 2008-2012

Year ⟍ Type	2008	2009	2010	2011	2012	Total
Collision	0	0	1	1	0	2
Be stranded	0	1	0	0	0	1
Contact damage	0	0	0	0	0	0
On the rocks	0	3	2	4	1	10
Wave damage	0	0	0	0	0	0
Fire / explosion	0	0	0	0	0	0
Sink	0	0	0	0	0	0
Other	0	0	0	0	0	0
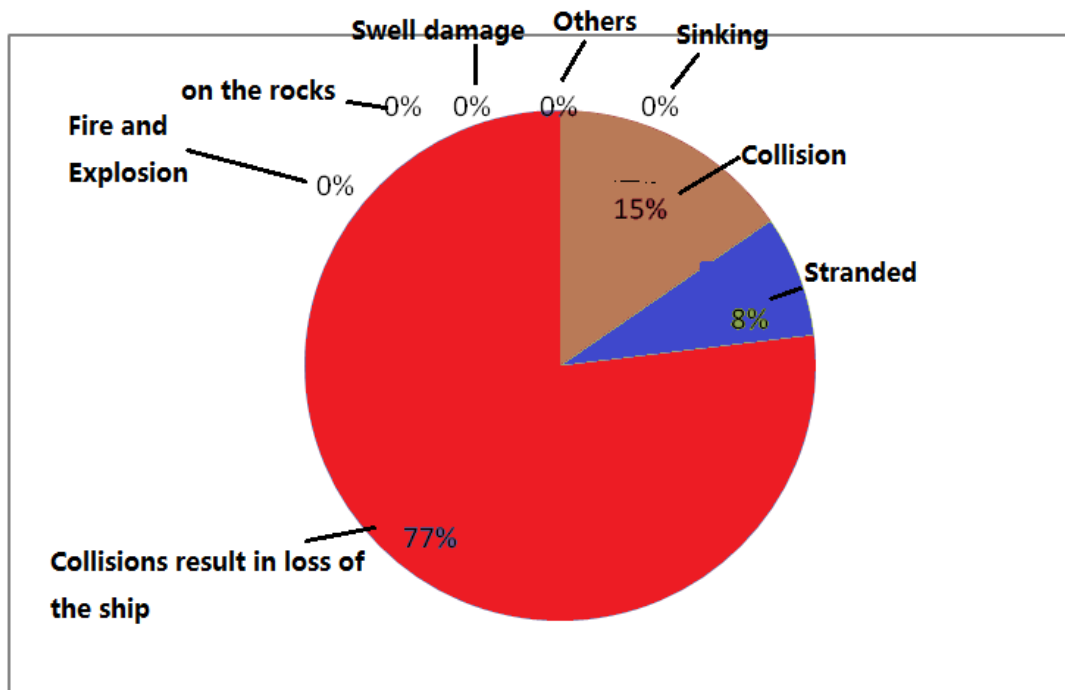
Figure-9 Accident species distribution map (2008-2012)

3.3 The distribution of accident types

Contact damage is the major type, with a total number of 10, accounting for 77% of all accidents, 8 accidents occur in berthing and unberthing, accounting for 61.5% of the total number of accidents. Other types of accidents are 2 crashes, 1 stranded, and there is no obvious distribution characteristic.

3.4 The regional distribution of the accidents

Accidents are mainly regional distributed in Zhapu Port, with a total number of 9, of including 8 are contact damage accidents and 1 collision accident; in Dushan Port waters occurred 2 accidents, 1 was grounding, and the other is contact damage occurred in the working process of the water industry; one of the accidents caused damage to the bridge; 1 crash occurred in Chen Shan anchorage.

Chapter 4   Analysis of Hangzhou Bay Bridge navigation situation

4.1 A profile of Hangzhou bay cross-sea bridge

Hangzhou bay bridge is one of the world's longest cross-sea bridges, with its length 36 km, two-way six lanes and the speed limit of 100 km/h. Its design working life is 100 year; a total investment is about 13.8 billion RMB. The construction began in November, 2003, and opened on May 1, 2008.
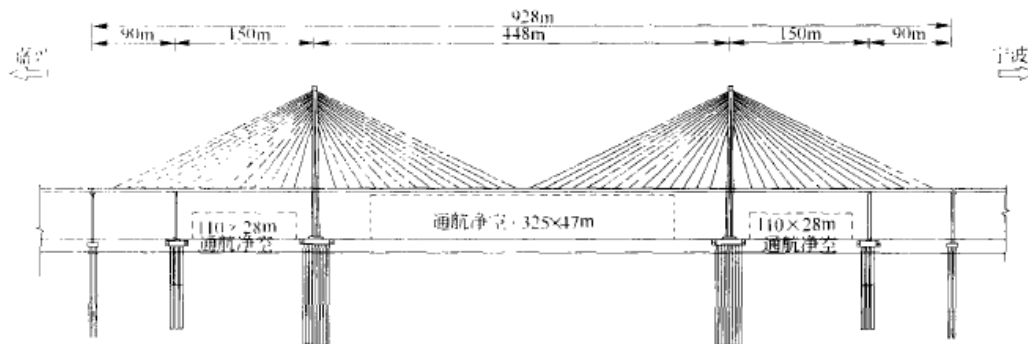
图 3   北航道桥桥跨布置图

Figure-10 The North Navigation Hole Arrangement Map(Lv Z.D,2004)

4. 2 Hangzhou bay cross-sea bridge capacity analysis of the ship

Firstly, the basic theory is queuing theory, which is also known as the theory of random service system. It is devoted to the study on the influence of random factors of overcrowding, a discipline, it uses the research of service system in the queue waiting probability characteristics to solve system's optimal design and optimal control problem.

Queuing theory is an important branch of operational research, which is also known as the application of probability, it has a strong practical background, which

originated in the early 20th Century when Danish Telecom engineer A. K. Erlang of Telecom is researching the crowded system.He published an article entitled " the Probability and telephone conversation theory ", which has created a history of queuing theory. After nearly a hundred years of efforts of mathematicians and operational research experts, queuing theory has become a mature theory, there have been thousands of literatures concerning this theory. With the rapid development of computer technology and queuing theory is changing, with its applications diversitied. At present, queuing theory has been widely used in many fields, such as telecommunications, transportation, production and inventory management, computer system design, computer network system, military operations, flexible manufacturing system. Fruitful results were achieved, and it has become an important mathematical tool for the engineering, management and technical personnel in system analysis.

General queuing process can be described as: customers in order to get certain service and arrive at the service facilities.If the service desk is occupied, they cannot be serviced immediately, but customers are allowed to wait in line, waiting to join a queue. After services they will leave the system immediately. From the point of view, the queuing system has three basic characteristics: the input process, the service organization, and the queuing rules. (Hiroaki, 1993)

4.2.1 Input process

Customers in processing are called input process queuing system. In this process, the source of customers reaching the queuing system is various, customers are generally not limited, or it is infinite. The customer arrival distribution can be continuous or discrete. Arrival may be single or a batch arrival. The interval time of coustomer arrival may be determined by the types or models of the queuing system. The arrival

of the customer may be independent of each other; however they may also be interrelated. The input process is the basic characteristics of the customer arrival time interval probability distribution.

Generally, we can use some typical distributions to discribe an arrival interval time and service time distribution, such as: M is negative exponential distribution or Poisson distribution; G is the general random distribution; D is to determine the type of distribution.

4.2.2 Service agencies

Service organizations contain the service station number and accept service of the number of customers and service time and service mode, these factors are uncertain, and the number of service station and service time is the main factors.

4.2.3 Queuing rules

Queuing Rules refers to the rules from the queue selection of customer service and common service rule is "first come, first serve", namely according to the arrival sequence to receive services, to reach the customer to accept service. Other rules include "to first service, stochastic service" and the "priority service".

