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Research on the collision risk of ships in Chengshanjiao Water based on SVM

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Research on the Collision Risk of Ships in Chengshanjiao Water Based on SVM

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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(Date): 30 June 2018

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Time flies, the life of the postgraduate is coming to an end. Fourteen months of study have benefited me a lot. And I am going to go out of the threshold of the campus. There recorded too much memory and touch of me in MSEM class. During this period of time, the schedules and arrangements were very compact. The students were very hard to learn and they already had to forget to eat in order to complete their study tasks. During the exam preparation week, our classmates helped and discussed with each other, then exchanged the expertise accumulated in their respective fields. This enabled us to have a broader perspective and a more complete and mature analysis in each subject.

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ABSTRACT

Title of Research paper: **Research on the collision risk of ships in Chengshanjiao water based on SVM**

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The TSS (traffic separation scheme) of Chengshanjiao promontory waters is the only one which was passed and recorded by IMO(International Maritime Organization)in China. This waters also became a high accident area because of the crossing traffic flows and massive fishing vessels during the fishing season. In order to reduce the probability of ship collision risk and prevent ship from the pollution accidents, MSA (Maritime Safety Administration) of China and Shandong brunch of MSA have organized some investigation, research and evaluation about this waters. In June 2014, The government of China had proposed a draft about amend of the TSS of Chengshanjiao waters and ship report scheme to the navigation sub-committee , communications sub-committee and search & rescue sub-committee which were established and organized IMO. The draft was passed by MSC No.94 conference. And this amend was officially implemented in June 1st 2015.

This paper involves tracing and collecting the information of ship traffic flow before and after the amend in Chengshanjiao promontory waters. And classify the collection data which about traffic flow, ship types and ship's speed into straight route and cross route; then longitudinal contrast with them. Quantifying the accident data by current standard accident level and established the evaluation index system of the accident consequence. And set up predict model of waters by means like SVM(support vector machine),IWRAP and Brown movement. And testify the amended data sample in 1 year, then analysis in order to get variable quantity of ship collision risk in Chengshanjiao TSS after amend and variable parameter which influence the collision risk. Based on this, comprehensively analysis the quantitative results of collision probability and collision consequences; then get variable quantity of TSS before and after amend in Chengshanjiao promontory waters in different channel part. Finally give a quantitative evaluation about TSS collision risk after amend.

In this paper, the collision consequence estimate and calculate based on SVM and single ship collision risk estimate example based on Brown movement have some value for refer in evaluate ship collision risk area.

Keywords: IWRAP-arithmetic; SVM; ;Brown movement; ;Chengshanjiao promontory waters

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LIST OF ABBREVIATIONS

AIS	Automatic identification system
IMO	International Maritime Organization
IWRAP	IALA Waterway Risk Assessment Program
MSA	Maritime Safety Association
TSS	Traffic Separate scheme
RBF	Radio Basis Function
SVM	Support Vector Machine
VTS	Vessel Traffic Service

Chapter 1 Introduction

1.1 Research background

Nowadays, under the circumstances of the rapid economic development of our China, the transportation industry as one of the fundamental industry has played a very important role in the rational allocation of resources and improvement of labor productivity, Water transport as the main means of trade transportation has always been a mainstay of the transport of goods in China. According to statistics in China, 99% iron ore, 93% foreign goods transport and 95% oil transportation is completed by maritime transport. Along with China’s sea transportation industry growing at the same time, the heavy vessel traffic flow density and many complex encounter situations on the coastal waters, the potential risk of ship accidents are increasing year by year.

Based on the above background, the Chengshanjiao waters in the northeast of Shandong peninsula are difficult to match the current economic development speed with the previously established channel traffic scheme due to the increasingly busy navigation environment.

As a result, In June 2014, the Chinese government put forward a proposal to revise the fixed line scheme and ship reporting scheme for the Chengshanjiao waters. The proposal was approved in November of the same year .

On March 5, 2015, the British hydro-meteorological bureau released the 10th issue of the marine notice which introduced the revised content of the ship's routeing and the modification of the chart.

In the following year, Ministry of transport issued the ship's routeing of Chengshanjiao waters (2015) and the No.19 Notice ship mandatory report scheme

(2015), and then the ship routing and ship reporting system (2015)They were implemented on June 1, 2015. On July 6, 2015, the Marine safety centre released the basic revision content of the "two schemes" in its 27th Maine notice.

Up to now, the revised ship's routeing has been in effect for more than two years. In the next period, the revised version of the ship's routeing in the waters of the Chengshanjiao water plays a better guarantee role in navigation safety and pollution prevention compared with previous revision. In addition, it has produced a good economy safety and social benefit to promote the development of coastal port economy.

1.2 Purpose And Significance Of the Research

In recent years, there are frequent merchant ships in the waters of Weihai. The usual routes of merchant ships are interlaced with many fisheries. So, water traffic accidents occur frequently in this area. According to the data of the Weihai maritime safety administration statistics. A total of 98 incidents occurred in the waters of Weihai from 2008 to 2016, in which 73 collision accidents account about 75% of total accidents. The collision accidents include casualties and economic losses. It can be seen that these accidents were mainly minor accidents whose number is 39 and take up about 53.4% of total accidents. There were 14 normal dangerous level accidents, about 19.2%. The proportion of major accidents and super major accidents are the same, both 13.7%. According to the incomplete statistics, the direct economic losses amounted to $445.58 million which are caused by the collision accidents during the last 8 years. In addition, 24 fishing boats sank in the accident, and the accidents caused 6 people died,9 people got hurt, 52 people missing. The accident detail refer to table 1.1; 1.2; 1.3.

Tab.1.1 Statistics of accidents from 2008 to 2016

Accident type	Grounding	Fire& Explosion	Collide	Sinking	Swell damag	Collision	
						Merchant ship	Merchant/ fishing ship
Number of accident	7	5	8	4	1	17	56

Tab.1.2 Statistics of collision accidents grade from 2008 to 2016

Accident level	Major accident	Serious accident	Ordinary accident	Minor accident
Number of accident	10	10	14	39

Tab.1.3 Statistics of collision accidents loss from 2008 to 2016

Direct economic loss（10,000）	Casualties（people）		
	Death	Hurt	losing
44515.8	6	9	52

The purpose of this paper is primary based on the statistical theory, IWRAP, Brownian movement and the model of ship risk assessment established by SVM. Then Chengshanjiao water as the research object was carried out to empirical analysis.

The feasibility of the model to promote the risk analysis of ship collision in similar waters is discussed.

1.3 Overseas and Domestic Research Status

1.3.1 Research status of ship risk analysis.

In the area of ship risk analysis, domestic research is relatively late compared with western developed countries, but it develops rapidly. In recent years, China has invested a lot of manpower and material resources in this field ,and regard as that as Important measures in order to support local economic development.

The professor Hui Ma used the grey system theory to quantify the risk of the ship manning environment. And the evaluation indexes that affect the risk are analyzed quantitatively.

Yongheng Xing referred to routeing system implementation effectiveness, economic efficiency and the three aspects of the impact of the waters, and combining the theory of fuzzy mathematics related to the Laotieshan canal ships routing system for performance evaluation.

Professor Fan Zhongzhou listed the various factors influencing the ships routing, and used the extension theory, grey theory and other mathematical methods to analyze the correlation between these factors and the impact on the ship’s routeing setting, thus established the comprehensive evaluation system, which can provide solutions on choose routes on different waters.

Sun jian and Wang Fengwu,etc established the factor set and comment set for the sailing situation of ships in the rough sea. Applying the D-S evidence theory to assess the safety scientifically.

Chu Lihui established the evaluation system by experts when he ensured the impact factors about the ship sailing safety around the adjacent water of Lianyun port. And he used the membership function via MATLAB simulation to secondly- identify the consequence to conform to the prediction.

Yang Tianxue, estimated the collision probability of ship and the method of collision consequence, and chose appropriate objects like are 30 ports such as Dandong, Dalian and Weihai by using the artificial neural network, they were used as training samples to build a neural network. The test samples are tested and ensure the results are satisfactory.

Ma Quandang, etc considered the Bohai gulf as the example and calculated the collision probability of the 10,000 GT bulks and oil ships under the cross route situation via the IWRAP model.

Dai jun,etc in order to obtain the generalized linear model, the accident probability is calculated, Based on Logistic model, the prediction model of ship collision accident in specific water area is established. Then, they take comparison test through the prediction of historical data and reality value.

Li Yajun established corresponding accident pattern mining model, using the fuzzy fault tree analysis method to discuss the fuzzy probability under different collision model of possibility distribution by collecting accident investigation report data.

Du Lei, etc established the model according to clustering algorithm and monte carlo simulation by extracting the feature points of the ship’s track; then made the estimation of collision probability of ships in free navigation area.

Internationally, the UK firstly proposed (Formal Safety Assessment, FSA) which apply to the ship traffic safety by extending the method (Probabilistic Risk Assessment, PRA).

Toke Koldborg Jensen et al. proposed a method to evaluate the efficiency of traffic separation in the waters with high density or restricted navigation. At the same time, Noue, K. proposed a quantitative model to evaluate the safety of ships in that navigation environment. Thus it can help route selection and development.

Tsou, M.C., proposed the method of finding the most seaworthy lines for ship navigation based on the ant colony algorithm in machine learning, so as to optimize the route and planning of the ship.

The United States has developed a predictable safety reference system and proposed (MSEP, Maritime Safety Evaluation Program). On this basis, Bee-hua Goh, Dimitri Val et al. demonstrated the applicability of the nonlinear model in the comprehensive evaluation plan for maritime safety is better.

In the field of ship routing, Y.C.Seong et al. incorporated traffic flow into consideration of determining the width of navigable channel.
S.J.B. ijlsma believed that the current and tide should be considered when determining the optimal route. Kum.S believed that the working strength and monitoring capability of VTS supervisors should be one of the influencing factors to evaluate the safety of ship navigation.

Rafal Szlapczynski innovatively applied evolutionary algorithm to simulation study of ship's optimal trajectory.

Curtis studied the effect of ship overtaking on channel width. On this basis, The minimum safe overtaking distance(MOSD) of the ship under the poor visibility was proposed. It is pointed out that the minimum width should be satisfied when designing the traffic system.

Abdel-galil studied the relationship between the width of the channel and the size of the ship, and applied the results of the research in field of ship. Then he proposed the concept of Standard Separation of ships. Abdel-galil suggested that it could determine the width of the channel according to the width of the standard separation. And the Japanese scholar Cane determined the ship in crowded waters and manning. The channel width of the restricted waters was evaluated. The relationship between the width of roadway and ship location was studied.

By referring to the above literature, we conclude that the previous risk assessment in the waters is mainly about the impact of collision and comprehensive evaluation of the probability of collision. This paper draws on the previous research results and takes the above two risk factors in order to quantitatively evaluate the collision risk of ship in the Chengshanjiao TSS.

1.3.2 Research status of SVM

So far, the artificial intelligence algorithm based on the SVM is mainly applied on the economy and management. Palaniswami and Fan proposed the optimization method of the penalty factor, which improved the effectiveness and accuracy of the sample selection. Tony et al predicted the one-week period government bond and got more accurate consequence.

Compared with the application of financial domain, SVM is still in the early stage on Marine traffic operation.

Chen shaoyang established the evaluation model of navigation risk in port waters by support vector machine, and the particle swarm optimization algorithm was adopted in the selection of support vector machine learning training parameters. which improved the learning efficiency and analysis effect of support vector machine model.

Li jun, taking the ships of the Yangtze river basin as an example, established the forecasting model of ship traffic accident by means of support vector machine, and obtained satisfactory output.

The SVM model is mainly applied in the financial field and some other statistical fields, which is similar to the artificial neural network machine learning algorithm, but it is different from the artificial neural net. The SVM does not need a large amount of training samples to establish the accurate prediction model. But because of the actual frequency of occurrence is relatively low to the ship collision samples, the advantage of the low sample value is that the SVM could be good in the model of the ship collision in evaluate water.

1.3.3Research status of Brownian motion model

The Brownian movement was initially mainly applied to the stock options in the financial sector, which was a starting point in the field of transportation engineering.

In aviation, in the master dissertation of Gao Junying of the stochastic differential equation was established based on Brownian motion in the air of free flight two aircrafts in different relative position relations such as crossover and synthetic for collision risk analysis, at the same time the literature assumes that the principle is based on the plane projection in the same horizontal plane, so for the applicability of the shipping transportation is the same.

Li Dan and Cui Deguang take the uncertainty factors which affect the aircraft as a Brownian motion. By using the theory of Brownian motion detection for air traffic conflict of short-term. In this paper, Brownian motion model was put forward under the variance of growth direct ratio with time increase point of view.

Yu Sheng and Zhang zhaoning projected the plane's three-dimensional flight to a horizontal projection plane and a vertical plane. Via Brownian motion is described as the random positioning error, and proposed the probability evaluation model of multi-machine collision

Brownian motion model is mainly used in aviation, but when in the aviation field impact assessment model, the first thing to evaluation object projection to the same level to calculate again. So, trying the model in the space in the waters of the collision risk assessment also has the feasibility.

1.4 Research thoughts and methods

This paper firstly collects and analyzes the overall navigation condition of the waters of Chengshanjiao and the before and after the revision traffic flow accident data of the external traffic control system. And then use IWRAP and Brownian motion to establish the mathematical model of collision probability. From macro and micro linear route and alert and mutual influence between different form the Angle of multiple revision before and after the ship collision probability comprehensive comparison and analysis.

