

Navigational Risk of Arctic Waters Based on System Dynamics

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Abstract

In order to improve the navigation safety of the Arctic waterway and avoid the risk of accidents. In particular, the unique characteristics of the region are prone to major risks, such as ice, harsh working conditions, unpredictable climate change and remoteness. Therefore, it is necessary to carry out risk assessment on the Arctic waterway and model and simulate the Arctic waterway with the help of system power. First, analyze the causes of the navigation risks of ships in the waters of the Arctic channel and the mutual effects of the causes. Secondly, according to the analysis, the navigation risk is mainly influenced by five systems, "man-machine-ring-tube-ice". Because of the characteristics of the Arctic region, the influencing factors of ice are discussed separately. Sub-systems are established, and the sub-systems are interconnected and influence each other. The dynamic flow diagram and the stock-flow diagram of the interrelationship between the causes of ship navigation risk on the Arctic route are proposed. Establish the equations of each influencing factor, evaluate the four risk reduction policies, and get the best plan. Finally, through the limit test and sensitivity test, the correctness of the model is verified. The results show that August and September each year are the most suitable for navigation. At this time, the navigation risk is the lowest in the whole year, and the risks caused by navigation from February to April are relatively large. Need to improve visibility during the voyage can effectively avoid navigation accidents and improve the safety and reliability of the navigation system.

Keywords

Risk assessment; System dynamics; Arctic route; Management strategy.

1. Introduction

With the development of globalization, international trade has become more frequent, and the water transportation industry has developed rapidly. In particular, in November 2017, China and Russia decided to jointly build the "Ice Silk Road", in which the Arctic route is the main route of the "Ice Silk Road", so the Arctic route is particularly important. The Arctic route has a harsh climate and is covered by snow and ice all year round. However, due to global warming in the past few years, the temperature of the Arctic has risen, and glaciers have melted, the Arctic route has gradually become an important route.

The safety issue of the Arctic route is the environmental issue that everyone pays the most attention to, of which ice research is the focus, proposed an object-oriented Bayesian network model based on navigation and operating system status, weather and ice conditions to dynamically predict the collision probability of ships on ice. However, the various factors of the Bayesian network model cannot influence each other, but in real life, most things are closely related. For this reason, the various factors can be connected by establishing a system dynamics model, also used the system dynamics method to establish the Arctic route safety model and believed that the Arctic route safety showed a positive development trend, in which the environment was the main factor. After finding the main factors through the VENSIM software, you can propose targeted policies based on the factors in order to improve the safety of navigation. Wlisses Bonelá Fontoura et al. [1] used VENSIM software to simulate the proposed

policies and found a policy with the highest economic benefits and the best safety performance. Hongbo Liu et al. [2] used methods different from those of VENSIM to evaluate, and used DEA methods to evaluate the applicability and efficiency of different policies in the system dynamics model. Yonglei Jian et al. compared the influence of different governance modes on the development of waterway transportation system and proposed a method for measuring the capacity of inland waterway network. Based on the systematic analysis of the factors affecting the navigation risk of the Arctic waterway, this paper adopts the method of system dynamics to construct a dynamics model of the navigational risk of the Arctic waterway, simulates each factor that affects the safety of navigation, and obtains the key factors of risk. Find the most efficient time for navigation in the Arctic and find the most efficient policy to improve safety.

2. Analysis of Risk Factors

2.1. Section Headings

There are four main sources of risks in the course of ships sailing. According to the viewpoint of safety system engineering, they are divided into human, machine, environment and management. That is, the four major risk systems of crew, ship, environment and management. Due to the particularity of the Arctic region, the ice factor is separated from the environment and discussed separately. According to these five subsystems, to determine the boundary of the system, first determine the five state variables of crew, ship, environment, management and ice, and continue to track the independent variables it depends on. Then determine the interrelationship of these five state variables. Taking ice risk system as an example, it is mainly affected by ice layer type, ice layer thickness, ice layer strength and floating ice, while ice thickness and ice layer strength are affected by temperature.

The Arctic is located in the ocean. February is the coldest and August is the hottest. The annual average temperature in the Arctic is between -15°C and -20°C. The average temperature in the Arctic in February is -25°C to -30°C, and the average temperature in August is -10°C to -5°C.

Table 1. Arctic temperature from January to December

month	1	2	3	4	5	6	7	8	9	10	11	12
temperature°C	-24	-30	-25	-20	-14	-11	-10	-8	-11	-16	-19	-22

According to the above method, the target hierarchy expansion method can be used for classification according to the logical classification method. Then, each target is gradually expanded into sub-targets or criteria, until these indicators can be analyzed qualitatively and quantitatively. Figure 1 Causality diagram of ship navigation risk system

As shown, the main causal relationship is as follows: personnel risk→crew holding rate→crew competency rate→crew performance rate→operation error→personal risk.