In order to describe a queuing system simply and clearly, D. g. Kendall (1953) introduced a set of symbols, he separated by a slash of three letters to illustrate the basic features of A queuing system, name is A/B/C, among which A stands for the customer arrival time interval probability distribution; B is the service time probability distribution and C is the reception desk. We all knew the basic model of the queuing system, the symbols as shown in Figure-11. It contains the following conventions: there is no limit to the number of customers overall, individual customers arrive; queuing rule is "first come and first service". (Kendall, 1960)
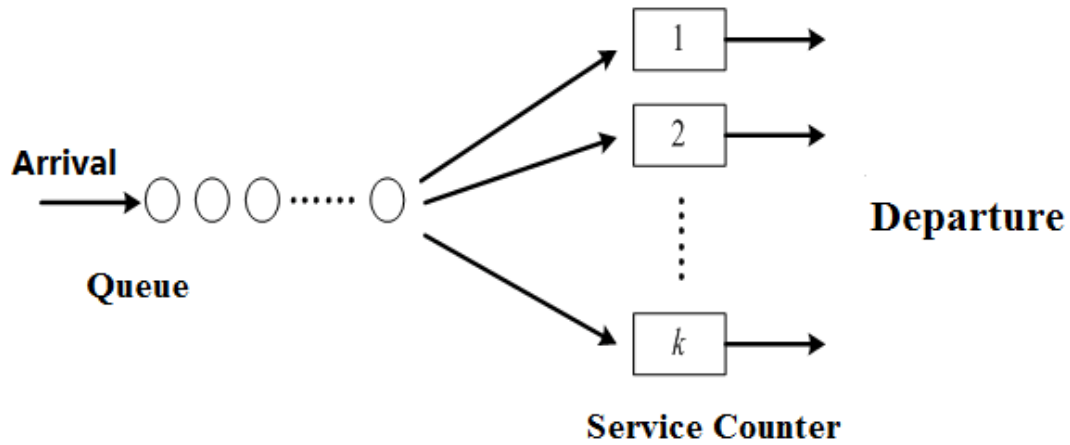
Figure-11 The general model of queuing process

The main basic characteristics of the queuing system are as follows:

a. Queue length

The number of customer waiting in the system is called queue length, which is the average value of the number;

b. Length

The total number of customers in the system called length, which is equal to the queue length and the sum of the expected number of customers in receiving services. Representation of its mean value is Lq.

c. Waiting time

At the moment of customers enter the system, they began to receive the service the period of time between their entries and receiving service, which is the queue waiting time; they are usually expressed in Wq, which represents average waiting time.

d. Residence time

Time that customers are in the system, it is equal to the queue waiting time and accept the sum of service time. The average time is W.

Queuing models often uses the following symbols:

λ —Average arrival rate, the number of customers arriving per unit time;

μ —Average rate of service, that is the number of customers receiving services per unit of time;

k —Number of parallel service stations;

$$\rho = \frac{\lambda}{\mu}$$ —Service intensity.

4.3 The calculation of the water line parameters in the bridge area

4.3.1 Ship domain model

In road traffic, a car always keeps a certain distance from the vehicle in front of it .This distance between the front and back vehicle in this interval should be long enough before a car reached the margin of safety. Besides the distance and speed, the car's braking performance, the driver's reaction ability and other factors are also of great importance. From the safety point of view, this distance interval has become a basic data for estimating the capacity of a road traffic or traffic capacity. (Inoue, 2000)

For this reason, a certain distance should be kept between ships that meet at sea or the front and back of the same channel. Because the motion of the ship is in the two-dimensional space (plane), it can be considered that there is a safe area around the ship. Inspired by the research results of road traffic engineering, the famous scholar Fujii, who started the research on the traffic capacity of a waterway in 1963, puts forward the concept of the ship's field. He defines the field as the first, the officers of the ship is to avoid entering the area around the ship.(Kendall,1960)
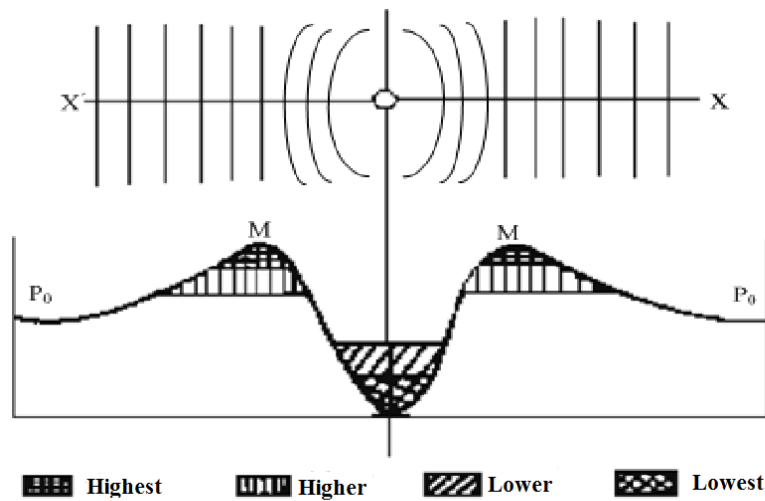
Figure-12 Determination of ship domain boundaries in the open channel (Inoue, 2000)

To determine the boundary in the field of ship, Dr Fujii studies a uniform density of traffic flow channel of an obstacle.

As shown in figure-12, the channel has a uniform density of traffic flow from a distance. Due to the presence of obstacles in the channel, the flow of traffic through the obstacles in the flow line has changed.

Along the cross section of the X - X ' line of traffic flow density was changed, as the diagram in the lower part of the curve, therefore, it will be obstacles on both sides of the traffic in the vicinity of the current density reached the maximum values of the two M points known as the obstacle of domain boundaries. If the obstacles are seen in front of overtaking ships, M point is on the boundary of the domain of the ship.

Obviously, the traffic flow of uniform density in the density in the obstacles or change of a ship density is the next factor for the ships to decide to take an evasive action. From a safe leeway to consider, the next ship steps aside not obstacles or before the ship itself, but a part of waters around them is the ship's field. The size or

location of the ship's field is directly related to the safety of the subsequent vessel's intention to maintain.

Dr Fuji did experiments to marine traffic investigation and ship's relative position of two dimensional frequency distribution analysis many times in Japan's coastal waters. He puts forward ship model in the field, namely ship (give way vessel) as the center, semi-major axis is along the center line direction, and short half shaft is the beam of an ellipse. Specific dimensions are related to such factors as the ship speed, density and tides in the field of ship.

The field scale of overtaken ship sailing conditions is 8L and 3.2L. When a ship sails within the port, it needs to slow down in the narrow channel; the field of ship scale is reduced to 6L and 1.6L, as shown in figure-13.
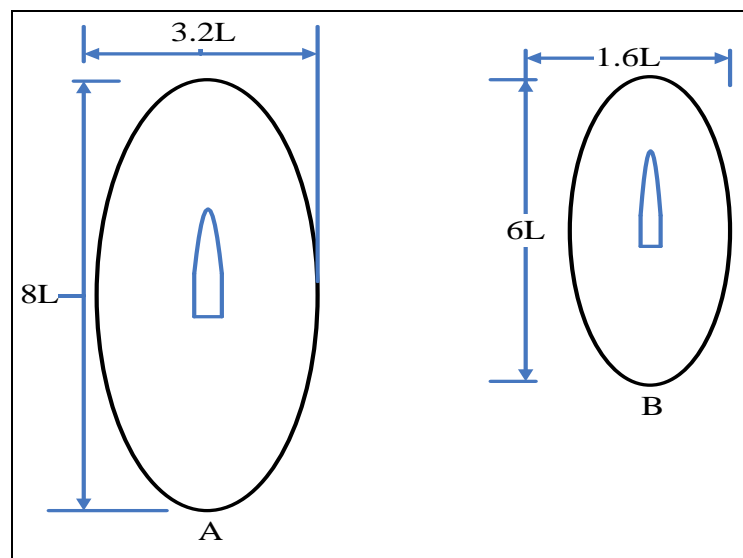
Figure-13 ship domain model

4.3.2 Navigation condition around bridge

Through the investigation and observation of area, it can be found that the ship arriving at the Hangzhou Bay Bridge matches the following conditions:

a. The bridge upstream channel depth is limited; the ship shall generally take the tide

through the drafting;

b. The arrival rate of the ship is proportional to the length of time in any small time period;

c. The probability of arrival of the ship is not affected by the previous arrival in any short period.

Therefore, the arrival process of the ship to the Hangzhou Bay Bridge follows a Poisson distribution. There is no limit to the queue length, and the queue theory can be used.

4.4 The parameters of the queuing theory

4.4.1 The average length (L)

According to the actual situation of the Hangzhou Bay Bridge, the ship statistics data of the Hangzhou Bay Bridge can be calculated by the ship's average length in 2010. The formula can be calculated as follows:

$$L_m = \sum_i c_i L_i$$

Formula：

L_m —Weighted average LOA

c_i —Weight coefficient

L_i —Single Ship Length

4.4.2 Average arrival rate (λ)

According to the observation data of Hangzhou Bay Bridge, the data can be obtained at an average of every hour.

4.4.3 Average passing bridge time (T)

The time for each ship to receive services, which is the time from the ship into the bridge area to the next ship can enter the bridge area.This time's distance is equal to D=1/2 (L+l), the time for a single vessel service:

T—Time (s) is single vessel receiving service;

D—Distance (m) is the ship in service time;

L—Ship's field length (m);

l—The length of the ship (m);

V—Ship's speed (kn).

4.5 Saturation evaluation system

Referring to the method of determining the capacity balance coefficient of the foreign port channel bridge, we combine with the actual situation of the Hangzhou Bay Bridge; this paper establishes the evaluation index of the saturation degree of the bridge area.

Table-5 Saturation evaluation index system

The actual traffic/theoretical value	State description
<0.9	Not saturated
0.9~1.0	Near saturation
1.0	Saturated
1.0~1.1	Over saturation
>1.1	Severe saturation

According to the above calculation result and the saturation evaluation system, the Hangzhou Bay Bridge's navigation ability is eight times larger than the domain model calculation in the normal traffic flow (8 kn) through capacity. When the traffic flow velocity increases, the degree of saturation can be alleviated. When we use 6

times the domain model to calculate the Hangzhou Bay Bridge through capacity, it would not reach saturation, but the calculation of bridge navigation ability is to assume that the traffic flow distributed every ideal states. According to research on the situation of navigation, Traffic flow of Hangzhou bay bridge is significantly higher than in the evening traffic flow during the day. So the traffic flow is saturated and even supersaturated in navigable peak of Hangzhou Bay Bridge.