On this basis, in this paper, support vector machine (SVM) was applied to historical data for machine learning and revised the waters before actual commercial fishing vessel collision between parameters as learning samples, then select the appropriate input indicators to revise before the waters of the accident consequences of collision prediction model is established with the training sample data. Finally, predicte and revise the waters of collision consequences for evaluation.

Finally, the above two factors were combined to obtain the comparison of water risks before and after the revision of the navigation system of the outside of the mountain area, and the corresponding conclusions were drawn.

Chapter 2 A brief introduction of the TSS in Chengshanjiao waters

2.1 Overview of the route in Chengshanjiao water

According to the Mandatory ship reporting scheme in Chengshanjiao water (2015) and the Ship routing system in the Chengshanjiao waters(2015) printed and distributed by Ministry of Transport. The latest edition of Chengshanjiao water area TSS schematic diagram are as follows.

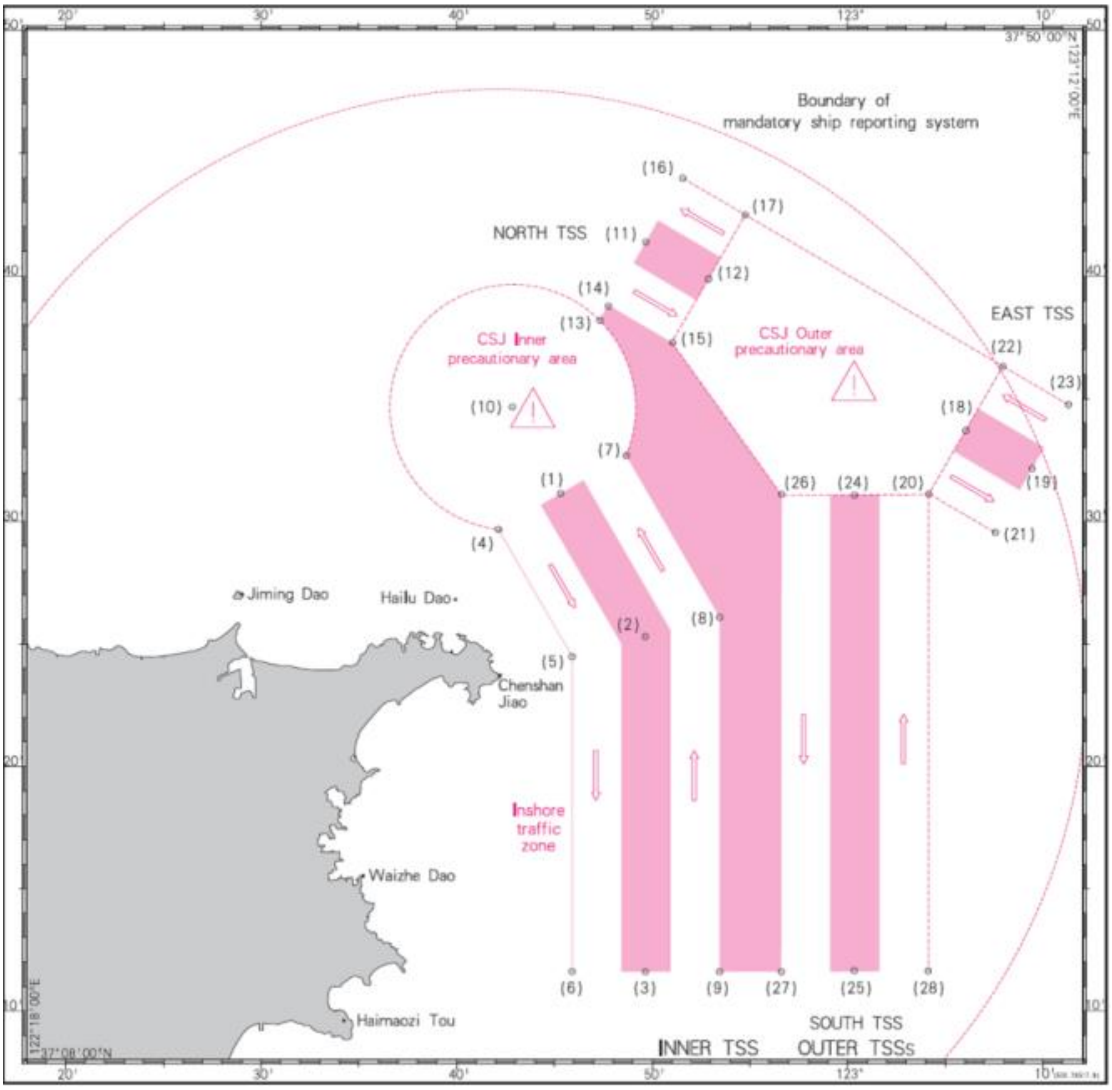

Fig 2.1 New edition of Chengshanjiao water area TSS schematic diagram(2015.6)

From the diagram, the new edition TSS is separated into internal TSS and external TSS. External TSS consists of the North, South and East TSS and external alert area. The paper mainly analyzes the changes of water risks before and after the revision of the external TSS.

2.2 Investigation and analysis of Marine traffic situation in Chengshanjiao water

According to the data from the Weihai MSA, this paper chose the door line data in the surrounding waters from the Jun 1 2015 to May 31 2016. Thus, the capture software can just screen-cut the door line by month and season.

Fig 2.2 The Gate-line of Chengshanjiao water area TSS schematic diagram

Tab 2.1Statistics of the ship flow rate

Door line	Passenger ship	Cargo	Non-transport ship	Dangerous Goods ship	Total
External TSS(door line 2+3)	1064	11648	2119	12550	27381
North of the external TSS(door line 5)	401	9523	2967	7016	19907
total	1465	21171	5086	19566	47288

The research subject of this paper is external TSS in Chengshanjiao water and collect the ship traffic volume information of the external TSS. From a year statistic about the door line volume of ships with Class A AIS, we can see that dangerous good ships(45.6%) and ships beyond 180m(50%) in external separate routes were obviously more than the same kings ships in internal separate routes(21%,23.3%). That means the external separate routes constituted a large portion of Chengshanjiao traffic flow, moreover mostly large ships. So it is significant for safety supervision to evaluate the risk change after amending the TSS of Chengshanjiao water.

2.3 Investigation and analysis of the traffic accidents in Chengshanjiao water

There is frequent merchant shipping in the waters of Chengshanjiao, besides many fishing vessels in the area. There are many overlaps between fishing areas and merchant ships routes. So there are frequent traffic accidents in the water area. From 2008 to March 2016,the total number of maritime accidents was 98.

Tab. 2.2 Distribution of the type of water accident under the jurisdiction of Weihai MSA from Jun 2008 to Mar 2016

Accident type	Grounding	Fire& Explosion	Collide	Sinking	Swell damage	Collision	
						Merchant ship	Merchant/fishing boat
Number of accident	7	5	8	4	1	17	56

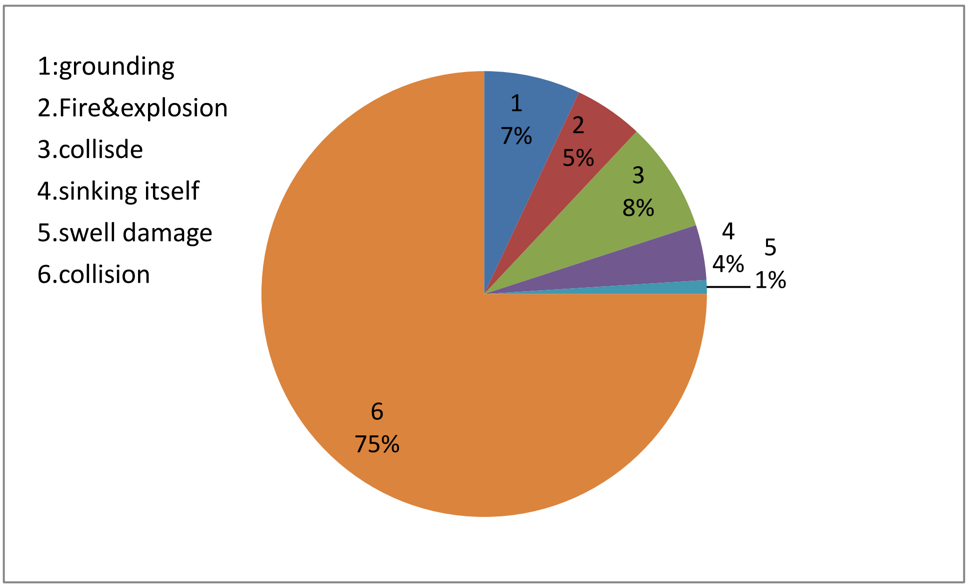

Fig.2.3 Pie chart of the type of water accident under the jurisdiction of Weihai MSA

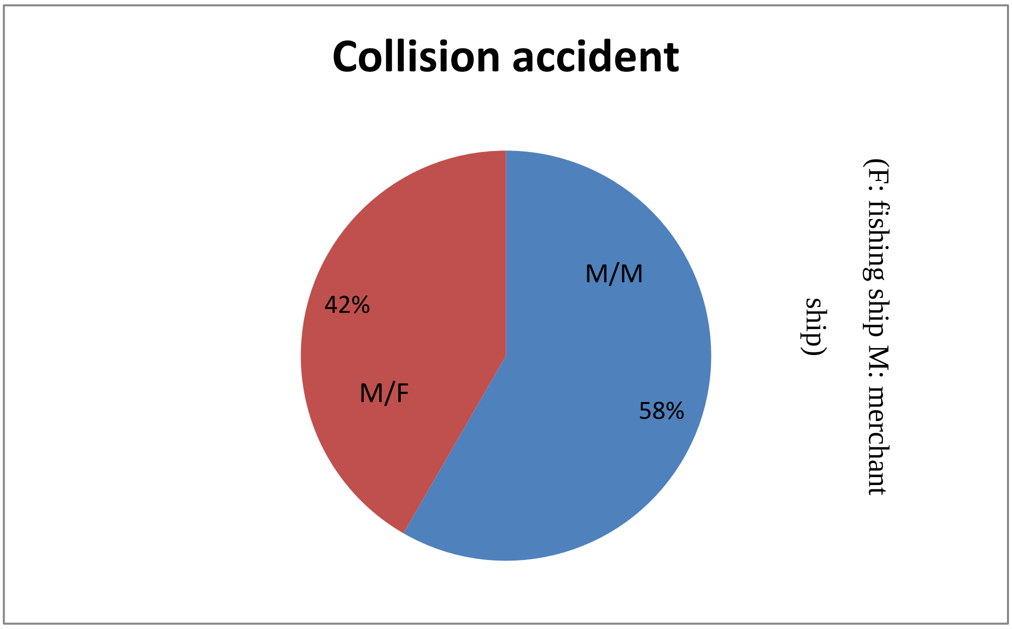

Fig.2.4 2008-2016 Pie chart of the type of water accident under the jurisdiction of Weihai MSA

As can be seen from the above chart, the water accident in the water area is mainly collision, accounting for 74.5% of the accident.

Only 25.5% of accidents occurred due to their own reasons, indicating that the area was in a traffic hub and the traffic was very dense.

The busy features lead to higher risk of collision in the whole water area. And in the collision accident, in the commercial fishing boats.

The collision, which accounts for 77% of the collision, indicates that the collision risk and the consequences of a collision between a merchant ship and a fishing boat should be considered in the assessment of the collision risk.

2.4 Chapter summary

This chapter mainly introduces the development process from the establishment to the revision of the traffic separation system in Chengshanjiao, as well as in this period.

The monitoring measures and the historical data are collected by the Weihai MSA

It is very important to establish reasonable collision probability calculation model and impact evaluation model.

The precondition is also the comparative data of the empirical analysis.

Chapter 3 Introduction and modelling of ship collision probability algorithm

Due to the dense traffic flow in the external traffic system of the Chengshanjiao, ships sailing fast and the fishing area are separated. It is of great significance to make the ships safer in the waters by estimating the collision probability of ships in the water.

Based on the previous research, the IWRAP algorithm is used to carry out in the large amount of estimation method of collision probability to modelling macro collision probability estimation.

At the same time, the algorithm and application conditions of Brownian motion model in the aviation field are also reviewed, and the collision probability estimation model is extended to the specific two ships in the water area.

3.1 Establishment of Brownian motion model

The Brownian motion is used as the random movement of small particles. Later, people used this motion to describe the uncertain events in real situation. The first Brownian movement was used in the financial field to simulate random fluctuations in the stock market.

Then the Brownian movement was introduced into the field of transportation engineering, which described the uncertainty of aircraft freely flying and the unpredictability of human factors in traffic. Compared with the field of financial mathematics, Brownian motion still belongs to the initial stage in the field of transportation engineering.

3.1.1 The basic assumptions of the model

The random process of Brownian motion on the probabilistic space Ω is $\{W(t, w); t \geq 0\}$, it meet:

1.The initial value is zero: $\forall w \in \Omega$, $W(0, w)=0$

2.Normality: For 0≤s＜1, W(t)-W(s)-N(μt-s, δt-s). For different moment "t", μ doesn't have be equal, it changed with the time. It showed the fluctuation centre of the {W(t, w);t≥0} in different moment. Image 3.1 as followes.