Ship risk → decision error → ship certificate rate → ship equipment operation normal rate → ship risk.

Monitor and manage risks → monitor system implementation → cruise mileage → ship safety inspection times → monitor and manage risks.

The nature of each parameter is determined according to the causality diagram of the vessel navigation risk system. See Table 2 for the parameter description of the vessel navigation risk system flow diagram.

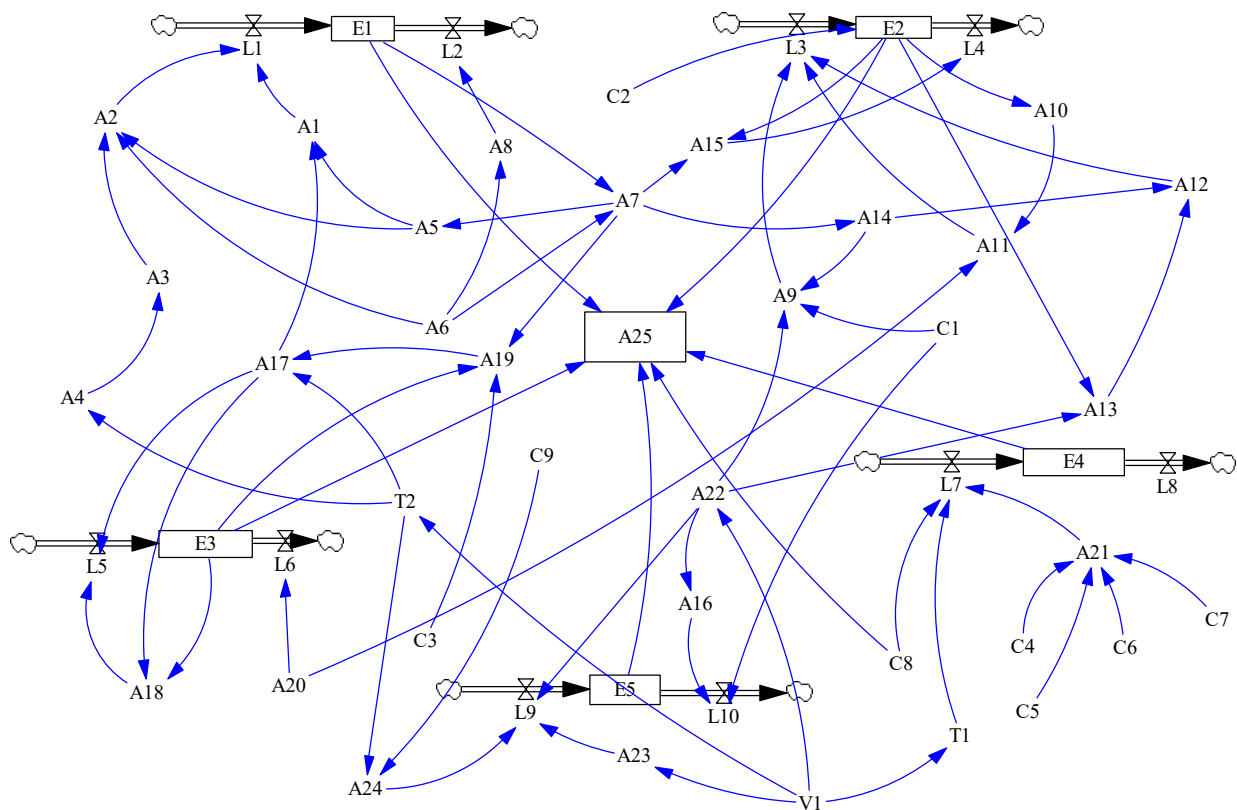


Figure 1. Causal Diagram of Ship Navigation Risk System

Based on the above, it can be obtained that the navigation risk is determined by the five subsystems and whether navigation is prohibited. The five subsystems are composed of the personnel risk subsystem, the monitoring risk subsystem, the environmental risk subsystem, the ship subsystem and the ice risk subsystem.