4.6 Calculation of traffic flow

Channel capacity and the traffic capacity of the channel are not the same, but the two are related. Traffic capacity is the maximum number of ships that can pass in a certain channel each unit time. Waterway capacity refers to the way of running the organization conditions under certain technical performance of the ship, channel section is (day, month, year, or cycle) by the number of ships and ship tons each unit time. Effect of channel through capacity is accepted, not only by its own channel condition, technical performance, natural environmental factors, but also by the port berth throughput and port operations of operation organization, regulation factors of VTS center.

Basic traffic capacity of one way straight line $C_b(V)$:

Formula:
$$C_b(V) = \rho_{max} \cdot W \cdot V = \frac{1}{r \cdot s} \cdot W \cdot V$$

ρ_{max} —Maximum ship traffic density

W —Channel width

V —Ship speed

r — The long side of the ship collision in the field of rectangular

s —The short side of rectangular collision in the field of ship.

If the elliptical collision is in the field

$$\rho_{max} = \frac{1.15}{r \cdot s}$$

Dr Fujii proposes the collision field model, according to the research at home and abroad, we can compare with the Hangzhou Bay Bridge area real navigation conditions, this paper uses 6 times the LOA domain model, however, and the ship domain numerical model of bridge waters is still too large. The domain model that long axis is 6L, short shaft is 1.6L (L is the LOA), but between the ships in the meet and cross meets different motion state and collision will be different in the field. In addition, collision is also affected by speed in different field, and other influencing factors, etc.

For example, we take the effective width-W of the bridge area is 93m, speed V is 8 knots, according to the display of Hangzhou Bay Bridge observation data and navigation of the ship average LOA is 50.4m, ship per hour through the ability can be computed as follows:

$$C_b = 1.15 \mathrm{W.V}/\mathrm{r.s} = 1.15 \mathrm{W.V}/9.6 \mathrm{L}^2 = 65 \quad \text{(ship/h)}$$

Then a day of ship passing capacity is 15560 ships.

4.7 Summary

4.7.1 Flow calculation result is 15560 vessels per day, The ship traffic statistics show each month investigation on ship flow rate, but according to the research on the Hangzhou Bay Bridge area, ship traffic flow in the daytime is more than ship traffic in the night and according to calculation results of queuing theory shows that through capacity has already reached saturation or over saturation, and ship traffic increases the risk of ship bridge at the peak of the Hangzhou Bay Bridge area.

4.7.2 Flow velocity of vessel is large, probability of waiting will increase, the time of passing through bridge is reduced, and queue time is reduced, but the speed of the ship is too fast to operate, this situation will be likely to cause accidents, ships passing through the bridge should be controlled.

4.7.3 According to the results of calculation and evaluation system, the traffic flow velocity is 8 kn, the ship has not reached saturation state, but if the size of navigation ships increases, the bridge waters will reach saturated state. We consider that a large ship passes the actual situation of Hangzhou Bay Bridge waters; ships' passing time of Hangzhou bay bridge will be increased. Research in the Hangzhou bay bridge shows that the traffic flow during daytime is faster than at night, this paper will take ideal situation in the calculation of the ship traffic, which is uniformly distributed in a day, so the traffic flow peak of Hangzhou bay bridge waters ship capacity does not reach saturation state.

Charpter 5. Analysis of Hangzhou bay bridge vessel traffic safety

5.1 Related factors of the bridge area

We can learn from "Study report of the Hangzhou Bay transportation channel engineering feasibility","Study on Hangzhou Bay transportation channel engineering: navigation standard additional demonstration report "and "the Hangzhou Bay Bridge Preliminary design: Waterway Engineering" and Hangzhou port, Shangyu port, Development Planning of Zhapu Port, bridge area objects of vessel traffic mainly included following:

5.1.1 Navigation capability of the north navigable hole

Navigation capability is GT 35,000 bulk carrier, mainly for the import and export of Haiyan&Qinshan ports. (China route guide, 2008)

5.1.2 Navigation capability of the south navigable hole

Navigation capability is GT 3,000 ship, mainly for the import and export of Shangyu port

Navigation capability is GT 1,000 ship, mainly for the import and export of Shangyu port

Navigation capability is GT 300 ship, mainly for the import and export of Hangzhou port fishing boats, general cargo ship and some engineering ship. (China route guide, 2008)

5.2 Current status of ship traffic flow

5.2.1 According to Jun 1st, 2012 to Nov 30th, 2012, 6 months VTS flow monitoring data for:

Table-6 Number of Bridge navigable waters

Number of Passing	Unit	Total
The North Navigable hole Ship	Ship	1116
The vessel density (The north navigable hole)	Ship/day	6
The South navigable hole	Ship	2438
The vessel density（The south navigable hole）	Ship/day	13

5.2.2 According to the Jiaxing VTS west report line and Haiyan port of import and export visa system (Nov 30th to Jun 1st, 2012), according tonnage statistics of ships bridge upstream activities of the ship to statistical results, as below:

Table-7 the area of Jiaxing MSA under the jurisdiction of the ship in accordance with the tonnage statistics

Time	Other ship	499t below	500～999t	1000～2999t	3000～4999t	5000～9999t	10000～24999t	25000～49999t	50000 Above	Total
2012Year 6-11 month	3533	36	3	62	12	47	16	0	0	3709

According to the Jiaxing VTS monitoring (Jun 1, 2012 to Nov 30th) in the Hangzhou Bay Bridge North and South channels, statistical results are as follows:

Table-8 Statistical table for ship type of North Channel of Hangzhou Bay Bridge in 2012

Ship	Operation ship	Non operating ship

type	Passenger ship	Bulk cargo ship	Container	Dry cargo ship	Tug	Multi purpose vessel	Engineering ship	Official ship	Other ship	total
Number of ships	0	126	1	120	4	41	1	114	709	1116

Table-9 Statistical table of ship type of South Channel of Hangzhou Bay Bridge in 2012

Ship type	Operation ship						Non operating ship			
	Passenger ship	Bulk cargo ship	Container	Dry cargo ship	Tug	multipurpose vessel	Engineering ship	Official ship	Other ship	total
Number of ships	0	22	0	53	1	19	1	14	2349	2438

Note: other vessels are not marked as vessels and fishing vessels

5.2.3 The Bridge area (upstream and downstream 3000 meters) vessels unberthing situation: according to visa system statistics, in July 1st, 2012 to Nov 30th, bridge upstream and downstream of Haiyan port C1C2 berths is 769 ships. According to the statistics of the tonnage of the ship as a table-10:

Table-10 Statistical table of the tonnage of the ship in accordance with the ship in the waters of the Hangzhou Bay Bridge

Time	499T Below	500 ～ 999 t	1000 ～ 2999 t	3000 ～ 4999t	5000 ～ 9999t	10000 ～ 24999t	25000 ～ 49999t	50000 ～ 74999t	75000 Above	Total
Jun--Nov 2012	76	10	273	99	172	139	0	0	0	769

Figure-14 According to the ship type statistics as shown in the table:
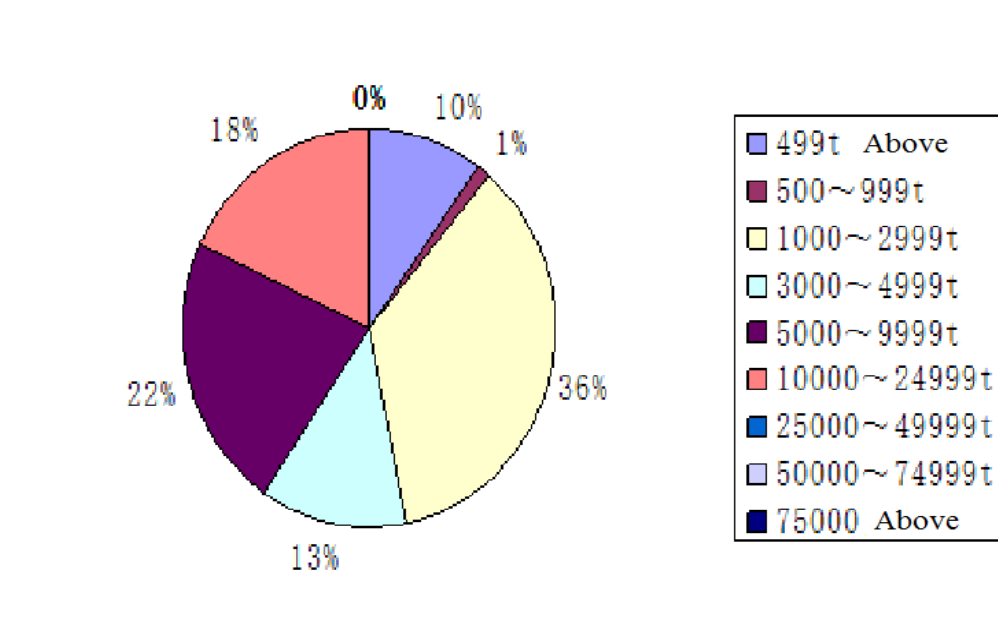
Table-11 Statistical table of the ship type in the waters of Hangzhou Bay Bridge, Jun--Nov 2012

Time	Passenger ship	Container	Crane ship	Bulk cargo ship	general cargo ship	Dry cargo ship	Pitch boat	Multi purpose vessel	Liquefied gas tanker	Chemical tanker	Tanker	total
Jun--Nov 2012	0	2	2	222	2	54	2	12	1	44	428	769

From the above data, we can see that ships of 5000GT above account for 40.4% in the bridge waters. From the ship type, oil tankers and liquefied ships account for 62%. As a result, large and dangerous cargo ships are mostly near the bridge area.