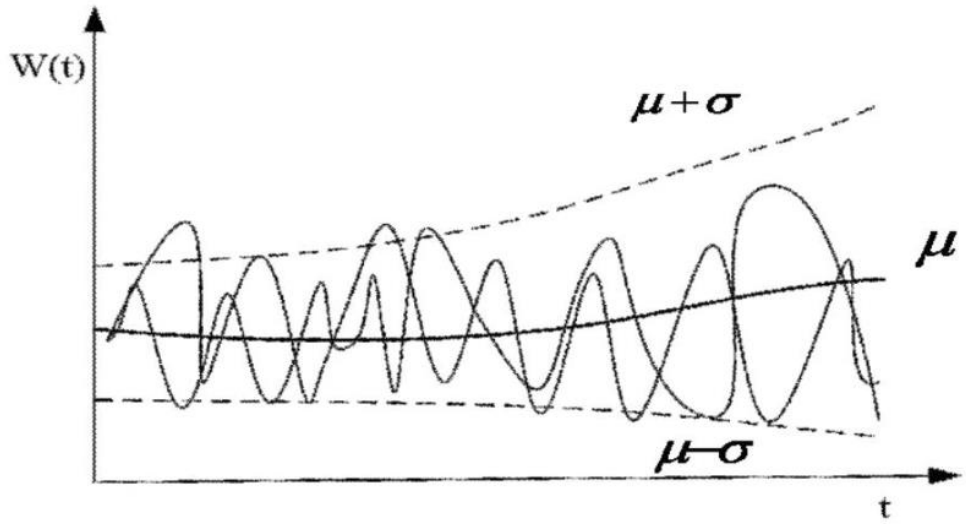

Fig .3.1 Schematic diagram of the average and variance correspond to time in random process

3.Independent increment property: W(t2-t1),W(t3-t2),W(t4-t3),….,W(t2n-t2n-1) ,they are independent. And we make the W meet the Brown motion, the function of the ship position "X":

$$dX=adt+bdW$$

adt represent the change of the ship position with the time. And bdW is considered as the noise and fluctuation of the changing route of the X. See figure 3.2. The actual motion of the ship can be seen as a linear motion process superimposed on a random motion process.

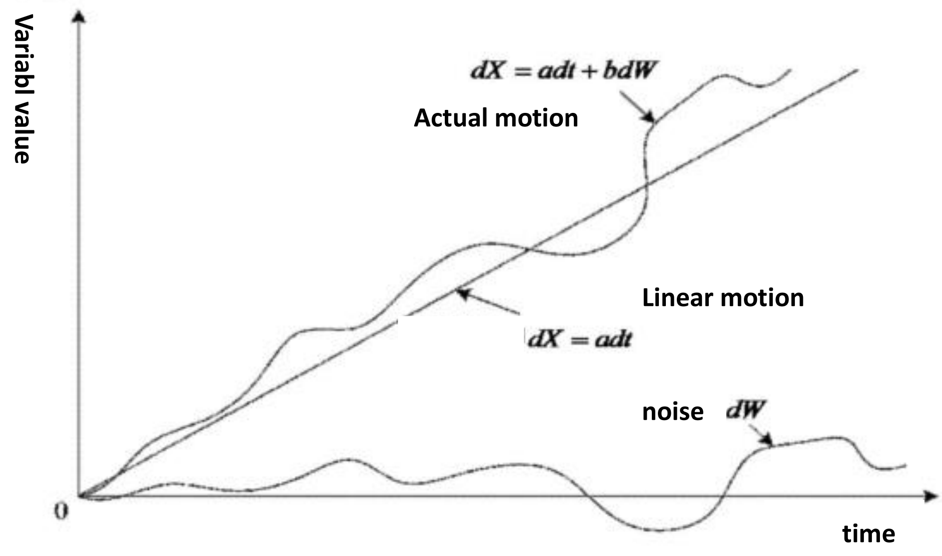

Fig.3.2 Movement of ship position schematic diagram

Thus, Since Brownian motion is based on the independent random time of probability theory. In order to assess the risk of collision, the following assumptions are required:

1.The position of the ship is independent.

2.Regardless of the weather and other factors

3.Do not consider the influence of the controller on the ship.

Because of the purpose of this research is to determine the change of ship collision risk in the same water area before and after the course revision. Meteorological factors have not changed much before and after the revision, so it can be used as irrelevant factors; Besides，Because Brownian motion is applied to the collision probability calculation of two ships in this paper in order to calculate the lower limit of the probability of collision before and after revision. Therefore, the impact of the controller is also applicable to the purpose of this research.

3.1.2 Collision probability model with the same direction.

Assuming ship A, ship B have the same direction, the initial distance between them is Δx, the speed are V1 and v2, and A is behind B, v1＞v2, so the relative speed is Δv= v1-v2. The stochastic differential equation of the ship direction :

$$\begin{cases} dSx(t) = \Delta vdt + \sigma 1dWx(t) \\ dSy(t) = \sigma 2dWx(t) \end{cases}$$

Sx, Sy are the relative distance on the sailing direction and the relative distance perpendicular to the direction of navigation. σ1,σ2 are the variance growth rate of the corresponding two directions in relative distance, and independent of each other. Wx, Wy are the standard one - dimensional Brownian motion and both are independent of each other.

Making the coordinate system turn into the standard Brown motion for ship A at origin point. Ship B move to the ship A at the constant speed Vd=| Δv|/σ1. The initial relative distance is translate to d= Δx/σ1, Refer to Fig 3.3, K and Sis the value of the major axis and minor axis of ellipse under the Fuji ship model. K=0.8/σ2,S=2L/σ1(ps: L is the length of the ship to be overtaken).

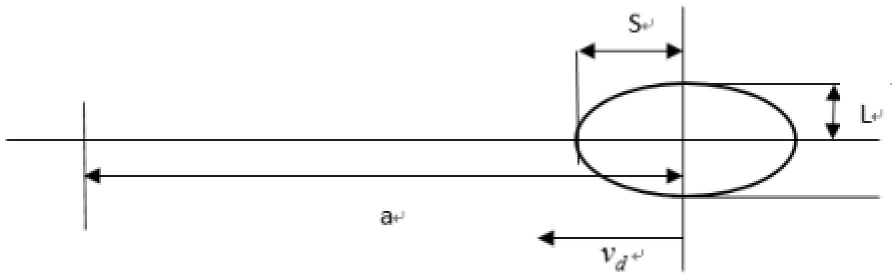

Fig. 3.3 Schematic diagram of the probability under the ship overtaking

When solving this model, it is necessary to integrate the irregular plane, but the closed surface can not be obtained, so the approximation method is used to solve it. Regard τ as the Wt(The first collision to the ship's central axis L), Event A={|Wy(τ)| ≤L}, so A∈C, P(A) ≤P(C). That can prove when the growth rate of Brownian motion variance is much smaller than the relative speed of the two ships. The risk of collision at some moment P(C) ≈P(A).

So, the approximate collision risk P(A) of the two ships overtaking in the form of T time is P(A):

$$P(A) = \int_0^T P_\tau(t)\left[1 - 2Q\left(\frac{K}{\sqrt{t}}\right)\right]\mathrm{d}t$$

There into：

$$P_\tau(t) = \frac{a}{\sqrt{2\pi t^3}} e^{\left(-\frac{a-\Delta v t^2}{2t}\right)}$$

$$Q(x) = \int_x^\infty \frac{1}{\sqrt{2\pi}} e^{\left(-\frac{t^2}{2}\right)} \mathrm{d}t$$

3.1.3 Collision probability model under cross-channel.

If there are two ships A and B sailing along the cross route, and the speed is v1 and v2, and A is behind B, v1＞v2, so the relative speed is Δv= v2- v1. The initial relative distance is Δx along the axis x, the initial relative distance is Δy along the axis y. See Fig 3.4.

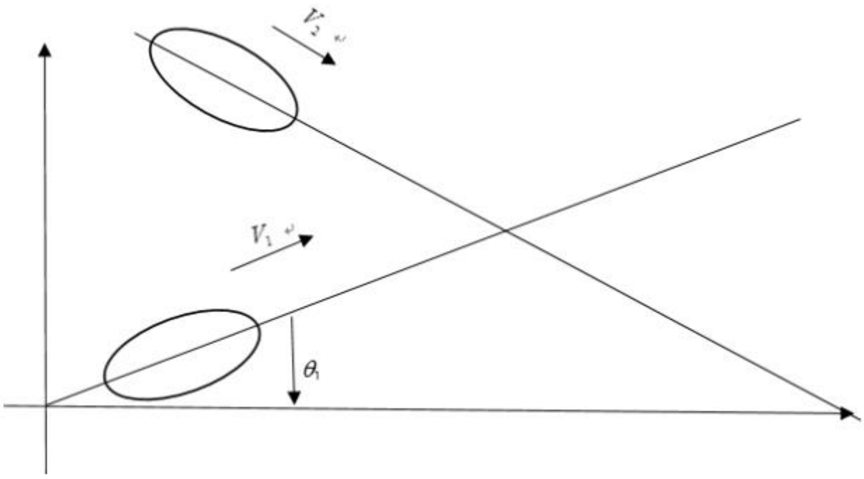

Fig.3.4 Schematic diagram of the probability under the ship crossing

The stochastic differential equation for ship A and ship B :

$$\begin{cases} \mathrm{d}\,X_t^1 = R_{\theta_1} v_1 \mathrm{d}t + R_{\theta_1} \Sigma^1 \,\mathrm{d}\,W_t^1 \\ \mathrm{d}\,X_t^2 = R_{\theta_2} v_2 \mathrm{d}t + R_{\theta_2} \Sigma^2 \,\mathrm{d}\,W_t^2 \end{cases}$$

Where:

$$\Sigma = diag(\sigma_a, \sigma_c)$$

$$R_\theta = \begin{pmatrix} \cos\theta & -\sin\theta \\ \sin\theta & \cos\theta \end{pmatrix}$$

X_t^1, X_t^2 represent the position at moment t of ship A and ship B, σa, σc represent the Variance growth rate on the sailing direction and perpendicular sailing direction. Then σa ＞ σc, and they are independent. W_t^1, W_t^2 are the independent standard 2-dimension Brownian motion.

Similar to the overtaking situation, the two ships' coordinating systems need to be transformed. Ship A is considered to be the standard Brownian motion at the origin, and ship B is moving at A relative speed Δv to ship A. The initial relative distance along the direction of navigation is converted to a.

$$a = \frac{p_x v_1 + p_y v_2}{\sqrt{v_1^2 + v_2^2}}$$

(PS: Px, Py are the relative position of two ships)

The initial relative position perpendicular to the direction of navigation is converted into b.

$$|b = \frac{|p_x v_1 - p_y v_2|}{\sqrt{v_1^2 + v_2^2}}$$

When the Wt enters the ship domain, the collision may occur. Similarly, the approximate collision probability of two ships under the situation of the encounter situation is obtained in period of time T.

$$P(A) = \int_0^T P_\tau(t)\left[Q\left(\frac{b-K}{\sqrt{t}}\right) - Q\left(\frac{b+K}{\sqrt{t}}\right)\right]\mathrm{d}t$$

Where:

$$K = \frac{0.8L}{\lambda_1 \lambda_2}\sqrt{\frac{v_1^2 \lambda_1^2 + v_1^2 \lambda_2^2}{2(v_1^2 + v_1^2)}}$$

$$\lambda_1 = \sqrt{\sigma_a^2 \cos^2(\frac{\theta}{2}) + \sigma_c^2 \sin^2(\frac{\theta}{2})}$$

$$\lambda_2 = \sqrt{\sigma_a^2 \sin^2(\frac{\theta}{2}) + \sigma_c^2 \cos^2(\frac{\theta}{2})}$$

$$Q(x) = \int_x^\infty \frac{1}{\sqrt{2\pi}} e^{\left(-\frac{t^2}{2}\right)} \mathrm{d}t$$

3.2 Establishment of IWRAP model

As a mathematical model estimating the collision probability of ships in the water, IWRAP combines the historical data of accident cause and AIS(Automatic Identification System). According to the type of water area, the model can be divided into two kinds of collision of straight route water and cross route water collision, and the collision situation of different waters corresponds to the corresponding geometrical collision model. The general formula is:

$$F = N_G \cdot P_C$$

$$\lambda = F / Q$$

Where, NG is the amount of the geometric collision ships during a year. PC is the reason probability. F is the amount of the collision ships. Q is the traffic value of ship in the water. λ is the ship collision probability.

It needs to mention that Pc can be influenced by many factors. In order to be brief，the paper regards default accident coefficient in IWRAP MKII software as the value of the reason probability

Tab.3.1 Reason probability value table

Accident situation	Pc(×10-4)	Accident situation	Pc(×10-4)
Heading collision	0.5	Bending collision	1.3

Overtaking collision	1.1	Coverage collision	1.3
Crossing collision	1.3	Grounding	1.6

3.2.1 Geometric collision model of straight channel

Under IWRAP straight channel collision geometric model, the ships heading to each other , the situation of collision happen like the diagram.