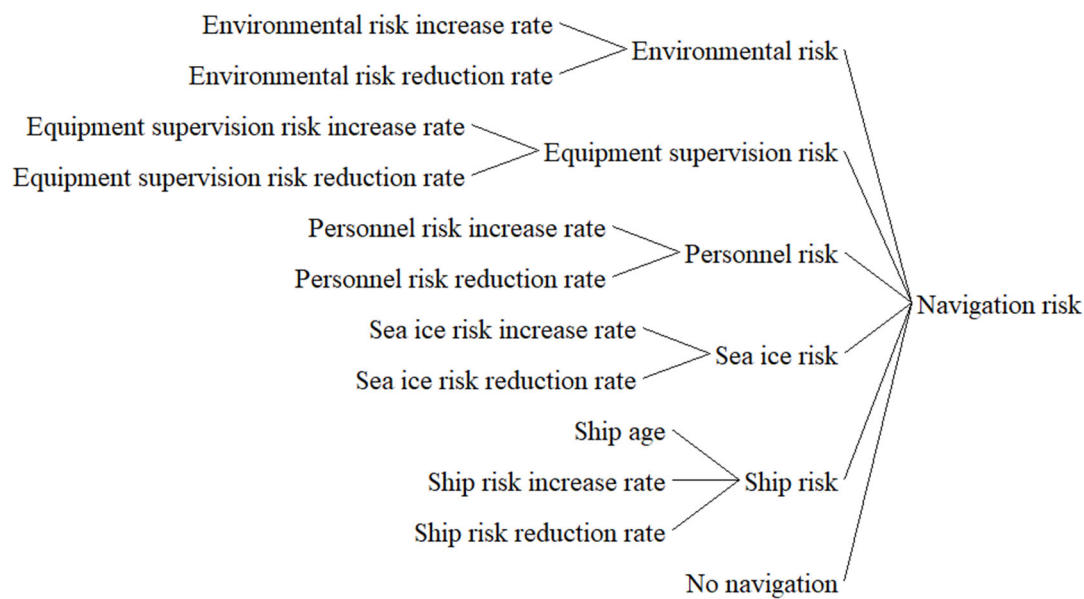


Figure 2. General Aviation Risk Level Analysis Table

Table 2. Parameter description of flow chart of ship navigation risk system

symbol	Variable type	Parameter meaning	symbol	Variable type	Parameter meaning
A1	Auxiliary variable	Early warning capability	C1	constant	Ship ice resistance rating
A2	Auxiliary variable	Wrong decision	C2	constant	Ship age
A3	Auxiliary variable	Temporary resilience	C3	constant	Equipment maintenance rate
A4	Auxiliary variable	Fatigue	C4	constant	Channel curvature
A5	Auxiliary variable	Communication	C5	constant	Channel width
A6	Auxiliary variable	Crew proficiency	C6	constant	Channel depth
A7	Auxiliary variable	Crew responsibility	C7	constant	Ocean current
A8	Auxiliary variable	Crew comprehensive ability	C8	constant	No navigation
A9	Auxiliary variable	Ship operation performance	C9	constant	Type of ice
A10	Auxiliary variable	Ship certificate rate	E1	Stock	Personnel risk
A11	Auxiliary variable	Ship equipment level	E2	Stock	Ship risk
A12	Auxiliary variable	Ship stability	E3	Stock	Equipment supervision risk
A13	Auxiliary variable	Speed	E4	Stock	Environmental risk
A14	Auxiliary variable	overload	E5	Stock	Sea ice risk
A15	Auxiliary variable	Ship safety inspections	L1	Flow rate	Personnel risk increase rate
A16	Auxiliary variable	icebreaker	L2	Flow rate	Personnel risk reduction rate
A17	Auxiliary variable	Radio and navigation failure rate	L3	Flow rate	Ship risk increase rate
A18	Auxiliary variable	Monitoring equipment management level	L4	Flow rate	Ship risk reduction rate
A19	Auxiliary variable	Equipment inspection times	L5	Flow rate	Equipment supervision risk increase rate
A20	Auxiliary variable	Equipment investment quota	L6	Flow rate	Equipment supervision risk reduction rate
A21	Auxiliary variable	Channel conditions	L7	Flow rate	Environmental risk increase rate
A22	Auxiliary variable	Sea ice density	L8	Flow rate	Environmental risk reduction rate
A23	Auxiliary variable	Sea ice thickness	L9	Flow rate	Sea ice risk increase rate
A24	Auxiliary variable	Ice strength	L10	Flow rate	Sea ice risk reduction rate
A25	Auxiliary variable	Navigation risk	T1	Table function	visibility
V1	Hidden variables	time	T2	Table function	Temperature
symbol	Variable type	Parameter meaning	symbol	Variable type	Parameter meaning