5.3 Prediction of Traffic flow

Since the bridge upstream channel depth is limited, the ship should generally take high tide to past the draft limit, and the upstream of bridge is not enough tide anchorage available, so the time of passing through the bridge area is relatively concentrated. The traffic density of the bridge increases in the key period of time (day focused on high tide about 2 hours earlier, two hours before the low-tide time. Shipping density of South and North navigable holes is predicted to exceed 6 ships / hour and 3 ships / hour; especially the 20 ships will pass through the south navigable hole every hour in 2025, which is equivalent to an average of passing of one ship per three minutes. Such a high density of navigation ships passing through the navigation holes in the rising (falling) tide, which has its impact on the safety of navigation doubtless.

5.4 Analysis of traffic risks and causes in the Hangzhou Bay Sea

5.4.1 Traffic safety risk analysis in the bridge area

In this paper, the fuzzy mathematical evaluation method is used to evaluate the traffic safety of Hangzhou Bay Bridge. The main reasons are as follows:

5.4.1.1 The complexity of the evaluation of traffic safety

Navigation safety evaluation is a complex quesition, factors that affect the safety of navigation are numerous and complicated, and the fuzzy concept of the indicators is not specific, and it's difficult to do accurate quantitative analysis and evaluation.

The main factors affecting navigation safety are as follows: Natural environment factors, the channel environment factors, traffic environmental factors, human factors. Each of the factors contains small elements, for example, human factors can include government management, shipping companies and seafarers and their family factors, etc. It is difficult to set an evaluation standard or do quantitative objective evaluation; therefore, we need to establish a mathematical model of the specific detail by using fuzziness of experience and opinions to quantify them.

5.4.1.2 The advantages of fuzzy mathematical evaluation

The evaluation of navigation safety degree is a strong system, with multiple influencing factors, complex structure, strong fuzziness and so on.

Fuzzy mathematical evaluation is an effective mathematical tool, which can solve the problem of fuzziness and provide a new and effective special channel for evaluating the safety of navigation environment. Application of fuzzy comprehensive evaluation

can not only be used in comprehensive evaluation of subjective indicators, but also can be used as an objective index of comprehensive evaluation, and relatively simple, which is easy to process the data , therefore, it is gradually commonly used in safety evaluation.

5.4.2 The establishment of the fuzzy comprehensive model

We set evaluation object for P; its set of factors（The index set）
U= {u1 u2 u3 … un}, Evaluation level set V= {V1 V2 V3…Vm}
Each of the factors in the U can be based on the level assessment of the fuzzy comprehensive evaluation, in order to get the evaluation matrix as shown below:

$$R = \begin{bmatrix} r^{11} & r^{12} & \cdots & r^{1m} \\ r^{21} & r^{22} & \cdots & r^{2m} \\ \vdots & & & \vdots \\ r^{n1} & r^{n2} & \cdots & r^{nm} \end{bmatrix}$$

rij is Ui Degree of membership of vj. (U, V, R) constitutes a fuzzy comprehensive evaluation model

Determine the importance of each factor index (weight), notes for vector A:

A= {a1 a2 a3 … an}, A element meet $\sum_{i=1}^{n} a_i = 1$

According to the above synthesis can be: $B = A \circ R = \begin{pmatrix} b_1 & b_2 & b_3 & \cdots & b_m \end{pmatrix}$

For the comprehensive fuzzy evaluation of the vector B to combine the fuzzy evaluation theory in the "maximum membership degree" or "the closest to the membership degree" principle, which can determine the evaluation object R the comprehensive evaluation level. In addition, if the results of the fuzzy evaluation (using the score), then the corresponding relationship is introduced as follows:

Table-12 Correspondence between fuzzy evaluation and numerical

Risk grade	Lowest	Lower	General	Higher	Highest
Score	1	2	3	4	5

The conversion method of risk grade score S is obtained by the relationship between the table-12 and the risk grade:

$$S = 1 \times b_1 + 2 \times b_2 + 3 \times b_3 + 4 \times b_4 + 5 \times b_5$$

The implementation of the evaluation model

5.4.3 Based on the index weight of FAHP

This paper uses the fuzzy analytic hierarchy process (FAHP) to determine the weight of each index factor. Determination of the principle and steps is as follows:

5.4.3.1 Construction of fuzzy complementary judgement matrix

In order to make a quantitative description of the relative importance of the two schemes, the fuzzy analytic hierarchy process can be used to give a quantitative method of 0.1 - 0.9 scale, as shown in table-13.

Table-13 the meaning of Scale 0.1 to 0.9 in Fuzzy Analytic Hierarchy Process

Scale	Definition	Description
0.5	Same important point	Compared with the two elements,the two are just as same important
0.6	More important point	Compared with the two elements, the former is a little more important than the latter.

0.7	Obviously important point	Compared with the two elements,, the former is more obviously important than the latter.
0.8	Strong important point	Compared with the two elements,, the former is more strong important than the latter.
0.9	Extremely important point	Compared with the two elements, the former is more extremely important than the latter.
0.1,0.2 0.3,0.4	Reverse comparison	If the element Ai and element Aj are compared in order to get the judgment matrix Rij can get the element Ai and element Aj are compared to get the judgment Rji=1-Rij

According to the specific meaning of the scale of 0.1 to 0.9 degrees, the element a1, a2，... an. The following fuzzy judgment matrix can be obtained by comparing upper A.

$$R = \begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1n} \\ r_{21} & r_{22} & \cdots & r_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ r_{n1} & r_{n2} & \cdots & r_{nn} \end{bmatrix}$$

R has the following properties:

① $r_{ii} = 0.5$;

② $r_{ij} + r_{ji} = 1, i = 1, 2, \cdots n; j = 1, 2, \cdots, n$;

③ $r_{ij} = r_{ik} - r_{jk}, k = 1, 2, \cdots, n$ 。

5.4.3.2 Calculatation the weight of each element

A fuzzy judgment matrix $R = \left(r_{ij} \right)_{n*n}$, The weight of the index factor is calculated as follows:

$$W_i = \frac{1}{n} \left(\sum_{k=1}^{n} r_{ik} + 1 - \frac{n}{2} \right), i = 1, 2, \dots n$$

In fact, assuming that there are m experts give a fuzzy complementary judgment matrix $A_k = \left(r^{(k)}_{ij} \right)_{n*n}$, K = 1, 2, ... , m, the experts can give comprehensive judgment matrix, the weighting vector is obtained $\overline{W} = \left(\overline{W_1}, \overline{W_2}, \dots, \overline{W_n} \right)^T$, among, :

$$\overline{W_i} = \frac{1}{n} \left(\sum_{k=1}^{m} \lambda_k \sum_{j=1}^{n} r^{(k)}_{ij} + 1 - \frac{n}{2} \right), (i = 1, 2, \cdots, n)$$

λ_k is the proportion of each expert, $\lambda_k > 0, \sum_{k=1}^{m} \lambda_k = 1$, In this paper, the average proportion of each expert is consistent, respectively is 1/m.

5.4.4 Index evaluation matrix based on fuzzy statistical method

In this paper, fuzzy statistical method is used to calculate the membership function value. This method can reflect the degree of membership in fuzzy concept.

Fuzzy statistical method can be described as follows: random region U of determined element V0 is on domain tension on set a clear judgment. For those who are not the same, a clear set of A can has different boundaries, but they all correspond to the same fuzzy set A Pressure.

Fuzzy calculation steps of the method of mathematical statistics: in every statistic, V0 is fixed, a value is changed, do experiment n time. The fuzzy statistics can be calculated according to the following formula:

V0 for A's Membership frequency＝V0 ∈ A Number of times／Total test times n

With the continuous increase of N, the membership frequency will tend to be stable; the value of this relatively stable is V0, which is relative to the value of A membership.

The calculatation by the method of frequency indexes of evaluation grade of membership degree vector are sequentially arranged; we can get the fuzzy comprehensive evaluation model to judge matrix R.