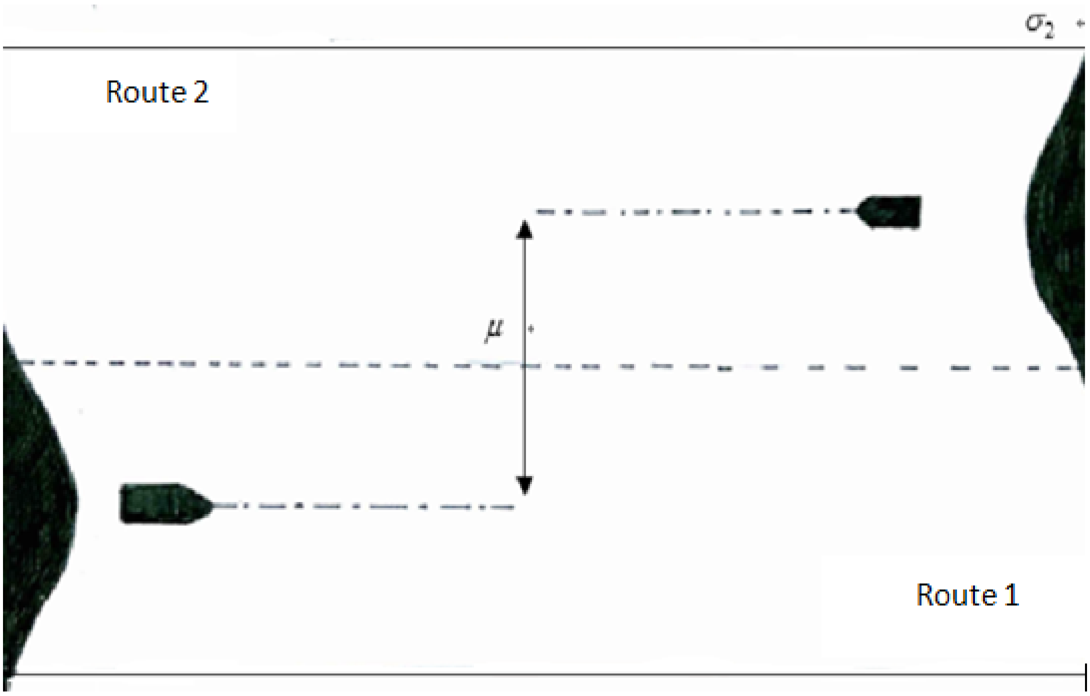

Fig. 3.5 Schematic diagram of collision probability in straight channel

At this moment, the traffic flow in the channel obeys normal distribution, the Geometry collision ship quantity formula of two ships as follow:

$$N_G^{head-on} = L_w \sum_{i,j} P_{G_{i,j}}^{head-on} \frac{v_{ij}}{v_i v_j}(Q_i Q_j)$$

Where: V_{ij} is the relative speed between two ships. Lw is the length of the channel,Q1, Q2 are the traffic flow of a kind of ships in the channel. V_i, V_j are the ship speed, $P_{Gij}^{head-on}$ is the accident probability of the collision which happened between two ships. The formula is:

$$P_{G_{i,j}}^{head-on}=\int_{-\infty}^{\infty}\int_{-y_i-\bar{B}}^{-y_i+\bar{B}} f(y_i)f(y_j)dy_i dy_j$$

After simplification:

$$P_{G_{i,j}}^{head-on} = \phi(\frac{\overline{B_{ij}} - \mu_{ij}}{\sigma_{ij}}) - \phi(-\frac{\overline{B_{ij}} + \mu_{ij}}{\sigma_{ij}})$$

Where, φ(x) is normal distribution function, μij is the transverse distance between the two ships. σij is joint distribution standard deviation. $\overline{B_{ij}}$ is the ship average breadth.

3.2.2Geometric collision model of cross channel

See figure 3.6,it is risk area of ships collision of two cross route. IWRAP model define two ships with a cross Angle between 10 °and 170 °.

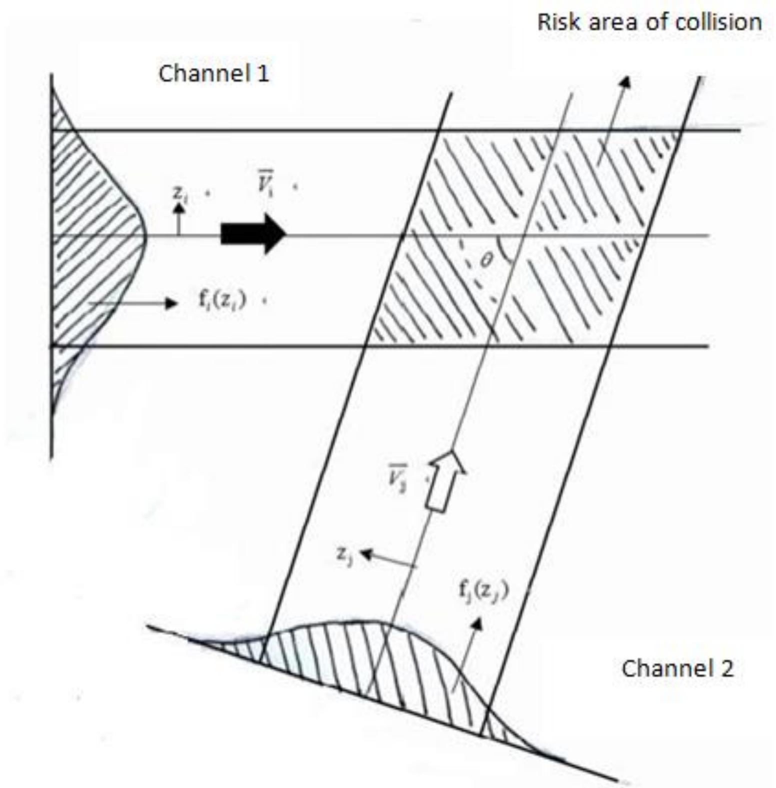

Fig. 3.6 Schematic diagram of collision probability in crossing channel.

The probability formula of the collision of the ship is as follows:

$$N_G^{crossing} = \sum_{i,j} \frac{Q_i Q_j}{V_i V_j} D_{ij} V_{ij} \frac{1}{\sin\theta}$$

Where: Q_i, Q_j are on behalf of the traffic flow of ship per time unit in channel, V_i,V_j are sip speed, V_{ij} are the relative speed between two ships, D_{ij} is the geometry collision diameter, θis the channel crossing angle.

Where:

$$V_{ij} = \sqrt{V_i^2 + V_j^2 - 2V_i V_j \cos\theta}$$

$$D_{ij} = \frac{L_i V_j + L_j V_i}{V_{ij}} \sin\theta + B_j \left[1 - \left(\sin\theta \frac{V_i}{V_{ij}}\right)^2\right]^{\frac{1}{2}} + B_i \left[1 - \left(\sin\theta \frac{V_j}{V_{ij}}\right)^2\right]^{\frac{1}{2}}$$

(L-length, B- Breadth)

3.3 Chapter summary

This chapter introduced the mathematical modelling of collision probability in the ship collision risk in the external traffic separation system of the Chengshanjiao. Two mathematical models based on Brownian motion and IWRAP were involved. The Brownian motion is a model of collision probability of two ships in the channel. It was used to evaluate the improvement effect before and after the revision of the water area. The IWRAP algorithm was used to calculate the collision probability of ships in the whole water area. It was further divided into two parts: the straight line and the warning area. The purpose was to evaluate the reduce degree of the probability of the ship collision in the external Chengshanjiao water.

Chapter 4 Support vector machine algorithm introduction and modelling

In a certain water area, the size of the collision risk of a ship is not only affected by the probability of collision, but also related to the consequences of the collision. In the recent research literature on the impact assessment, it is found that collision consequence may be in collision with ship's tonnage, collision angle, ship speed and collision position, type of ship, age of ship and other factors.

Based on the previous research, this paper adopts the regression algorithm of SVM in machine learning to affect the ship collision to establish Model, which is a significant advantage over other machine learning methods. Because it requires only a small amount training samples to find suitable support vectors for simulation prediction and to get the corresponding results within a given error range. In the last ten years, there have been more than 20 incidents of commercial and commercial vessel collision. The current situation of this model is more applicable to other machine learning methods such as neural network.

4.1 Establishment of SVM regression model

4.1.1 Support vector machine principle introduction

Support Vector Machine (SVM) is a kind of finite data set.A machine Learning method of Statistical Learning Theory (SLT) is developed by Vapnik. And proposed by Chervonenkis in 1971. The two scholars used the large number theorem in the functional space. The principle of structural risk minimization lays the foundation for pattern recognition learning theory. In machine learning. Artificial Neural Networks (ANN), bayesian theory, etc. The support vector machine can calculate the learning law in the case of limited samples.

The basic idea of support vector machine can be described by the linear two-dimensional optimal classification surface shown in FIG. 4.1

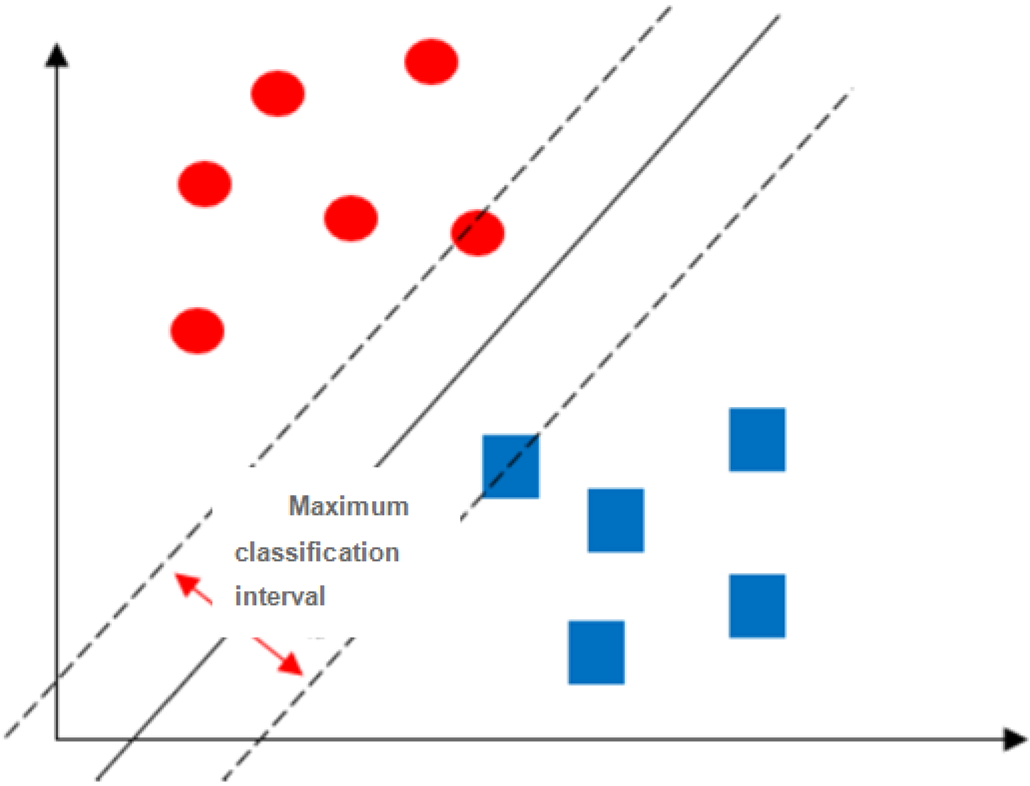

Fig. 4.1 Schematic diagram the optimized classifying level

As shown in the figure above, the real line is the classification line separating the upper and lower classes of samples, while the two sides are dashed to the classification line. The distance is the classification interval (Margin). And the optimal classification line, that is, when the two dashed lines reach the maximum classification interval. The centreline of the Maximum margin. The above situation is extended to three dimensional space, which is the optimal classification line. For optimal classification surface.

4.1.2 linearly separable

(xi,yj), i=1,2,…,n, xi∈Rd，yi∈{1,-1}, The general form of the linear discriminant function is f(x)= ω*x +b , The corresponding classification equation is as follows:

ω*x+b=0 (4.1)

The discriminant function is normalized, make |f(x)| ≥1,Where:

yi(ω*x+b)-1≥0, i=1,2,…,n (4.2)

Where: the class interval is $\frac{2}{||\omega||}$,the interval maximum equivalent to minimum||ω||2. So satisfy the formula ,and make the optimal classification surface is when $\frac{1}{2}||\omega||$ 2 is minimum.

Therefore, the optimal classification surface problem can be expressed as a constrained optimization problem. Then under the constraint of the formula 4.2,we find the minimum value of the following function:

$$\varphi(\boldsymbol{\omega})=\frac{1}{2}\|\boldsymbol{\omega}\|^2 \qquad (4.3)$$

In order to solve the equations, make the Lagrange function as follow:

$$L(\boldsymbol{\omega}, b, \alpha)=\frac{1}{2}\|\boldsymbol{\omega}\|^2-\sum_{i=1}^{n}\alpha_i[y_i(\boldsymbol{\omega}\cdot\boldsymbol{x_i}+b)-1] \qquad (4.4)$$

αi is the multiplier of the Lagrange. To find the minimum value of the Lagrange function, Partial differential with respect to ω, b, α_i, and make the value of them into zero, so:

$$\begin{cases}\frac{\partial L}{\partial \boldsymbol{\omega}}=0 \Rightarrow \boldsymbol{\omega}=\sum_{i=1}^{n}\alpha_i y_i \boldsymbol{x_i}\\ \frac{\partial L}{\partial b}=0 \Rightarrow \sum_{i=1}^{n}\alpha_i y_i=0\\ \frac{\partial L}{\partial \alpha_i}=0 \Rightarrow \alpha_i[y_i(\boldsymbol{\omega}\cdot\boldsymbol{x_i}+b)-1]=0\end{cases} \qquad (4.5)$$

According to (4.2) and (4.5), we can transform the optimal classification surface face problem to the dual problem of convex quadratic programming:

$$\begin{cases}\max\sum_{i=1}^{n}\alpha_i-\frac{1}{2}\sum_{i=1}^{n}\sum_{j=1}^{n}\alpha_i\alpha_j y_i y_j(\boldsymbol{x_i}\cdot\boldsymbol{x}_j)\\ \alpha_i\ge 0, i=1,\cdots,n\\ \sum_{j=1}^{n}\alpha_i y_i=0\end{cases} \qquad (4.6)$$

Where, αi is the multiplier of the Lagrange.