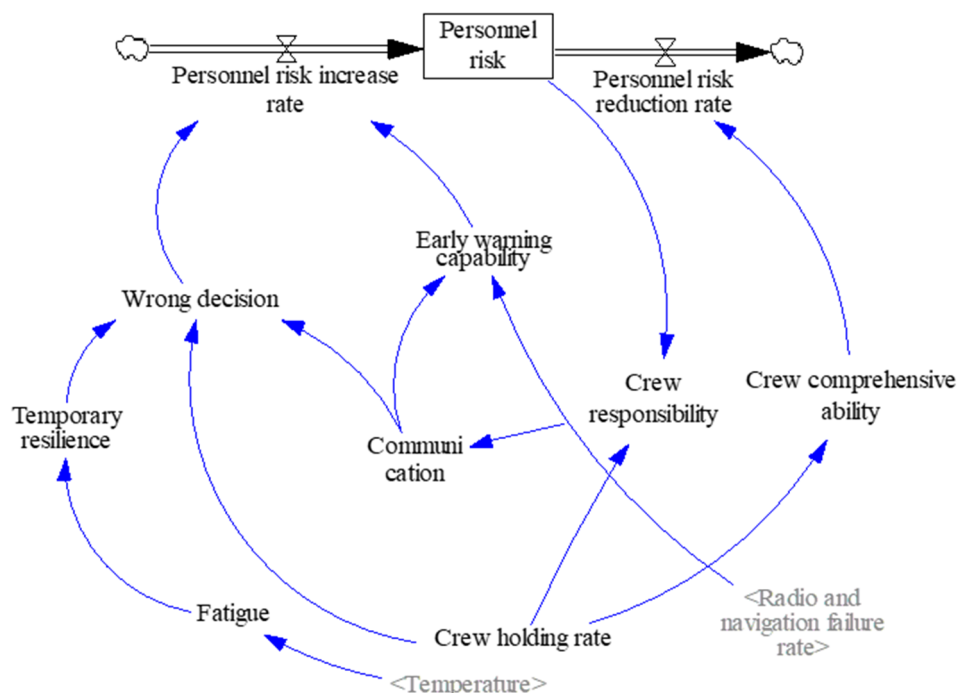
3. System Dynamics Model Construction

One of the most basic shortcomings of the cause-effect diagram in system dynamics is that it cannot express the difference between variables of different properties, and can only describe the basic aspects of feedback structure changes. State variables are the most important quantity in system dynamics, but the causality diagram cannot express the concept of accumulation. According to the causality diagram of the vessel navigation risk system as Figure 1 and the parameter description of the flow diagram of the vessel navigation risk system in Table 2, the flow inventory diagram is established, divided into five subsystems, and the inventory flow diagram of each subsystem is drawn.

First, the table function data in the model is treated with minimal dimensionlessness. At the same time, the parameter estimation of some variables needs to be scored by experts. The influence coefficient between the variables is determined by the Likert five-level scale method, and the basic data is obtained by questionnaire survey.

3.1. Personnel Subsystem

Based on the analysis of the causality diagram of the general aviation risk management SD simulation model, combined with the characteristics of the elements in the personnel subsystem and the causal relationship between them, the flowchart of the personnel risk subsystem is drawn as shown as Figure 3. The personnel subsystem process As shown as figure.



Flow chart of personnel subsystem

Figure 3. The personnel subsystem process As shown in the figure

3.2. Monitoring Subsystem

Based on the analysis of the causal relationship diagram of the SD simulation model of general aviation risk management, combined with the characteristics of the elements in the personnel subsystem and the causal relationship between them, the flowchart of the monitoring risk subsystem is drawn as shown as Figure 4. Monitoring subsystem process As shown in the picture.