Through the above two steps W and R can be obtained, then it can be brought into the above built mathematical model so as to achieve a comprehensive and quantitative evaluation of the safety degree of navigation environment. (Zhou, Z.Y, 2015)

5.5 FAHP Analysis

Based on FAHP evaluation index weight calculation of Hangzhou Bay bridge navigation environment safety assessment has a total of 9 evaluation indicators,

respectively, belonging to the three first-level indicators. In order to get the index importance comparison judgment matrix, the questionnaire was issued to the crew, the port, the shipping companies and the navigation safeguard department, and so on. The questionnaire (see Appendix A) was issued to the 20 experts. After sorting the questionnaire, the weights of the experts is equal (each is 1 / 20), and the weight of the index is calculated as follows:

The weight of the three first-level indicators in the total target layer:

W0= [0.5367   0.3046   0.1588]

The weights of the two level indexes in each category are:

W1= [0.5365   0.3126   0.1508]

W2= [0.5359   0.3005   0.1636]

W3= [0.5087   0.3227   0.1687]

The weight calculation of the lowest level of each index in the index system:

(W = [W0 (1)*W1, W0 (2)*W2, W0 (3)*W3])

As shown in Table-14 and Figure-16:

Table-14 the weight of each index in the index system

Index	Weight
Wind	0.2879
Flow	0.1678
Fog&Visibility	0.0809
Channel width	0.1632
Channel depth	0.0915
Channel bend	0.0498
Traffic flow	0.0808
Obstruction	0.0512

AIDS to navigation	0.0268
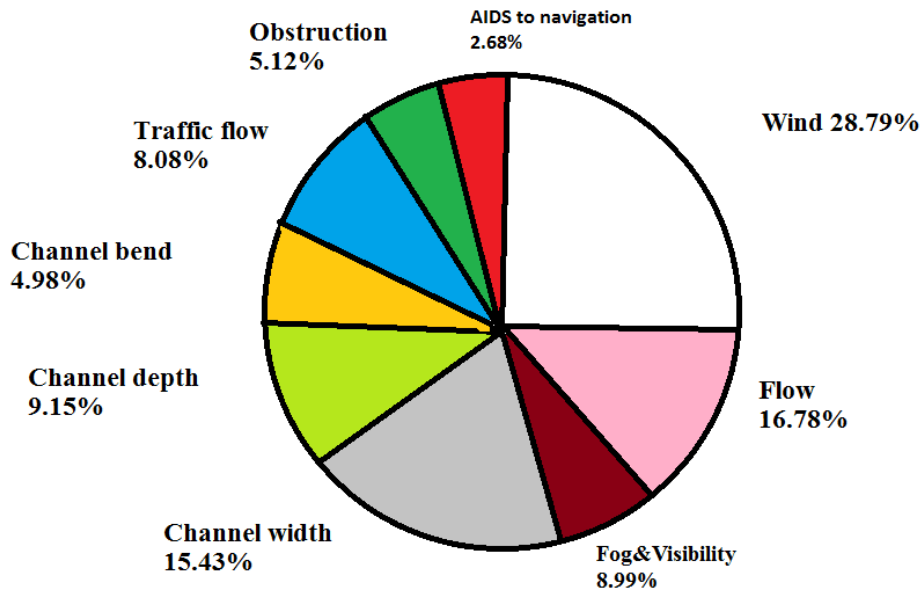
Figure-15 Numerical value is the weight vector of each index.

We calculated the index weight in the index system, wind (including typhoon), water flow (including tide), channel width, fog and visibility, traffic flow and other indicators of weight is bigger, these factors account for ship navigation safety factors affecting the risk of large. Thus, we should pay attention to the improvement of indicators in the navigation safety management.

5.5.1 Single factor risk assessment based on the frequency statistics

In order to make the evaluation results in accordance with the requirements, to achieve the full intergration of the subjective and the objective, this paper uses the evaluation index value table and described each index of evaluation criteria

above.We respectively sent to MSA, crew, port, shipping companies and maritime security department, and we receive questionnaires results from a total of 20 experts. The paper calculates the data and determines the risk grade of each index.

Table-15 as shown in the following:

Table-15 Level determing of index risk

Number of people		Risk level				
		lowest	lower	general	higher	highest
Evaluation index	Wind	1	1	8	8	2
	Flow	0	2	4	11	3
	Fog&Visibility	0	1	4	11	4
	Channel width	3	5	10	2	0
	Channel depth	1	2	10	6	1
	Channel bend	6	2	9	2	1
	Traffic flow	2	5	8	4	1
	Obstruction	4	4	4	7	1
	AIDS to navigation	4	7	6	3	0

The ratio method was used to determine the membership degree of the single factor, that is, the ratio of the number of each reviews level and the ratio of the total number of all the evaluation items is the membership degree of evaluation indicators. The membership degree of each evaluation index is as follows:

Table-16 Calculation of evaluation membership

Frequency		Risk level				
		lowest	lower	general	higher	highest
Evaluation index	Wind	0.05	0.05	0.4	0.4	0.1
	Flow	0	0.1	0.2	0.6	0.2
	Fog&Visibility	0	0.05	0.2	0.6	0.2
	Channel width	0.15	0.25	0.5	0.1	0
	Channel depth	0.05	0.1	0.5	0.3	0.1
	Channel bend	0.3	0.1	0.5	0.1	0.1
	Traffic flow	0.1	0.25	0.4	0.2	0.1
	Obstruction	0.2	0.2	0.2	0.4	0.1
	AIDS to navigation	0.2	0.35	0.3	0.2	0

Table-16 Number is a navigation safety level of environmental risk assessment index of judging matrix R.

Based on statistical results, index system, wind, current, fog and visibility, obstacle navigation etc., we can analyze risk level. Four indexes belong to the higher level of risk, which is a greater degree. Most researchers think wind, flow, fog and visibility, obstruction risk level is higher (risk level is above "general"). Therefore, we should take measures to reduce the risk of indicators in the actual management.

5.5.2 Comprehensive evaluation results of navigation environment safety

We make W and R substituted into formula of the fuzzy comprehensive evaluation, and we can get Hangzhou Bay Cross Sea Bridge navigable environment based on fuzzy comprehensive evaluation results for:

B=W*R= [0.0821   0.1300   0.3653   0.3388   0.0838]

Therefore, according to the "maximum membership degree" in the fuzzy mathematics, we can determine the safety of the navigation environment of the Hangzhou Bay Bridge, which belongs to the "general" level.

In addition, we will get the result of fuzzy evaluation (using score), according to the model, the Hangzhou bay bridge navigation environment risk score:

S=1*b1+2*b2+3*b3+4*b4+5*b5=3.6832

That is, the Hangzhou Bay Bridge navigable environment risk can be quantified as 3.6832.

From the perspective of the process and result of the navigation environment risk assessment, the Hangzhou Bay Cross-sea Bridge navigable environment risk mainly is from natural environment and traffic environment, including wind, typhoon, flow and tidal, traffic flow and obstruction. It is recommended that the related department should improve the safety of Hangzhou bay bridge maritime meteorological support, establish a severe weather warning forecast system, and we need carry out all-weather monitoring of bridge waters, organization of traffic flow, increase the efficiency of the traffic management.

5.6 Risk analysis of ship bridge collision

Summary and analysis of the past accidents and dangerous situations, the bridge

accidents mainly have the following three forms:

One is the ship touches the bridge pier. Bridge pier is the most vulnerable to the impact of the location of the ship in water. Because ships are not familiar with the change of navigation and they strayed into the bridge area of the non navigable waters touching the pier, sometimes ships are out of control, and touch the pier by inertia or airflow.

Secondly, ship touchs the ship bridge box girder; the ship bridge is more than maximum height above the waterline at the ship over the design height of bridge. There are two main situations, hight of crane ship and special ships are higher; on the other hand, headroom height of the bridge is lower.

Thirdly, ship crashs the bottom of bridge frequently occurring in inland tidal waters, due to the ebb and flow of the tides, it leads a result on distance between changes of the deck and the water surface, ship's officer estimates mistake, and due to the high tide will make the hull of the ship further crash bridge, this situation will make a serious threat on the bridge.

By the case analysis of bridge accidents, all problems of ships also have the bridge itself factors, at the same time, bad navigation environment could also lead to accidents, the risk of Hangzhou bay bridge is bigger and bigger.

5.6.1 Bridge auxiliary facilities

Non-navigable hole have not structural anti-collision facilities, in accordance with "the navigable seagoing vessel bridge navigation standard ", non-navigable hole are mandated by the construction structural anti-collision facilities. However, when seaman is not familiar with the channel or neglection, the ship mechanical equipment is fault, bad weather and sea conditions such as ship strayed into the non-navigable bridge waters lead to touch bridge risk, the non navigable pier does need against

unexpected ship collision force.

5.6.2 Traffic flow

In recent years, with the development of marine economy and construction of port, Jiaxing port also ushered in an unprecedented development, the rapid increasing of berths occurs in the port, the current Jiaxing port already has 40 production berths, of which 28 berths are ten thousand tons.