The (4.6) exist unique solution. If α_i^* have the optimal solution, there are:

$$\boldsymbol{\omega}^*=\sum_{i=1}^{n}\alpha_i^* y_i \boldsymbol{x}_i \qquad (4.7)$$

Where, SV α_i^* is sample not equal to zero.

Plugging SV in constraint condition of formula(4.6), then get the optimal classification surface function:

$$f(\boldsymbol{x}) = \operatorname{sgn}\left\{\sum_{i=1}^{n} \alpha_i^* y_i (\boldsymbol{x}_i \cdot \boldsymbol{x}) + b^*\right\} \quad (4.8)$$

b* is the threshold of classification.

We can use the formula(4.2) to get b* , or obtained via whichever kind of two kinds of SV. Formula(4.8) is the general description of the SVM.

4.1.3 linearly non-separable

As we can see from (4.2), for linearly non-separable, we can not effectively separate two kinds of sample by a classification surface. At this time, we quote the relaxing factor, so we allow the classification exist. Therefore, the (4.1) needs to satisfy the requirement as follows:

$$y_i \cdot (\boldsymbol{\omega} \cdot \boldsymbol{x_i} + b) \geq 1 - \mu_i, \ \ i = 1,2 \ldots, n \quad (4.9)$$

At the same time, based on formula(4.3) we add the penalty term $C\sum_{i=1}^{n} \mu I$, then the target function becomes:

$$y_i \cdot (\boldsymbol{\omega} \cdot \boldsymbol{x_i} + b) \geq 1 - \mu_i, \ \ i = 1,2 \ldots, n \quad (4.10)$$

Where: C is arithmetic number, named penalty factor. Correspondingly, formula(3.6) becomes:

$$\begin{cases} \max \sum_{i=1}^{n} \alpha_i - \frac{1}{2} \sum_{i=1}^{n} \sum_{j=1}^{n} \alpha_i \alpha_j y_i y_j (\boldsymbol{x}_i \cdot \boldsymbol{x}_j) & \\ 0 \leq \alpha_i \leq C, & i = 1, \cdots, n \\ \sum_{i=1}^{n} \alpha_i y_i = 0 & \end{cases} \quad (4.11)$$

When αi ＞0, xi is the SV.

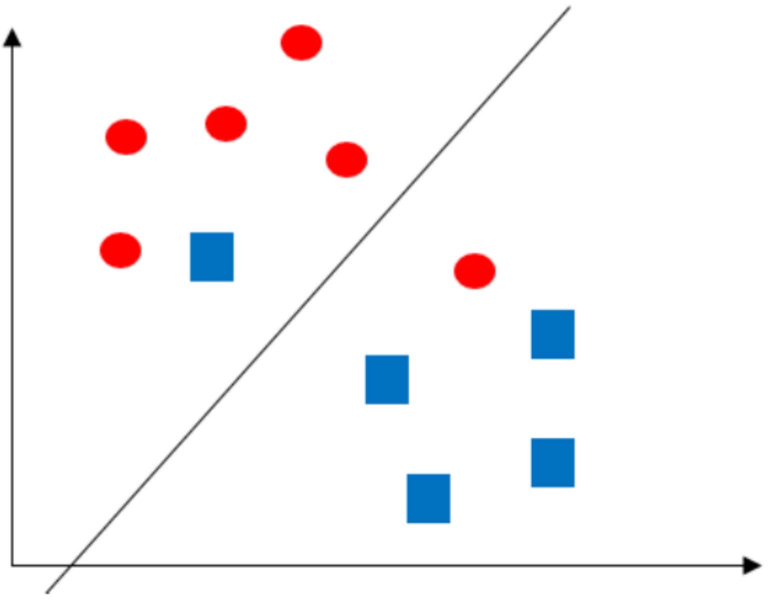

Fig4.2 Linear unsparable situation

4.1.4 Nonlinear situation

In the above two sections, the optimal classification problem is obtained. However, most of the classification in practical applications cannot be accurately differentiated by linear means. For example(4.3), that involve the nonlinear classification

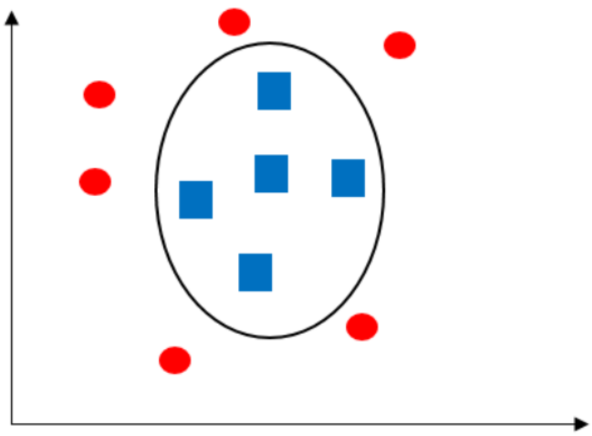

Fig4.3 Nonlinear situation

For nonlinear situation, we need to do a nonlinear transformation, It is mapped to a higher dimensional space by some function. Then, find the optimal classification plane in high dimensional space. The functions we use are called kernel functions.

Take two dimensional nonlinear classification problem as an example, Fig 4.4, After mapping to high dimensional space, it can be transformed into a convex quadratic programming linear optimization problem.

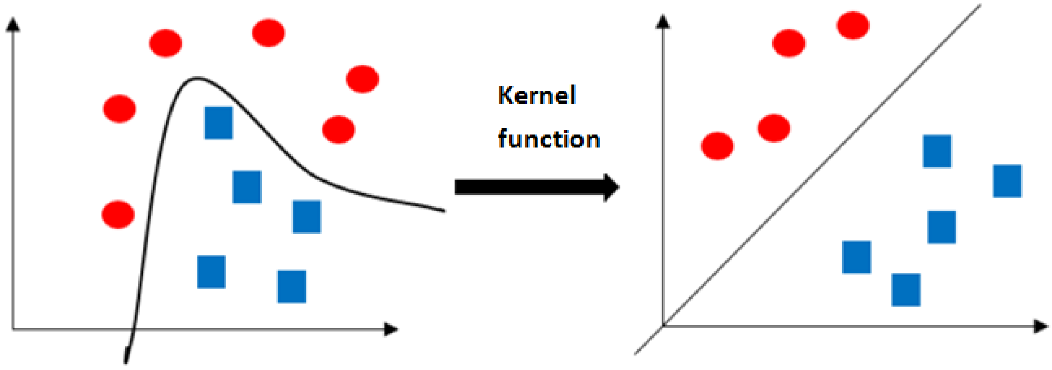

Fig4.4 Schematic diagram mapping by Kernel function to high dimension

At the same time, we can see from (4.6),(4.8), Whether the target function or the optimal classification function. All the training samples involve only dot product, So there's no separate x. Therefore, it is only necessary to realize the dot product operation of kernel function in high dimensional space. we don't have to figure out the exact expression for the kernel function in the high dimensional space.

Thus, Dot product kernel function G(xi, xj),then the target function transform to the (4.12):

$$Q(\alpha)=\sum_{i=1}^{n}\alpha_i-\frac{1}{2}\sum_{i=1}^{n}\sum_{j=1}^{n}\alpha_i\alpha_j y_i y_j K(x_i,x_j) \quad (4.12)$$

Accordingly, the classification function becomes the formula(4.13):

$$f(\boldsymbol{x})=\mathrm{sgn}(\sum_{i=1}^{n}\alpha_i^* y_i K(\boldsymbol{x}_i,\boldsymbol{x})+b^*) \quad (4.13)$$

By doing so, the problem of dimension disaster in the algorithm is solved. When constructing the discriminant function, the comparison vector in the input space is eliminated, and the non-linear transformation of the sample is eliminated.

1.Choice of kernel function

In support vector machines, the key to determine the predictive ability of SVM analysis is to determine the selection of kernel function and relevant parameters. Radial basis functions(RBF), polynomial kernel(poly),Sigmoid function and Fourier function are commonly used kernel functions.

Polynomial kernel(poly):

$$f(\boldsymbol{x}) = \operatorname{sgn}\left\{\sum_{i=1}^{n} \alpha_i y_i \left[(\boldsymbol{x}_i \cdot \boldsymbol{x}) + 1\right]^q - b\right\} \quad (4.14)$$

"n" is the number of supporting vectors, One of the things about polynomial kernel functions is that in the case of higher order Numbers, the learning effect is better, At low order, the generalization performance is better. The disadvantage is the long training time. And we can see from (4.14), the function has 3 parameters, and it is difficult to optimize.

2. Radial basis functions(RBF):

$$f(\boldsymbol{x}) = \operatorname{sgn}\left\{\sum_{i=1}^{n} \alpha_i y_i e^{\left(-\frac{|\boldsymbol{x}-\boldsymbol{x}_i|^2}{\sigma^2}\right)} - b\right\} \quad (4.15)$$

Compared to polynomial kernel functions, The expression for the radial basis kernel function has only one parameter, The workload of parameter optimization is greatly reduced. Moreover, the calculation of radial basis kernel function is more concise

3.Fourier function:

$$f(\boldsymbol{x}) = \operatorname{sgn}\left\{\sum_{i=1}^{n} \alpha_i y_i \frac{\pi \cosh\left(\frac{\pi - (\boldsymbol{x}_i - \boldsymbol{x})}{\sigma}\right)}{2\sigma \sinh\left(\frac{\pi}{\sigma}\right)} - b\right\} \quad (4.16)$$

The Fourier kernel also has only one parameter, But only when the kernel function under the condition of the objective function, it is very smooth to ensure good approximation effect in high dimensional space, so we often join a regularization parameter, thus increasing the difficulty modelling.

4.Sigmoid function:

$$f(\boldsymbol{x}) = \operatorname{sgn}\left\{\sum_{i=1}^{n}\alpha_i \tanh\left[v(\boldsymbol{x}_i \cdot \boldsymbol{x}) + a\right] + b\right\} \quad (4.17)$$

Sigmoid function is the discriminant function of layer 3 neural network, The hidden node corresponds to the support vector, but there is no problem of the local minima of the neural network in the support vector machine method.

Based on the above analysis, the radial basis kernel function of equation (4.15) was selected for modelling in this paper.

4.2 Classification of the consequences of ship collision accidents

According to the new "statistical measures on maritime traffic accidents" issued by decree no. 15 of the ministry of communications of the People's Republic of China on September 30, 2014, the results of the collision are divided into five levels according to the casualties, economic losses and environmental pollution caused by the collision. Refer to the table4.1

Tab.4.1 Grading of maritime traffic accident in China

Accident level	Casualties	Direct economic loss(RMB)	Standard of oil spills pollute water(tons)
extraordinarily serious accident	Death(include missing) more than 30 people, or serious injury more than 100 people	loss＞100,000,000	spill＞1000

major accident	Death(include missing) more than 10 people but less than 30people, or serious injury less than 100 people but more than50 people.	100,000,000 ＞ loss ＞ 50,000,000	1000＞spill＞500
Large accident	Death(include missing) more than 3 people but less than 10 people, or serious injury more than 10 people but less than 50 people	50,000,000 ＞ loss ＞ 10,000,000	500＞spill＞100
Ordinary accident	Death(include missing) more than 1 people less than 3 people, or serious injury more than 1 people but less than 10 people	10,000,000 ＞ loss ＞ 1,000,000	100＞spill＞1
Minor accident	Accidents not up to the general accident level		

Internationally, according to the accident classification standards of the international maritime organization (IMO), the consequences of ship collision accidents are divided into three levels: major accident, large accident and ordinary accident.

Tab.4.2 Grading of maritime traffic accident in IMO

Accident level	Contingency determination
Major accident	Maritime accident involving the death or serious environmental damage of the ship's total loss
Large accident	In addition to major accidents involving fire, explosion, collision, stranding, touch, natural disasters, hull fracture or possible defects such as hull host malfunction or serious structural damage (such as underwater hull), make the ship can not sail accident; Pollution accidents (regardless of the amount of pollution);Failure of a ship that must be assisted by a tug or shore
Ordinary accident	Ship accidents causing specific losses except major accidents and large accidents, including potential accidents

4.3 Determination of evaluation indicators

In order to select evaluation indexes for ship collision accidents, the author has read a lot of relevant literature. Yan huaran used the rough set method to analyze the collision consequences of ships according to the ship tonnage, ship age, type, ship speed and collision position. Tian Yang analyzed the collision impact in his master's dissertation by using six factors including: artificial neural network, visibility, the wind, flow velocity, channel width, the weighted traffic, navigation, mark. Ye Congshen analyzed the collision impact in his master's dissertation by using six factors including: ship’s tonnage, type, ship speed, collision position, collision angle, encounter situation and encounter ship’ speed.