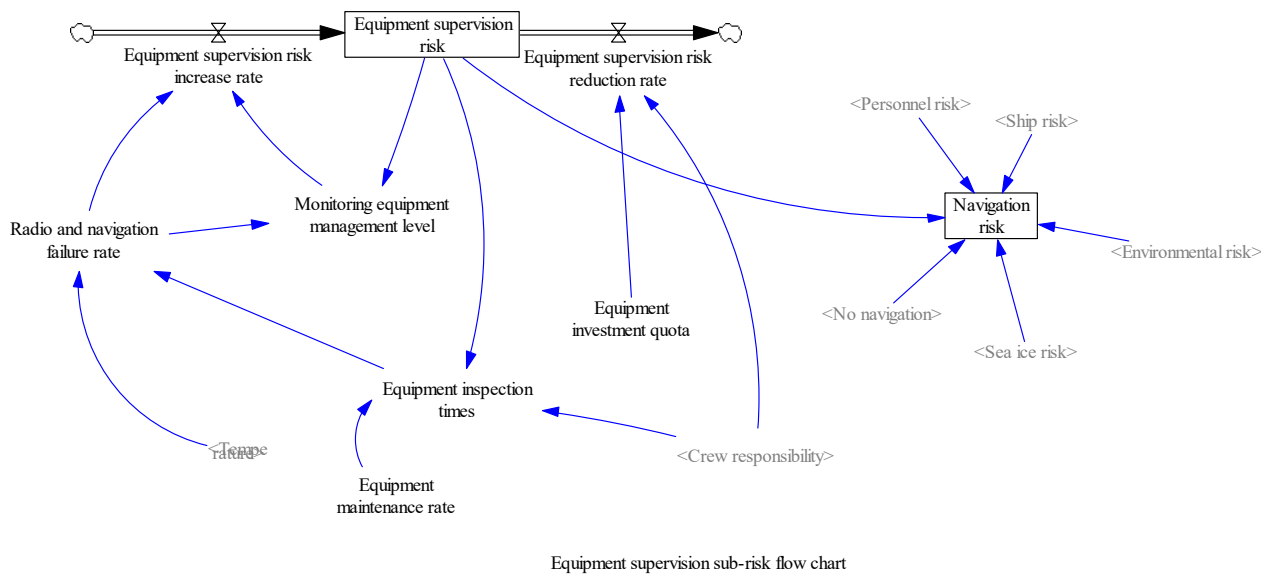


Figure 4. Monitoring subsystem flow chart

3.3. Environmental Subsystem

Based on the analysis of the causal relationship diagram of the SD simulation model of general aviation risk management, combined with the characteristics of the elements in the personnel subsystem and the causal relationship between them, the flowchart of the environmental risk subsystem is drawn as shown in Figure 5 Environmental subsystem process As shown as Figure 5.

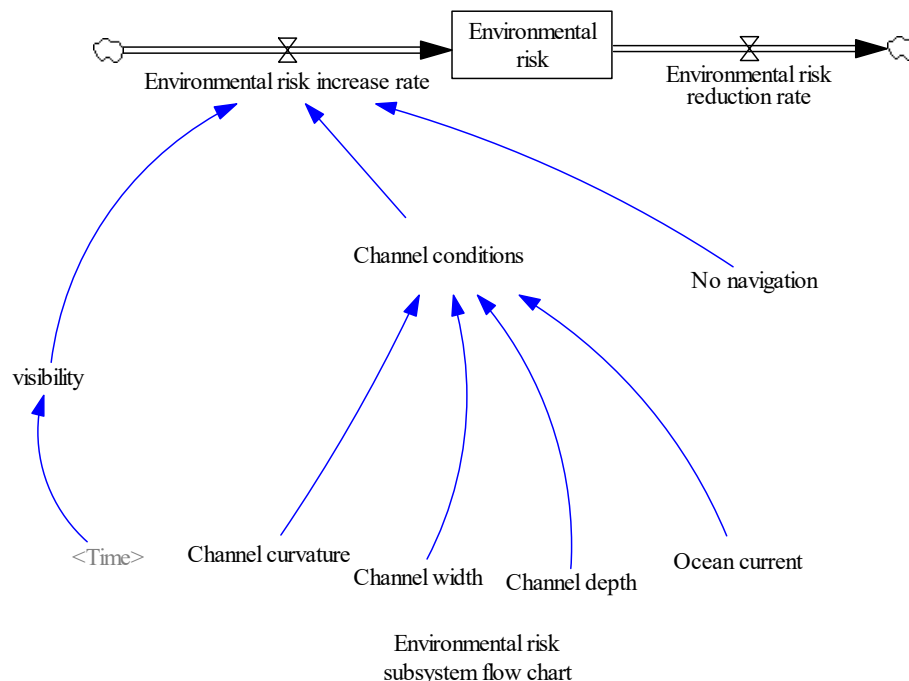


Figure 5. Environmental subsystem flow chart

3.4. Ship Subsystem

Based on the analysis of the causal relationship diagram of the SD simulation model of general navigation risk management, combined with the characteristics of the elements in the personnel subsystem and the causal relationship between them, the flow chart of the ship risk subsystem is drawn as shown in Figure 6 Ship subsystem process As shown as Figure 6.