5.6.3 Dragging of Ships

Zhapu Anchorage has been adjusted and merged into one anchorage, anchorage recently Bridge pitch axis only is 0.7 nm (about 1.3 km).This is very dangerous to the bridge.Once Ships are dragging, consequence is unimaginable.

5.6.4 The lack of port information

Before a ship arrives at the port, the master should fully understand the situation of hydrology, meteorology, navigation environment and so on. But a lot of ships do not meet the relevant provisions of the requirements; they do not understand port information, which may lead to accidents.

5.6.5 Construction work

In recent years, with the development and construction of jiaxing port, sea construction work increases, some accidents or danger occur. Although their distance is away from the hangzhou bay bridge, the accident vessels or maritime facilities once fail to control, a drifting will seriously endanger the bridge safety.

5.6.6 Ship machinery fault

In recent years, the accidents of ship machinery have been increasing year after year; which are closely related to the condition of the ship, the quality of the fuel, the operation of the crew and so on. When the ship is in the bridge area, main engine is out of control, mechanical failure and other mechanical reasons and ship can not be operated normally, it is likely to cause the accident to touch the bridge.

5.6.7 Bad weather factor

Heavy fog, storms, typhoons and other bad weather are also important factors to increase the risk of the ship. Fog reduced visibility significantly, the number of accidents data show that poor visibility when the number of ship collision of the bridge accidents is 4 times more than ordinary accident. In addition, during the period of the typhoon influence, Hangzhou bay waters was not sheltered, it was hard to avoid ship dragging. Once area encountered strong winds, the ship appeared dragging; it would face a major risk for bridge. At the same time, because of no shelter, port emergency tug had left the port, when the crisis occurs, the emergency control ability is weak.

5.6.8 Limit of bridge and navigation aids

Navigation width and height of bridge are limited, navigation aids are not validity sometimes, flow speed and factors of bridge traffic safety is an important influence.

5.7 The influence of the bridge itself on navigation safety

5.7.1 The impact on the route

All the ships crossing the axis of the bridge must pass from the South or north of the main or sub navigation holes, we should ensure the safety of the bridge, and other bridge holes are prohibited. Not only traffic density of the navigable ship is increasing, but also complexity level of traffic flow is increasing, this situation leads to the ship sailing in the bridge area with more difficulty.

5.7.2 The flow condition

According to the research, high tide, downstream point of the bridge nearly high tide area has a slight elevation, upstream point of the bridge has decreased; Low tide changes mainly occur in the bridge area, the upstream has raised, the downstream has decreased. Because the concentration of the water current velocity increased slightly, ebb's flow velocity decreased, the rest of the waters flow velocity overall decreased, and a decline is less than 6% in general. These are a direct impact on the effect of ship motion speciation or indirectly affect on the driver's steering; these situations lead to the practical difficulties of ship maneuvering.

5.7.3 Flow turbulence of pier

Through the flume experimental observation shows, flow structure around the pier including before the pier water level surge wave, water flow of down pier and both sides around the separation layers are formed in the wake vortex and released to near the bed surface on both sides of the pier and pier is small eddies formed in the vicinity of the bed surface horseshoe vortex and piers on both sides of the boundary flow and the vortex will have a greater role in the adsorption of pier around the upper

waters. When a ship passes through the bridge, this interaction will attract the stern of the ship that is swept to the pier, and it endangers the safety of navigation. It is a major cause of pier collision of ships.

5.7.4 Mooring environment

According to "the navigable seagoing vessel bridge navigation standard "(JTJ311-97) bridge location and navigation hole is arranged provisions:" the bridge should keep clear of fairway bends, rapids, confluence, ferries, port operation area and anchorage, the distance should ensure the safety of navigation of the ship. " Bridges across the sea, the lower reaches of the ship are not less than four times the length of the ship.
The bridge of navigational 10000DWT and above ship should be away from the distance which may be appropriate to increase. Even if only considering the calculated according to 35,000 ton ship as representative (length 250m), axis 1km range of Hangzhou bay bridge should not build anchorage. And actually, due to the influence of Hangzhou Bay, Qiantang River tidal bore is up to 5 m/s and above, ship's mooring should use a more adequate safety distance, otherwise, once the ship goes dragging and the bridge will face a great threat.

5.8 Traffic management situation

Jiaxing MSA is responsible for the management of Hangzhou Bay Bridge water area, Jiaxing MSA is traffic management center responsible for the bridge water area of VTS monitoring and traffic flow organization and law enforcement, maritime search and rescue and anti-pollution incidents in the emergency reaction.

a.VTS: VTS on the bridge area was covered by the waters of ships to carry out dynamic monitoring; they provide information for ships, and other services to help navigation, to avoid the occurrence of ships hitting the bridge accident. At present, VTS has become an effective means of ship traffic management, and VTS information is more and more important to the management department. At the same time, VTS as a source of information collection can also provide a wealth of shipping traffic information. Network development produces the information sharing platform, VTS management area of the ship dynamic and ship real-time dynamic information in the bridge area, including ship in navigation position, course and speed, anchoring position, the berthing position and ETA etc.. At the same time, traffic control center and on-site law enforcement departments establish law enforcement linkage mechanism, and they can deal with various types of accidents and protect the bridge area navigation safety.

b.Cruise: We can use the cruise to control safety, to eliminate security risks timely. Grid management has been carried out on the bridge area, on-site law enforcement departments should increase cruise frequency, extend cruising time, expand cruise coverage and strengthen measures, and carry out bridge area navigation aids service. JXMSA should control ship navigation order, make the rules for bridge construction work safety supervision and inspection, and routes of ship navigation, berthing, work behavior, promptly investigate and deal with all kinds of illegal behavior, and eliminate the hidden risks of bridge safety.

c.Joint supervision cooperation mechanism

The establishment of the navigation bridge joint supervision cooperation mechanism would ensure navigation safety in bridge area. As the coordination unit of bridge safety operation management, the Management Bureau of Hangzhou Bay Bridge needs coordinate the establishment of a joint mechanism of maritime, traffic police, special police, road administration, and bridge Owners Company, held regularly bridge safety meetings, and do some notification and disposal of potential safety risk exists in the bridge.

We need to examine the bridge area obstacle of fishing nets in the fairway, navigation function, bridge equipment's condition.

5.9 Law safeguard

Government authorities should obey "The people's Republic of China Maritime Traffic Safety Law"," the law of the people's Republic of vessel traffic management system of safety supervision and management regulations ", "the law of the people's Republic of China Marine Environmental Protection Law", "the people's Republic of China Road Management Regulations", "the people's Republic of China Water Pollution Prevention Law "and other laws and regulations. Zhejiang MSA issued the implementation of the "Hangzhou Bay sea crossing bridge traffic safety management regulations" in May 1st, 2008. Zhejiang MSA issued the implementation of the "Jiaxing ship traffic management system supervision and management rules" on October 1st, 2011.

Chapter 6 Conclusion and Suggestions

As an active collision avoidance system, the bridge area navigation system can provide navigation information service, ship management and navigation guidance. Through the study the system we could better ensure the bridge water area bridges safety for sailing ship, avoid a ship passing bridge due to negligence or the occurrence of the season, weather and other reasons caused the ship bridge collision accidents. With the decreasing cost of the equipment, the system has been widely used to bridge area navigation safety and production provides necessary assistance and information for ship navigation, they create a good foundation for the scientific management of bridge area, these measures wil bring good economic and social benefits.

6.1 Existing problems

6.1.1 Anchorage distance

Zhapu pilotage and quarantine anchorage is near from the Hangzhou Bay Bridge, the bottom of anchorage is of poor quality, rapid flow, prone to the ship dragging, such as a direct threat to the safety of the bridge; since area of Chenshan anchorage is small, there are many dangerous mooring ships, which causes most ships to be anchored in anchorage surrounding and adjacent waters, the relative anchorage orders are in disorder; since range of Changchuanbei anchorage and Qinshan anchorage are small and shallow, it can not meet the most ship mooring requirements.

6.1.2 The lack of anchoring positions

Government authorities have built planning of Caiqishan anchorage in four anchorage constructions, Jiaxing Port has general cargo ship mooring anchor 53, dangerous goods anchoring position is 7. Although it can meet the needs of recent general cargo ships at anchor, it can greatly alleviate the pressure of lack of anchorage, but recent demand for dangerous goods shipping berth will reach 17, dangerous goods anchorages will be lacked.

In a long term, the anchor position demand will reach 75.5, dangerous goods anchorage is 19, and the port does not plan to build more routes.   If the above four anchorages construction will no longer open up new anchorage in the near future, this situation will form a new anchorage tensions, lack of shipping dangerous goods anchorage will be more prominent in the recent future.

6.2   Solutions

6.2.1 Anchor building

Four anchorages should be constructed as soon as possible, and they should meet the basic needs.

Adjustment or the construction of a new anchorage interacts with the channel of water; it will improve the navigation efficiency. For example, the adjustment of Chenshan port and West berth channel can avoid ship entering and departuring, take large angle steering. We need improve the area of navigation environment; improve the safety of ship navigation and safety of mooring.