The aim of this paper is to evaluate the collision risk before and after the revision of the outer channel navigation system in Chengshanjiao waters. Therefore, the meteorological environmental factors in collision accidents are independent variables in comparative analysis. So, it is not considered as a key factor. At the same time, combining previous research results, this paper selects the tonnage, type, speed, collision, collision angle, encounter situation as six indexes into v Chengshanjiao waters outside traffic separation scheme of collision prediction model input.

1.Ship tonnage

Ships passing Chengshanjiao are mainly dangerous cargo ships and cargo ships, as well as a few passenger ships, its tonnage is mainly between several thousand to 30,000 tons, so the tonnage is divided into four grades in this paper. The corresponding parameter values are shown in table 4.3.

Tab.4.3 Ship tonnage parameter table

Ship tonnage(t)	10,000＜	10,000-3,000	30,000-50,000	＞50,000
Value in model	1	2	3	4

2.Ship types

Ships sailing in Chengshanjiao are mainly merchant ships, fishing ships. Among them, the merchant ships are mainly cargo ships and dangerous cargo ships. Therefore, the ship types in this paper take these three ship types as the target samples. The values of main parameters are shown in table 4.4. It's important to note that, for the collision between fishing boats, the loss is small and the record is limited. Therefore, the collision types of fishing boats and fishing boats are not considered

Tab.4.4 Ship type parameter table

Ship type	Cargo ship	Dangerous cargo ships	Fishing ships
Cargo ship	1	2	3
Dangerous cargo ship	2	4	5
Fishing ship	3	5	N/A

3.Ship speed

According to the speed statistics on the BLM-SHIPPING software, The ship speed of the external channel TSS is about 10 knots on average. Therefore, the ship speed is divided into three grades. As shown in table 4.5

Tab.4.5 Ship velocity parameter table

Ship speed	[0,8]	[8,14]	[14, ∞]
Value in model	1	2	3

4.Collison position

According to existing accident samples before revision, the approximate collision position of the ship at the time of the accident can be collected. When data simulation is carried out, the same collision location is used for simulation. For the ship being hit. ship collision positions are divided into:{ Bow, amidships, stern}={1,2,3}

5. Collision Angle

Because the data of collision angle is difficult to obtain, the corresponding collision angle is calculated based on the collision position and the track line before the collision. Specific quantitative indicators are shown in table 4.6.

Tab.4.6 Collision angel parameter table

Angle(°)	[0.15]	[15,45]	[45,90]
Value in model	1	2	3

6. Encounter situation

During the sailing process, the possible situation of the ship is divided into two parts:{overtaking, head to head, crossing}={0,1,2}

7. Accident consequence grade

Combined with table 4.1 and table 4.2 and the occurrence of accidents in the waters of Chengshanjiao in recent 8 years. the consequences of the accident grade is divided into 3 categories:{minor, large, major}={1,2,3}

4.4 Selection and dispose of training samples

Chengshantou water area is an important coastal traffic fortress, commercial fishing boats are active in the waters. Multiple fishing areas and multiple traffic flows converge, resulting in frequent water traffic accidents in the waters. From 2008 to 2015, there were 92 water accidents, as shown in table 2.3. There were 71 collision accident, 56 between merchant and fishing boats, accounting for more than 75 percent.

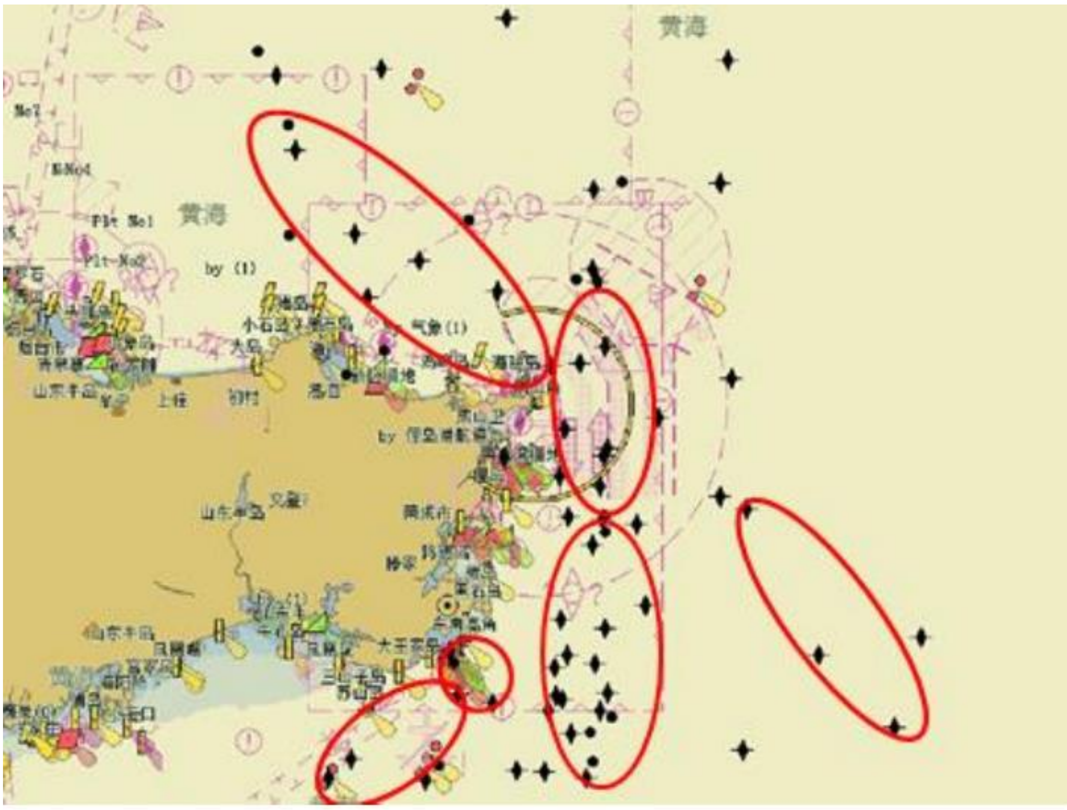

Fig.4.5 The schematic diagram of ship accident distribution and tracks during 2008-2015

Considering the characteristics of support vector machines described in selection 4.1, and compared with other machine learning methods such as artificial neural network，Support vector machines for events with fewer training samples. So, its predictions are more accurate. Since there are only a dozen accidents in the target water area each year, it is suitable to use support vector machine method for sample training.

In this paper, collision accidents in Chengshanjiao waters from 2008 to 2015 were selected as training samples. The specific input values are collected by referring to the six indicators described in section 4.3. The output index of the training sample is the reference of accident grade in section 4.1.

At the same time, the first 5 samples in table 4.5 were taken as test samples, and the last 20 samples were taken as training samples, a training sample of collision consequence of ship with SVM is established. By quantifying the indicators, the data in table 4.5 is changed into the quantified data shown in table 4.6

Tab.4.7 2008-2015 The statistical table of ship accident

No	Date and time	grade	type	casualty	Economy loss(10,000yuan)
1	2013-06-05 01:13:00	Large	C/F	1 missing	200
2	2013-06-06 00:00:00	Minor	C/C		45
3	2013-05-08 06:10:50	Minor	C/F		48
4	2012-12-20 00:57:00	Major	D/F		200
5	2012-10-03 02:15:00	Minor	C/F		
6	2012-08-30 02:25:00	Minor	C/F	6 missing	
7	2012-08-07 11:30:00	Minor	C/F	1 hurt	
8	2012-07-28 06:00:00	Large	D/F		
9	2011-12-31 19:26:00	Major	D/F	9 missing	300
10	2011-12-31 05:45:00	Minor	C/F		50
11	2011-11-24 04:07:00	Minor	D/F		
12	2011-03-13	large	C/F		105

	06:17:00				
13	2010-11-29 02:20:00	Major	C/C		700
14	2010-09-06 04:50:00	Minor	C/F	1hurt	20
15	2010-08-27 04:27:00	Large	C/F	1death, 4missing	220
16	2010-05-04 16:15:00	Major	D/F	1death 7mmissing	110
17	2010-5-2 02:20:00	Major	C/C		10000
18	2009-10-29 22:13:00	Large	C/F	1death 1missing	20
19	2009-09-17 16:30:00	Minor	C/F		40
20	2009-03-26 02:38:00	Minor	D/F		17
21	2008-10-17 06:35:00	Minor	C/F		45
22	2008-10-09 22:30:00	Minor	C/F		13
23	2008-06-12 07:30:00	Minor	C/C		9
24	2008-06-12 07:30:00	Minor	C/F		30
25	2008-05-26 07:35:00	Minor	C/F		20

(C: Cargo ship F: Fish ship D: Dangerous cargo ship)

Tab.4.8 2008-2015 The quantification statistical table of ship accident

Serial number	Ship 1 (ton)	Ship 2 (ton)	Type	Ship1 (speed)	Ship2 (speed)	collision angle	Encounter situation	Collision position	Accident grade
1	2	1	3	2	2	1	1	2	2
2	1	1	1	1	1	1	0	1	1
3	1	1	3	1	1	1	0	3	1
4	3	1	5	2	3	3	2	2	3
5	1	1	3	1	1	1	0	3	2
6	1	1	3	1	1	1	0	3	1
7	1	1	3	2	2	1	1	1	1
8	2	1	5	2	1	2	1	2	2
9	2	1	5	2	3	2	2	2	3
10	1	1	3	1	1	1	0	1	1
11	1	1	1	1	1	1	0	3	1
12	1	1	3	2	1	3	1	2	2
13	2	3	3	2	2	3	2	2	3
14	1	1	5	1	1	1	1	1	1
15	3	1	1	2	2	2	2	2	3
16	2	3	3	2	2	3	2	2	3
17	3	1	3	2	3	3	2	2	3
18	2	1	5	1	2	3	1	2	2
19	1	1	3	1	1	2	0	1	1
20	1	1	5	1	1	1	0	3	1
21	1	1	3	1	2	1	0	3	1
22	1	1	3	2	1	2	1	1	1
23	1	1	1	1	1	1	0	3	1
24	1	1	3	1	1	1	0	1	1

25	1	1	3	1	2	1	0	1	1

4.5 Establishment of analysis model of ship collision consequence

Input the above model into the support vector machine for training, the training accuracy of 20 samples is 100%, and the classification accuracy of 5 test samples is 80. See figures 4.6, 4.7 and 4.8