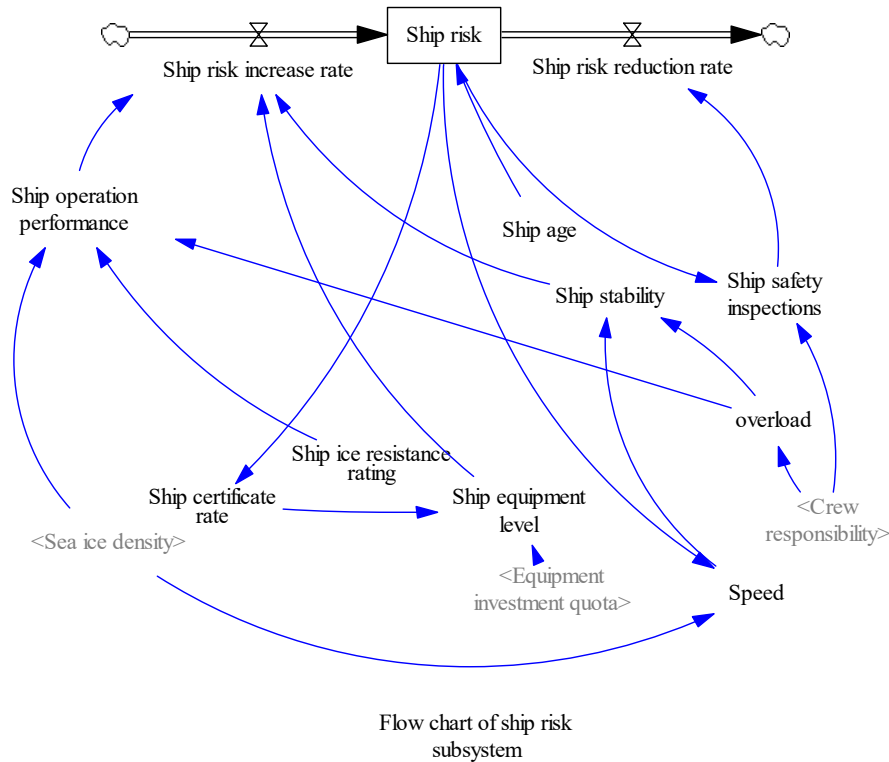


Figure 6. Flow chart of ship subsystem

3.5. Sea Ice Risk Subsystem

Based on the analysis of the causal relationship diagram of the SD simulation model of general aviation risk management, combined with the characteristics of the elements in the personnel subsystem and the causal relationship between them, the flow chart of the ice risk subsystem is drawn as shown as Figure 7 Ice Risk Subsystem The flow chart is shown.

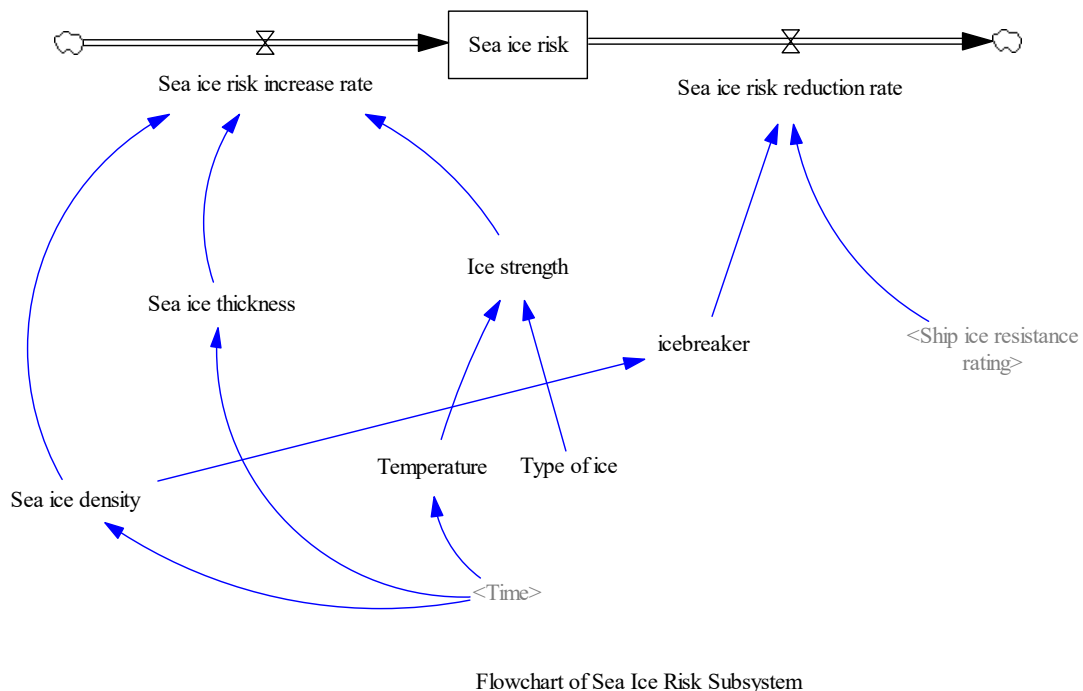


Figure 7. Flow chart of ice risk subsystem

During the ban on navigation, the risk of navigation is zero.

The results of the operation are as follows.

It can be seen from the figure that the smallest traffic risk of the year is in August and September, of which the traffic risk is highest in March and April. Navigation needs to be paid attention to, and crew and equipment need to be paid more attention.