To further strengthen the research on the planning of port waters, we should adjust the anchorage distribution. We need strengthen the construction of public anchorage area, improve utilization rate of mooring waters, and avoid the dispersion of water

which water depth is 10 meters above. For example, we can build a new anchorage near Wangpanshan, increase the number of anchorages, to meet the needs of port waiting for berth and mooring.

Government authorities need to give priority to the planning and construction of the dangerous goods anchorage, dangerous goods transport increases in Jiaxing Port, the number of dangerous goods import and export will be bigger and bigger, the amount of berth is increasing year by year, in addition to the existing Chenshan anchorage and planning of Caiqishan anchorage, we should plan to build a new dangerous goods anchorage.

6.2.2 Definite anchorage

At present, ships can choose anchor mooring freely, and this situation results in a waste of space, inefficient use of anchorage. The relevant departments should study related management strategies, and strengthen the maintenance, such as setting a fixed anchor points.

6.3 Ship's measures to ensure the safety

6.3.1 Human factors

a.   The performance of the ship

The officer should be familiar with ship's maneuvering performance and the relevant data. The ship's maneuverability includes the performance of speed and direction. Since approach channel is relatively complex, ship maneuvering is restricted by many factors, and the captain should know how to control its speed.

b. The port navigation elements

A captain should collect relevant data, whether his ship should apply for pilotage or not, before a ship arrives at a port, its officers should study the relevant books, get familiar with the waterways, depth of water, situation of buoy, understand the situation with the turning area, anchorage, obstacle navigation area.

c.Understanding of the hydrology

A captain should understand the direction, structure, length, depth, size and accessibility of the dock. He needs to observe whether there is any influence on the operating ship, dredging ship etc.. The terminal information is very important to the safety of the dock.

d.The influence of wind and flow

The flow direction and the flow velocity are a regular pattern, and the effects of the flow may be fully predicted. The use of flow pressure from the wharf should pay attention to the rational use of flow pressure. We should pay attention to the flow of the ship; especially the officer operates the ship in the condition of low speed.
Ships are affected by cross flow; especially large ship should be cautiously operated. Container ships may be affected by the effect of side wind, especially containers are in a "fully loaded" state and the draft is not large enough, the wind pressure sometimes exceeds the flow pressure. The wind pressure is an important factor berthing and unberthing. We often need to consider the effect of wind flow and wind pressure on the operation of the ship.

e.The use of the tug

The power and the number of applications should be based on ship displacement, water conditions, weather and other circumstances to make arrangements at the time.

f.Application of anchors

An anchor is a strong symbol, which is the shield of the captain. We need to consider the anchor performance, windlass speed, chain breaking force, the water depth and draft, drop anchor, length of loose chain, degree of understand and experience.

g.The use of navigational aids

Radar, especially with ARPA radar, is a powerful assistant to the captain. And sounder, log, the electronic chart, GPS and other equiments provides intuitive and effective help.

6.3.2 Management factors

a.Control of berthing and unberthing time

We need to control ships operating actions of berthing and unberthing. This time is generally related to objective factors such as tide. We should implement the control of traffic flow; a certain period of time allows the operation of a single. We can reach the effect of unidirectional ship flow organization.

b.One-way navigation

In order to achieve the maximum utilization rate of the channel, the effect of the single traffic flow can be achieved.

c.Unified scheduling

We need to set a port control station in accordance with the schedule and arrange ship entering the port and terminal operation.

d.Broadcast safety information

We need broadcast safety information regularly or irregularly, regulate the ship and rely on the safe operation of the ship, so as to achieve the orderly operation of the ship.

6.3.3 The safety supervision

a. Prohibit berthing and unberthing during sharp tide of the ship

Jiaxing Port is located at the mouth of Hangzhou Bay, and range of tidal flow is rapid and large, these situations do not conducive to the vessel berthing and unberthing. Especially in the 1.5 hours after the low tide to low tide after 3.5 hours, the flow rate is urgent. At present, the berthing and unberthing of Jiaxing port should be strictly controlled by the ship in this time period.

b. VTS safety information broadcast

We need broadcast safety information for reducing the occurrence of accidents, especially we need remind first time arrival ship, provide assistance to ship.

6.3.4 Safety guarantee measures

According to the navigable natural conditions and the high traffic density of the Hangzhou Bay Bridge, we need to create and maintain a good and harmonious bridge navigation environment and navigation order. We suggest JXMSA carrying

out the supervision countermeasures from the following several aspects:

a. Perfect the bridge safety regulations

For the change of ship traffic, authority formulated "The Hangzhou bay bridge navigation safety management regulations", "Jiaxing supervision and management regulations of vessel traffic management system assessment standardize the order of bridge navigation", and we can evaluate rules and further standardize the order of the navigable waters of the Bridge.

b. Routine inspection

Government authorities need strengthen the daily bridge safety management in the government department in charge of the bridge under the unified coordination, and then we can set safety management responsibility, strengthen the daily maintenance. By monitoring of sedimentation and scour situation, we can discover and eliminate the safety risk.

c. Safety protection system

Establish safety protection system for non-navigable holes. There are a large number of non-navigable holes in the bridge, the safety protection of the piers of the 270 non-navigable spans of Hangzhou Bay Bridge is considered.

With the increase of vessel traffic flow, it is recommended to set up a non-navigable hole safety protection system, and the system should be prevented in the bridge area, which is a set of management, monitor, intercept, anti-collision, SAR integrated prevention system:

Firstly, the formation of specialized emergency management team, the use of the bridge VTS, CCTV and other systems for the implementation of 24-hour non

navigation monitoring, focusing on the maintenance of anti-collision facilities, guide signs, we can organize intercept and rescue.

Secondly, government authorities need to establish the necessary hardware management facilities, such as the establishment of the ship collision facilities; Elastic collision avoidance facilities are recommended.

d. Law enforcement

Government authorities should implement law enforcement measures in the bridge area and cruising. They suggest a specially equipped ship with patrol boat, the establishment of the inspection system, and a better understanding of the bridge navigable environment. They should investigate all kinds of Bridge District illegal behavior in the area around the bridge to maintain the navigation order, and discover and eliminate potential causes of accidents as soon as possible. JXMSA can further strengthen organization and management by VTS system, and then we provide the provision of information service in the bridge. JXMSA can guide ships to sail through the bridge, and regulate the behavior of ships through the bridge.

e.Navigational AIDS

JXMSA use methods of tug and compulsory pilotage for vessels under manipulation of limited or poor weather.

f. Capability of SAR

For strengthening emergency response, we suggest that port companies increase the allocation of appropriate tugs for enhancing rescue capabilities of navigation dense waters. Due to the special climatic conditions in Hangzhou Bay, it is recommended that we should set anti-wind, fast speed, the high power tugs, and support the

construction of rescue-based dock near the shoreline, and then we can do an effective implementation of the bridge waters in incident emergency rescue, and meanwhile we can take measures for ship drifting risk.

6.6 Conclusion

Through the above analysis, we can conclude that the navigation safety risk factors are not too high in the Hangzhou Bay Bridge area, but there are still many underlying problems. Fairway navigation safety of the bridge area is a very serious matter, which is related to the water shipping safety, and the safety of bridge construction and bridge traffic. Government authority shouldn't has any negligence. Therefore, JXMSA should construct a long-term mechanism for the safety management of the waterway in the bridge area, through constantly practice, summarize, so as to gradually improve the conditions of accumulation. Authorities of marine management need to increase supervision, and waterway management department should do a good job for the ship's officers to strengthen their training skill and safety education. The coordination of various departments will be a long-term task. With a high sense of responsibility and commitment, the navigation safety management of Hangzhou Bay bridge area will reach a new step in the future.