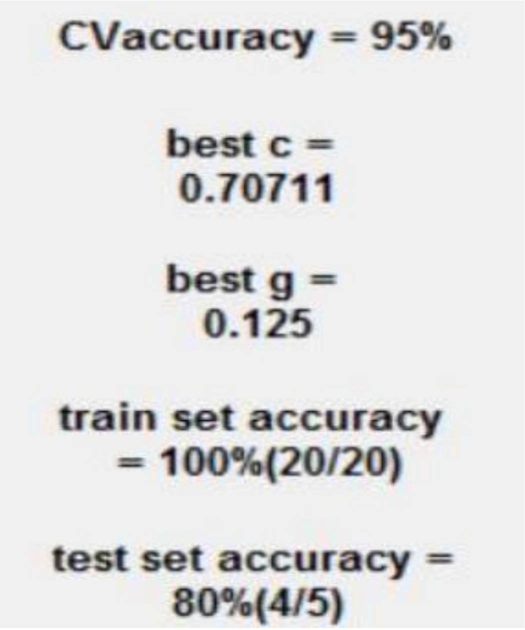

Fig. 4.6 Outlet result of test sample accuracy

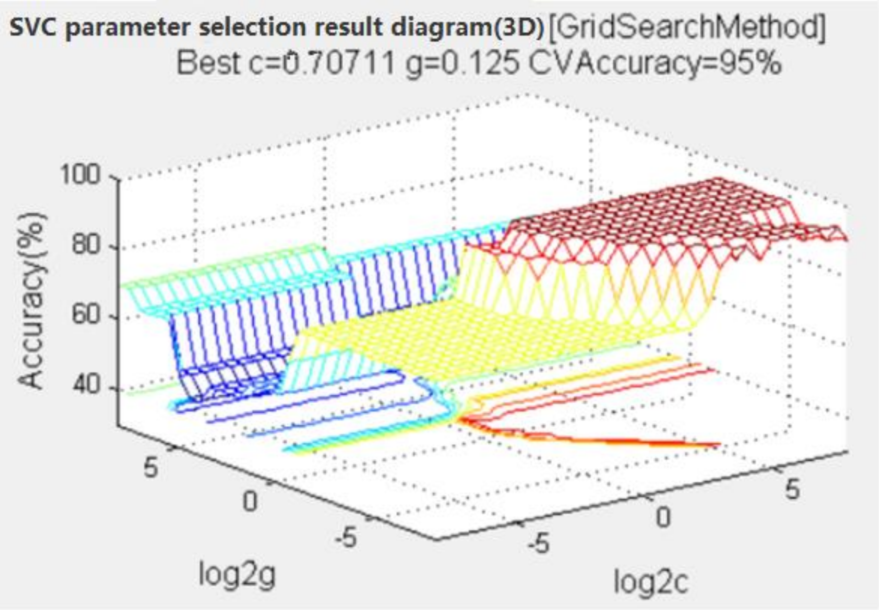

Fig. 4.7 Slack variable and punishment parameter

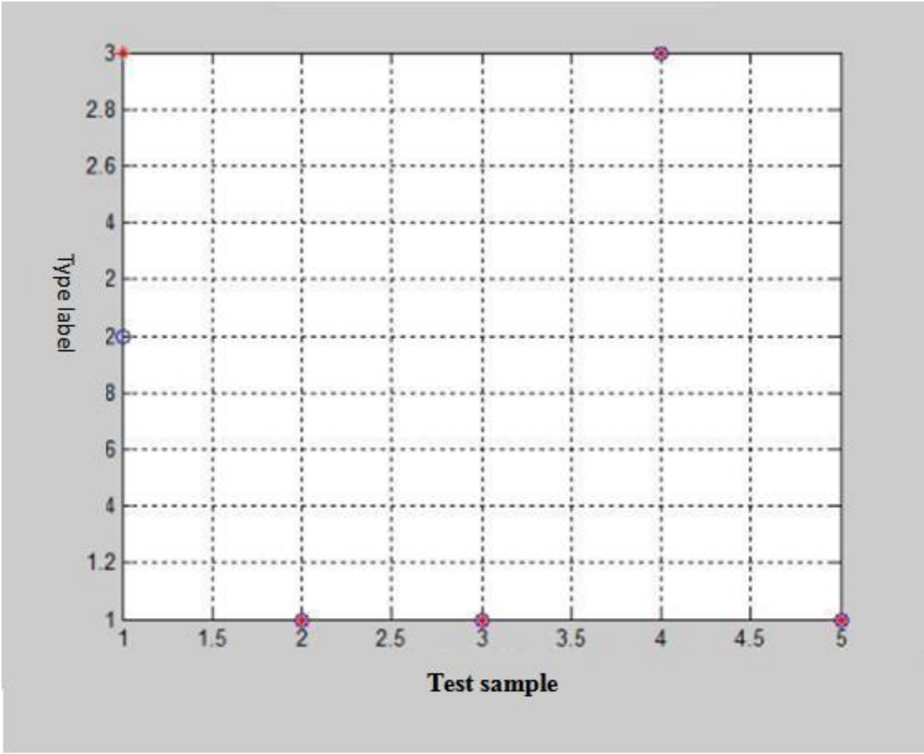

Fig. 4.8 Output of test sample result

Therefore, Finally, the parameters of the support vector machine model applicable to the assessment of the collision consequences of ships in the external channel of Chengshanjiao water are C=0.707, g=0.125.

4.6 Verification of ship collision consequence analysis model

According to the latest data provided by the Weihai MSA, On Dec 12th, 2016,there was a collision accident between cargo ships and fishing boats in the TSS alert area under the external waters of Chengshanjiao. There were no casualties. Relevant departments defined the accident as a minor accident according to the same evaluation method as the sample data obtained in section 4.7, and the specific parameter quantitative value is shown in table 4.7.

Tab.4.9. The quantification statistical table of ship accident

Ship1	Ship2	type	Ship1 speed	Ship2 speed	Collision angle	Meeting situation	Collision position	Accident level
2	1	3	2	2	2	1	2	1

Bring the data from the above table into the support vector machine model in section 4.5 to evaluate the collision consequence in external of Chengshanjiao. The results are shown in figure 4.9 and figure 4.10. The output is 1, that is, the accident grade is 1

The feasibility of the model is demonstrated by the minor accident.

```
>> SVM_GUI
Accuracy = 100% (20/20) (classification)
Accuracy = 80% (4/5) (classification)
>> load('   Testsample'     )
>> SVM_GUI
Accuracy = 100% (20/20) (classification)
Accuracy = 100% (1/1) (classification)
>>
```

Fig. 4.9 Output of testify sample result

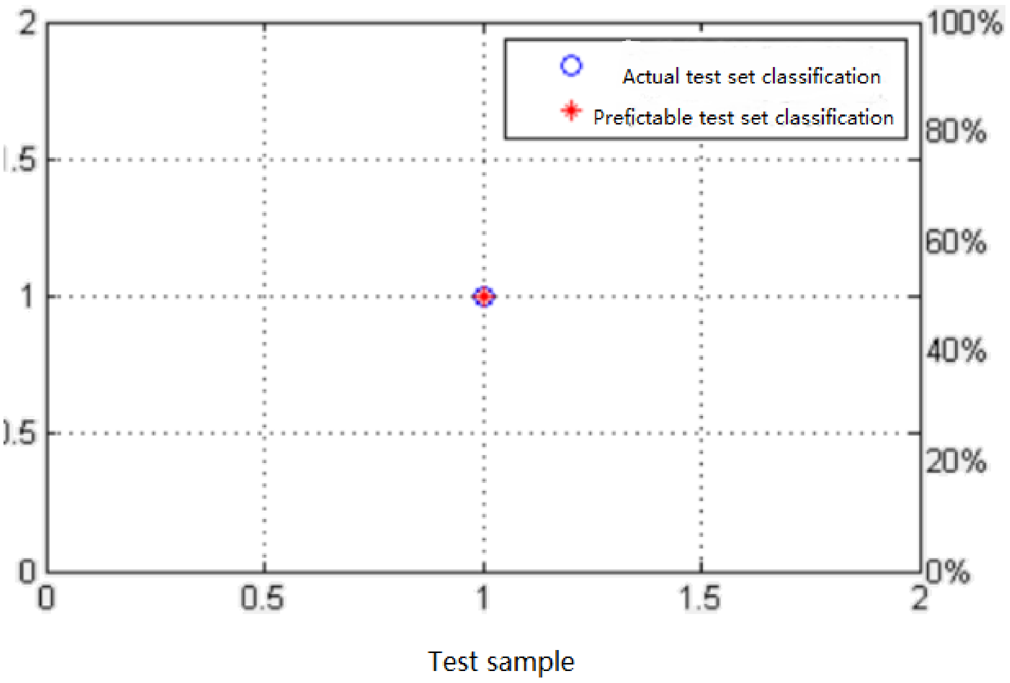

Fig. 4.10 Output of testify sample result

4.7 Chapter summary

In this chapter, the principle of SVM is introduced, and the collision consequence evaluation model of ship is established based on this theory. An appropriate index is selected as the input of the model. Based on the training and testing of the model and the historical accident in the water area as the training sample, the parameter values C and g applicable to the ship collision consequence assessment in the water area are obtained. Finally, according to the new accident data obtained recently, the result also meets the expectation.

Chapter 5 Real evidence analysis

5.1 Data collection

Figure5.1 & 5.2 are the overall meeting situation drawing before and after the revision of the TSS in the outer part of the area. Before the revision, there were many complicated meeting situation between ships, And there are still a lot of encounters in the straight-line area. So for the sake of simplicity, intercept the average ship encounter angle in the warning area before revision(about 30°). The cross situation of the revised ship mainly occurred in the alert area shown in figure 5.2. Cross angle about 45 °

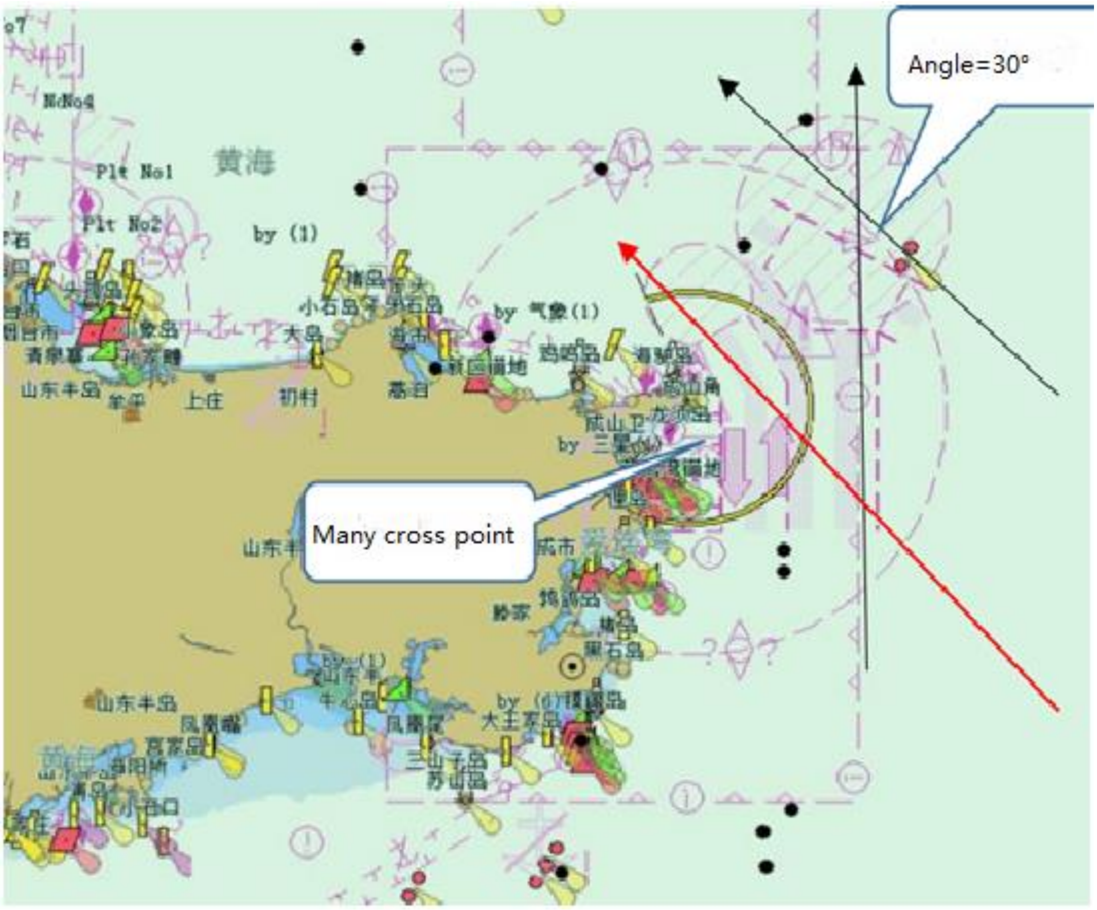

Fig 5.1 Crossing angle of channel before amendment schematic diagram

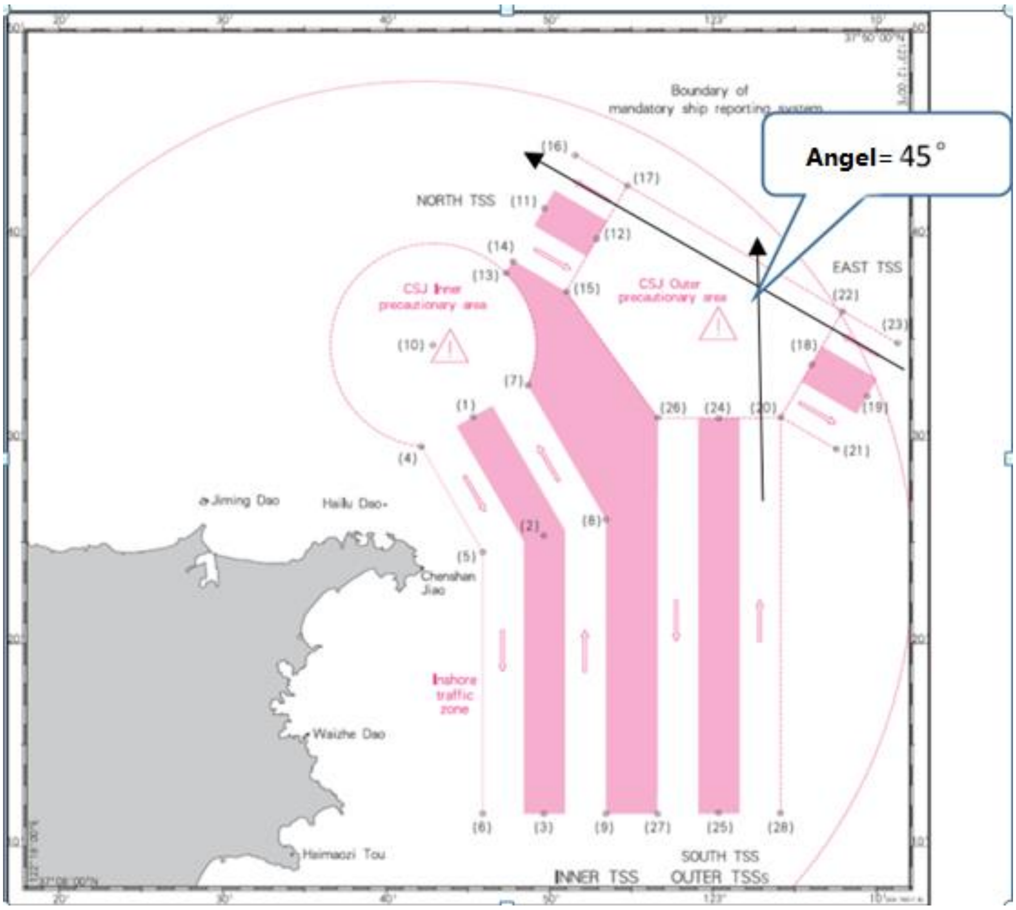

Fig. 5.2 New edition of Chengshanjiao water area TSS schematic diagram

(1) Traffic flow analysis

On June 1, 2015, the new outer channel navigation system of Chengshanjiao was officially implemented, therefore, AIS data for the whole year of 2014 and from June 2015 to June 2016 (hereinafter referred to as 2016) were selected for traffic flow observation before and after the revision. As shown in table 5.1

Tab. 5.1 Statistics of the ship flow rate

Door line	year	Passenger ship	Cargo ship	Non-transport ship	Dangerous cargo ship	Total
External TSS	2016	401	9523	2967	7016	19907
	2014	723	9198	1885	6721	18525

In order to meet the calculation needs, the annual traffic flow in the above table is converted into the average traffic flow per hour as shown in table 5.2, where the annual traffic flow is calculated according to 365 days.