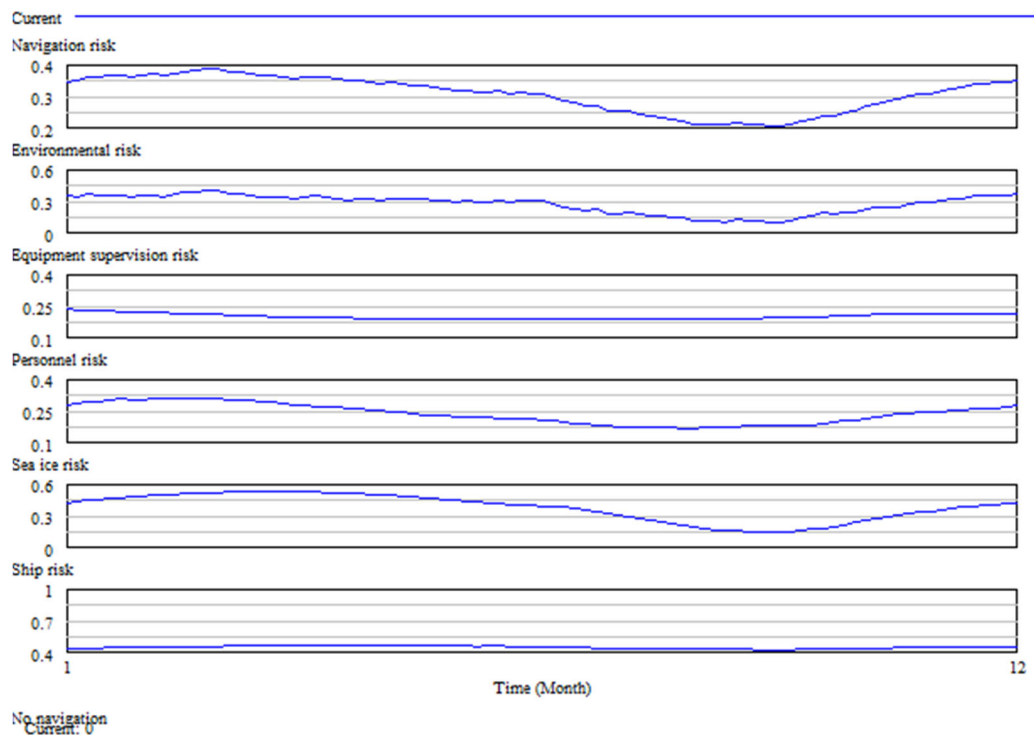


Figure 8. Navigation risk

4. Comparative analysis of risk policies

Based on the Arctic route navigation risk model, the four subsystems of "people-ship-environment-management" are analyzed, through various adjustable variables, and on the basis of in-depth analysis of each variable, it is proposed from the aspects of personnel security, ship performance and environmental control. Change the value of various parameters in terms of aspects and risk control, simulate the trend of changes in the navigation risk of the Arctic route, and find economical and reasonable management strategies.

(1) Option 1: At the level of personnel protection, reduce the occurrence of safety accidents from the source, and increase the crew performance rate by 20%.

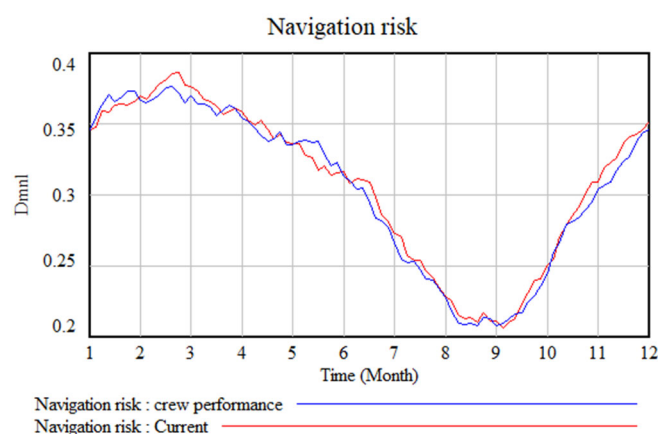


Figure 9. General navigation risks of Option 1

It can be seen that increasing the crew performance rate by 20% can reduce the risk of ships sailing.

(2) Option 2: Improve visibility, increase visibility by 20%.

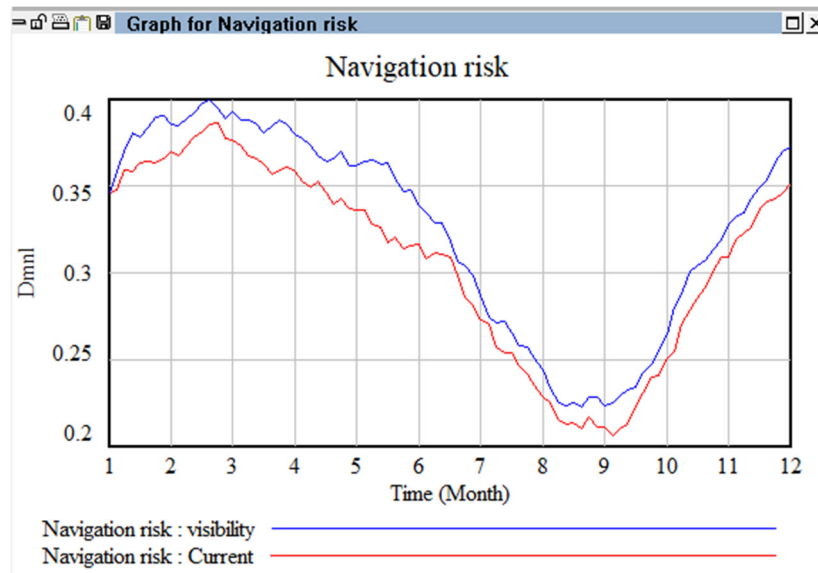


Figure 10. General navigation risks of Option 2

It can be seen that increasing the visibility by 20% will significantly reduce the navigation risk, and the navigation risk of ships can be reduced by improving the visibility.