References

Chen L. &Cao L., (2000), *Macroscopic analysis of Water traffic safety,* Doctoral Dissertation of Dalian Maritime University, *2000*

Chen Q., (2013), *Research on effects of human factors in shipping navigation safety*, Master Dissertation of Wuhan University of Technology, P19-27

China route guide, (2008), *The Chinese people's Liberation Army Navy Command Navigation Department,* 2008.2-4

Feng, X.J, *Study of atmospheric and tides,* Guangdong Meteorology, 2002.3(1), P7-8

Geng L, (2013), *Safety evaluation of navigation environment in Dalian Port Dayaowan waters*, Master Dissertation of Dalian Maritime University, 2013

Guo K.&Qu B.,(2010), *Analysis of Navigational Safety Issues of Large Ship in Ningbo Port*,Ship&Ocean Engineering,P121-124

Guan Z.J., (1997), *Vessel traffic accident analysis,* Journal of Dalian Maritime University, 1997.2(1), P3-4

Han L.X, *Research and application of some basic problems in offshore sea area water environment comprehensive management,* Journal of Hohai University, 2011, 6(3), P15-16

Hiroaki Kobayashi, The *maritime traffic safety evaluation,* Proceedings of the Japan

Maritime Association, 1993.79(2):15-16

Huang C.H. , HU S.P, Gao D.Y.,Wu H.F., Xuan S.Y., Peng Y.,(2013), *Risk assessment of navigation safety in bridge water areas,Journal of Safety and Environment,*Journal of Safety and Environment,2013.12(Vol.6),P238-242

Inoue Kinzo, *Safety evaluation of marine traffic,* Proceedings of the Japan Maritime Association, 2000

Inoue Kinzo, *Restricted waters collision handling difficult degree evaluation,* Proceedings of the Japan Maritime Association, 2000

Jiaxing MSA, *Research on Jiaxing port navigation environmental factors, 2013*

Kendall D,G(1960), *"Geometric ergodicity and the theory of queues", in Arrow, Kenneth J.; Karlin, Samuel; Suppes, Patrick, Mathematical models in the social sciences, 1959:* Proceedings of the first Stanford symposium, Stanford mathematical studies in the social sciences, IV, Stanford, California: Stanford University Press, pp. 176–195

Liu Y.,(2011),*Safety Evaluation of Navigation Environment for Dalian New Port*, Master Dissertation of Dalian Maritime University, 2011

Li M.J.&Mei C.W.,(2012),*On Assessment of Marine Traffic Safety of Jiaxing Port Based on Fuzzy Comprehensive Evaluation,*Science&Technology Vision,2012.34(49),P44-45

Li D.X.,(2004), *The factors and Countermeasures of the traffic safety of the ships in the waters of the bridge,* Department of marine technology, Zhejiang Institute of Communications,2004,P1-4

Li Y.,Zheng B.Y.,Chen H.B., (2007), *Analysis and evaluation of navigation safety influenced by navigation environment in port,*Journal of Waterway and Harbor,2007.10(Vol.28),P345-347

Lu Z.W.,(2015), *Maritime navigation safety and efficiency analysis,*China Water Transport,2015.09,(Vol.15),P53-54

Lv Z.D. &Wang R.G., *Scheme design of Hangzhou Bay Bridge,* Hangzhou bay bridge project headquarters& CCCC highway planning and design institute, 2004, P49-58

Ma H., (2000), *Tend to be more practical for the maritime safety comprehensive assessment method,* Doctoral Dissertation of Dalian Maritime University,Dalian Maritime University Press,2000

Ma H.&Wu Z.L., (2006), *Comprehensive evaluation of Harbor waters operating environment risk,* Journal of Dalian Maritime University,2006.04(3)

Tan Z.R., (2002), *the environment risk evaluation method research of Port handling,* Master Dissertation of Wuhan University of Technology, 2002

Wang F.J., (2012), *Study of the Navigation Risk Assessment Model in Channel Waters*, Master Dissertation of Dalian Maritime University, P5-11, P30-39

Wen Y.Z.,(2001), *Xiamen safety of navigation environment system analysis* ,Journal of Dalian Maritime University,2001.03(01), P5-6

Wu H.W., (2011), *Evaluation on the Safety of Navigation in the Bohai Sea are*, Master Dissertation of Dalian Maritime University, P58-61

Wu Z.L., (2004), *Marine traffic engineering,* Dalian Maritime University Press,2004

Wang, J. J, & Geng, B. ,(2010), *Probabilistic risk assessment and safety measuremen ts of bridges under vessel collisions*. Beijing: China Communications Press.

Xiao L.X, (2007), Study *on the matters and methods of bridge and nearby waterway navigation assessment*, Master Dissertation of Wuhan University of Technology, 2007,P57-65

Xiong S.L., Zeng J., Han H.Q., *Influence of Hangzhou bay major bridge on water*, Proceedings of Zhejiang Institutes of Hydraulics and Estuary, Hangzhou, 2006, P1127-1136

Xu X.P., (2013), *Bridge of ship navigation safety and management - to Sutong bridge as an example*, China Water Transport,2013.11(Vol.13), P36-37

Xu T.J., *Safety evaluation research of Zhoushan sea area navigation environment ,* Master Dissertation of Dalian Maritime University,2008

Yu Yang,(2010),*Analyzing the environment safety of navigation in port taking Dalian port as an example*, Master Dissertation of Dalian Maritime

University,2010.06,P12-18

Zang J.M., (2014), *Research of FSA on piloting safety Evaluation of Ningbo Port Waters*, Master Dissertation of Dalian Maritime University, p5-11

Zhang P., (2007), *Assessment of the risk degree of navigation environment in waterway,* Master Dissertation of Dalian Maritime University,2007

Zhang D.H., (2007), *The integrative evaluation and implement tof harbor environment for the opening of navigation,* Master Dissertation of Dalian Maritime University, 2007, P2-4, P10-12, P29-64

Zhang S.G.,(2006),Weng Yao-zong,Xiong Zhen-nan, *Safety assessment of port sea-route and dock navigation,* Journal of Dalian Maritime University,2006.11(Vol.32),P43-47

Zhang W.&Chen Z.F., (2010), *A Bridge-waters Area Ship Safety Navigation System*, Traffic information and security, 2010.06(28), P40-43

Zheng Z.Y. &Li H.X.,(2008), *Study of Navigation Safety Evaluation in navigable Waters,*Navigation of China,2008.06.(Vol.31),P13-134

Zhong J.L., Yang Z.F., Zhao H.M.,(2011), *Accelerate the construction of jiaxing port of trinity, ports and logistics service system*,Port Perspective,2011.07,P15-18

Zhou Z.X., (2010), *Bridge sailing ship safety management,* Traffic information and security, 2010.1(28), P14-15

Zhu Y.H., (2002), *Risk analysis on the Hangzhou Bay Bridge during Project Construction*,Master Dissertation of Southwest Jiaotong University,2002,P37-40

Zhou Z.Y.,(2015),*Research on the Safety Assessement and Countermeasures of Hangzhou Bay Bridge Navigation Enviroment*, Master Dissertation of Dalian Maritime University, 2016,P7-10, P33-37

APPENDIX: A Questionnaire

"Hangzhou bay bridge navigation environment safety evaluation and Countermeasures" Questionnaire

Dear experts:

In order to carry out "the Hangzhou Bay sea crossing bridge navigation environment safety evaluation and countermeasure research", we need to use your professional knowledge to obtain navigation environment information, so we carry out investigation to the expert.

1. The questionnaire-1 is the importance index system comparison table.

    By the number in the table 1 below, the questionnaire 1 each vertical and horizontal bar as shown in the table each factor compared one by one.

Table-1   Scale 0.1 to Scale 0.9 importance comparison table

Scale	Definition	Description
0.5	Same important point	When compared to the two elements, the two are just as important
0.6	More important point	When compared to the two elements, the former is a little more important than the latter.
0.7	Obviously important point	When compared with the two elements, the former is more obviously important than the latter.
0.8	Strong important point	When compared to the

		two elements, the former is more strong important than the latter.
0.9	Extremely important point	When compared to the two elements, the former is more extremely important than the latter.
0.1,0.2 0.3,0.4	Reverse comparison	If the element Ai and element Aj are compared in order to get the judgment matrix Rij can get the element Ai and element Aj are compared to get the judgment Rji=1-Rij

For example, in the table below, horizontal column B is "obviously important", fill in "0.7"; longitudinal column B is "extremely important" than horizontal column C, fill in "0.9". D and self comparison, fill in "0.5".

Table-2 Grade sample

	A	B	C	D
A	0.5	0.7		
B	NONE	0.5	0.9	
C	NONE	NONE	0.5	
D	NONE	NONE	NONE	0.5

2. Questionnaire 2 was the risk grade of each factor.

For example the risk level in Table 3, "F factor" is judged for "high", fill in the corresponding column "√".

Table-3 "F factor" Risk level judgement

Degree of risk	Low Risk	Lower Risk	General Risk	Higher Risk	High Risk
F factor				√	

Questionnaire-A

The importance comparison of the 3 categories of indexes

	Natural environmental factors	Channel condition factors	Traffic environmental factors
Natural environmental factors	0.5		
Channel condition factors	NONE	0.5	
Traffic environmental factors	NONE	NONE	0.5

The importance comparison of the 3 indexes in the natural environment factor

	Wind	Flow	Fog and visibility
Wind	0.5		
Flow	NONE	0.5	
Fog and visibility	NONE	NONE	0.5

The importance comparison of the 3 indexes in the channel condition factor

	Channel width	Channel depth	Channel bend
Channel width	0.5		
Channel depth	NONE	0.5	
Channel bend	NONE	NONE	0.5

The importance Comparison of the 3 indexes in the traffic environmental factor

	Traffic flow	Obstruction	AIDS to navigation
Traffic flow	0.5		
Obstruction	NONE	0.5	
AIDS to navigation	NONE	NONE	0.5

APPENDIX: Questionnaire B

The risk Level of each factor

		Risk Level				
		Lowest risk	Lower risk	General risk	Higher risk	Highest risk
I N D E	Wind					
	Flow					
	Fog and visibility					
	Channel width					
	Channel depth					

X	Channel bend					
	Obstruction					
	Aids to navigation					