Tab.5.2 Statistics of the ship flow rate per hour

Door line	year	Passenger ship	Cargo ship	Non-transport ship	Dangerous cargo ship	Total
External TSS	2016	0.046	1.087	0.339	0.801	2.272
	2014	0.083	1.050	0.215	0.767	2.115

(2) Representative ship types

The main vessels sailing in the waters of Chengshanjiao are passenger, cargo, non-transport and dangerous goods vessels, and the number of passenger ships is small because of their fixed routes, Therefore, it is not an object calculated separately in this paper. The proportion of cargo ships and non-transport vessels of dangerous goods is about 53%, 29% and 14% respectively. There are quantitative criteria of importance. And the majority of non-transport vessels are fishing boats. Therefore, in this paper, cargo ships and dangerous goods vessels in the TSS water are selected to represent the ship type. Its main dimensions are shown in table 5.3

Tab.5.3 Statistics of the ship size and type

Ship type	Length(m)	Breath(m)	Draft(m)
Cargo ship	200	28	14.3
Dangerous goods ship	150	30	10.9
Fishing boat	55	8	3.6

(3) Ship speed

The ship speed in this paper is read by BLM-SHIPPING software, and the AIS data of 2014 and 2016 above are combined and specific data are shown in table 5.4.

Tab.5.4 Statistics of the ship velocity

Speed	Average speed(2014)	Average speed(2016)
Cargo	9	10
Dangerous cargo ship	11.8	13.4
Fishing ship	12.2	12.8

5.2 Collision probability assessment

5.2.1 Collision probability assessment for a single ship example

According to the third chapter, Brownian motion theory and relevant models. Let's say the variance of two boats grows at the same rate as 1. The specific motion parameters of the two vessels are shown in table 5.5

Tab.5.5 Movement parameter table of ship A and B

Channel type	year	ship	Speed(kt)	Cross angle	initial transverse distance(nm)	Initial longitudinal distance(nm)
Cross channel	2014	A/B	15/10	30	0.5nm	2
	2016	A/B	17/12	45	0.5nm	2
Straight Channel	2014	A/B	10/7	Not Applicable	Not Applicable	2
	2016	A/B	11/9	Not Applicable	Not Applicable	2

Substitute the above parameters into equations (3.3) and (3.5) respectively. Through MATLAB calculation, the collision probability of a single ship is obtained as shown in table 5.6

Tab.5.6 Single ship collision probability table

Channel type	year	collision probability
Internal warning area	2014	9.26*10-5
	2016	5.71*10-5
Straight channel	2014	1.92*10-5
	2016	1.35*10-5

It can be seen from the above table that the probability of collision between two ships in the revised waters has significantly decreased. It needs to be explained that there are a lot of cross situations in the linear channel of the external TSS before the revision. It can be seen from the above table that the probability of cross collision is much higher than the probability of overtaking and colliding. After the revised linear channel waters this situation will be basically eliminated. Therefore, the risk of collision in the water is also greatly reduced. It mainly concentrated on the alert area, and the shipping routes in the original alert area are intersected in several places. After the revision only two ship’s intersection of N cross NW, ship’s intersection N cross SE . Compared with the situation of chaotic and random navigation before the amendment, the ship track steering in the revised alert area is more predictable, so the ship collision risk in the waters of the alert area is also reduced.

5.2.2 Collision probability assessment in total channel

Bring the above data into the equations (3.9) and (3.10) in section 3.2. According to the calculation of MATLAB, the collision probability between different ship types of the linear and cross routes in Chengshanjiao water and the collision probability of overall water area is shown in table 5.7, table 5.8 and table 5.9.

Tab.5.7 Straight channel collision probability table

Year	Straight section	Number of geometric collisions	Probability of cause(10-4)	Number of colliding ships(10-3)	Collision probability(10-5)	Overall collision profile(10-5)
2014	East	1.37	1.3	17.810	8.421	3.386
	South	1.24	0.5	0.062	0.029	
2016	East+ South	2.56	0.5	0.128	0.149	0.149

Tab.5.8 Alert area collision probability table

Year	Warning area	Number of geometric collisions	Cause probability	Number of colliding ships	collision probability
2014	whole	171.395	1.3*10-4	22.281	10.095
2016	whole	114.953	1.3*10-4	14.944	6.577

Tab.5.9 Alert area collision probability between two different type vessel table

Year	ship types	Number of geometric collisions	Number of colliding ships(*10-4)	Collision probability(*10-4)
2014	Cargo ship	52.961	6.885	3.255
	Dangerous cargo ship	16.684	2.169	1.026
	C/DC ship	30.812	4.006	1.894

	F/C ship	59.338	7.714	3.647
	F/DC ship	48.362	6.287	2.973
2016	Cargo ship	20.137	2.618	1.152
	Dangerous cargo ship	6.296	0.818	0.360
	C/DC ship	13.111	1.704	0.750
	F/C ship	24.263	3.154	1.388
	F/DC ship	18.942	2.463	1.084

It needs to be explained that the ship collision model of IWRAP linear route is based on the principle of normal distribution, so the main parameters are the distance between ships and the width of the channel, there is not much to do with the parameters of the ship itself. This is more suitable for macroscopic calculation of the overall collision probability in a particular water area. At the same time, because the collision probability of ships on the linear route is far less than that of the cross route; therefore, only the collision probability analysis of the whole route is carried out in the linear route.

By comparing the data in the above table, it can be seen that the overall collision probability of the linear route decreased by 95.60% after the revision. the overall collision probability in the alert area decreased by 34.62%.It can also be seen from table 5.9, the probability of collision between different types of ships in the alert area also decreased significantly. It indicates that the revised outer TSS of Chengshanjiao area has obvious improvement on the safety of ship navigation compared with that before the revision. Especially in the eastern and southern sections of the route, since the revision basically eliminated the phenomenon of vessels crossing in this area, the probability of collision in this area decreased significantly.

5.3 Collision consequence assessment

5.3.1 Assessment before revision

Because the data is known before the TSS of Chengshanjiao waters were revised, which was in table4.5, the collision consequences before revision can be directly analyzed according to the actual data. The probability distribution table of accident level after ship collision can be obtained, as shown in table 5.10.

Tab. 5.10 Accident consequences probability distribution

Minor accident	Large accident	Major accident
0.56	0.16	0.28

It should be emphasized that, according to figure 5.1, the existing collision accidents are mostly cross-collision. That means, before the revision of the external channel TSS, ships in the linear channel do not strictly follow the recommended sailing directions but choose their own turning points. Therefore, it is not possible to divide the unified area of route before revision into straight route and cross route. It is also difficult to divide into straight water area and warning area. However, according to the data statistics and the evaluation indicators established in section 4.3, the cross angle between the two ships before the accident is taken as the distinction. According to the quantification of the accident index in section 4.3, it can be concluded that the average collision consequence in the water area before the revision is 1.72.

5.3.2 Revised collision consequence prediction

For the collision consequences of the revised TSS of Chengshanjiao water, data simulation was carried out according to the SVM model established in section 4.5.

The selected data are the same as those accident ship's type, tonnage and collision position in the same warning zone and straight channel waters. According to the AIS data in section 5.1 and the ship data in BLM-SHIPPING, samples are selected, and the corresponding collision accident grade was predicted by the SVM model.

See the table below.

Tab.5.11 The statistical table of water area after amendment

Serial number	Ship1 tonnage	Ship2 tonnage	Ship type	Ship 1 speed	Ship2 speed	Collision angle	Meeting situation	Collision position	Accident level
1	2	1	2	2	2	3	1	2	1
2	1	1	1	1	1	3	0	1	3
3	1	1	2	1	1	3	0	3	1
4	3	1	3	2	3	2	1	2	2
5	1	1	2	1	1	3	0	3	1
6	1	1	5	1	1	2	0	3	2
7	1	1	2	2	2	2	1	1	1
8	2	1	2	2	1	2	2	2	2
9	2	1	5	2	3	3	2	2	1
10	1	1	2	1	1	2	0	1	1
11	1	1	2	1	1	2	0	3	3
12	1	1	3	2	1	3	1	2	1
13	2	3	1	2	2	3	0	2	3
14	1	1	2	1	1	2	1	1	1
15	3	1	2	2	2	2	2	2	2
16	2	3	1	2	2	2	2	2	2
17	3	1	2	2	3	2	2	2	2
18	2	1	2	1	2	3	1	2	1
19	1	1	5	1	1	2	0	1	3
20	1	1	2	1	1	2	0	3	1
21	1	1	3	1	2	3	1	3	1

22	1	1	2	2	1	2	1	1	1
23	1	1	1	1	1	3	0	3	2
24	1	1	2	1	1	2	0	1	1
25	1	1	2	1	2	2	1	1	3

We can see that among the 25 groups of simulation data, there were 5 major accidents, 7 large accident and 13 minor accidents. Therefore, the average collision risk of the revised system is 1.68. Slightly lower than before the revision. Despite ships crossing situation on the alert area, compared with the revision before the chaotic situation, the revised alert area of the ship track was turned to the predictability of strengthening, so the risk of collision is also reduced in alert area waters.

5.4 Water risk assessment

The magnitude of risk R in the water area should depend on the collision probability P in the water area and the comprehensive impact of collision consequence C. the specific expression is as follows:

$$R=[(p_1,c_1),(p_2,c_2),...,(p_x,c_x),] \quad (5.1)$$

In the actual evaluation process, in order to meet the purpose of comprehensive comparison, the above equation can be rewritten into the form shown in equation (5.2).

$$R=\sum(p_i \times c_i) \quad (5.2)$$

Therefore, according to the assessment results of collision consequences in sections 5.2 and 5.3, the overall risk comparison of the outer TSS of Chengshanjiao is shown in table 5.11

Tab.5.12 The comparison table of the water area risk

Channel type	Year	Collision probability(10-5)	Collision consequence	Risk assessment value

Linear channel	2014	3.386	1.72	5.824
	2016	0.149	1.68	0.250
Cross channel	2014	10.059	1.72	17.301
	2016	6.577	1.68	11.049

From the table, it can be seen that the revised outer channel TSS of Chengshanjiao waters, both the straight channel waters and the cross warning areas, have significantly reduced the overall risk level compared with that before the revision. The overall risk of direct route decreased by 95.71%, and that of cross route (alert area) decreased by 36.14%.Therefore, it can be concluded that the implementation of the new ship TSS in Chengshanjiao water provides a better guarantee for the navigation safety of ships.

5.5 Chapter summary

This chapter uses the ship collision probability calculation model and ship collision consequence prediction model established in the first two chapters. An empirical analysis of the model is made on the outlying channel navigation system in Chengshanjiao area. In the calculation of collision probability, this chapter respectively calculates the collision probability between different types of ships with different collision probability of a single ship and the overall collision probability of waters. In the prediction and analysis of collision consequences, the simulation data are used to calculate the changes of ship collision consequences before and after revision in the navigation system of outer channel of Chengshanjiao. The above two types of calculations have shown that the revised outer channel navigation system in the waters of Chengshanjiao has significantly improved the ship collision risk compared with that before the revision.

Chapter 6 Summary and prospect

This paper takes the traffic separation scheme of Chengshanjiao external waters as the research object, established the collision model through macro and micro dimensions. At the same time, it combined with support vector machine (SVM) classification algorithm to predict and analyse the consequences of collision, finally the following conclusions are drawn:

On the direction of collision probability, the revised collision probability are lower than before the revision in both the linear routes and the cross routes

On the ship collision consequences, the machine learning model based on support vector machine (SVM) calculation the results show that the revised ship collision effect is slightly lower than before revision. Although ships crossing situation on the alert area, but compared with the precious mess situation. after revision, the predictability of ship track in alert area is enhanced

Separate ship numerical examples to verify the ship collision probability in linear route is far lower than the cross route. Compared with the cross route ,the turning point of revised traffic separation scheme is not normal. There is great improvement in the situation of random crossing of the ships. The crossing of the ship was concentrated in the alert area. It reduces the overall risk of the channel and makes it easier for regulators to monitor the high-risk areas.

In terms of innovation in this paper, it is the first time to apply the Brownian motion to single ship example. At the same time, support vector machine (SVM) model is applied to the field to evaluate consequences of collision, and finally the satisfactory results is achieved.

As for the deficiency of this paper, the Brownian motion and support vector machine (SVM) are widely used in the field of finance and option pricing, forecasting stock prices. For shipping industry the related literature in the field of transportation is very limited. The above two models also need further completion. In addition, because of the random crossing in Chengshanjiao waters in direct routes before revision, this paper took the busy eastern areas as cross route, the southern region was still seen as straight routes. there is no further detailed division, In the calculation of collision risk, a more suitable method should be found to complete the subdivision of water in the future.

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