By comparing the above two schemes, it can be found that by improving the visibility, compared with other schemes, improving the visibility can greatly reduce the risk of ship navigation. The use effect is the best, and the increase in the crew performance rate and the normal operation rate of the shipboard equipment can not reduce the risk to a great extent, and the effect is minimal. Explain that subsequent risk research can focus more on visibility management.

(3) Sensitivity test

Sensitivity testing checks whether the corresponding changes in other model variables are reasonable when one parameter of the model changes. Sensitivity testing is mainly performed on those parameters whose estimation accuracy is not high.

Sensitivity test 1: Sensitivity test for flow rate, the test results are as follows:

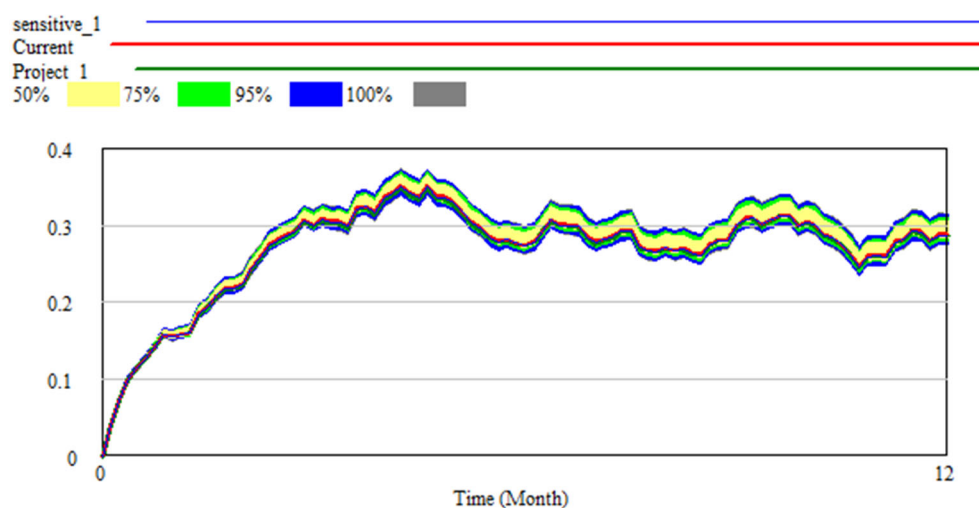


Figure 11. Sensitivity test

Carry out a sensitivity test for the age of the ship. The test results are as follows:

75% of the simulation results fall in the yellow area, and 100% of the simulation results fall in the gray area. Similar to the previous analysis, it is found that all the running results show numerical sensitivity, but no behavioral patterns. Sensitivity, it can be said that the running results of the model passed this sensitivity test.

5. Conclusion

A method based on a system dynamics model is proposed and implemented to analyze maritime transport risks in the Arctic sea. The system dynamics model is used to analyze the one-year navigation risk of the Arctic route. According to the results of the analysis, the eighth and September of the year are suitable for navigation, and the risk of navigation is the lowest at this time. The risk of navigation from February to April is higher, which may be due to the low temperature in winter and the higher probability of abnormal weather, making it unsuitable for navigation. At the same time, three strategies to improve navigation safety were evaluated, and it was concluded that Option Three has the most significant effect of increasing visibility by 20%. Secondly, increasing equipment investment can also significantly reduce navigation risks. This result will reduce navigation risks in the future. Provides some ideas. The probability obtained by the proposed method can be used to support the ship's operational decision.

References

- [1] Wlisses Bonelá Fontoura, Gisele de Lorena Diniz Chaves, Glaydston Mattos Ribeiro. The Brazilian urban mobility policy: The impact in São Paulo transport system using system dynamics. *Transport Policy*, vol.73(2019), p. 51-61.
- [2] Hongbo Liu, Yunfeng Liu, Huannan Wang, Jiangye Yang, Xia Zhou. Research on the coordinated development of greenization and urbanization based on system dynamics and data envelopment analysis——A case study of Tianjin. *Journal of Cleaner Production*, vol.14(2019), p.195-208.
- [3] Farzaneh Daneshzand, Mohammad Reza Amin-Naseri, Mehdi Asali, Ali Elkamel, Michael Fowler. A system dynamics model for optimal allocation of natural gas to various demand sectors. *Computers & Chemical Engineering*, vol.12(2019), p.88-105.
- [4] Kung-Jeng Wang, Kun-Shan Lee, Jia-Hong Liao. Technology cooperation modeling of multiple profit-centered business units: A system dynamics framework *Mathematics and Computers in Simulation*, vol.162(2019), p.195-201.