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Risk Assessment of Maritime Traffic Safety Based on Catastrophe Theory

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Abstract: *Maritime transport plays a pivotal role in foreign trade and world economic growth. However, the catastrophic nature of maritime accidents has posed a serious threat to life and the environment. Maritime transport safety is a complex system susceptible to human, equipment and environmental risks. Based on the catastrophe theory, this paper evaluates the risk of Marine traffic, discusses the current development of Marine traffic, the current situation of the Marine traffic environment, and analyzes the applicability of catastrophe theory and the value of Marine traffic safety risk assessment. The basic principle of catastrophe theory is also introduced, and the analytic hierarchy process, N-K model, interpretive structure model, catastrophe series method and other Marine safety risk assessment methods are compared. The catastrophe theory is selected for Marine traffic safety assessment, and the Marine traffic safety risk assessment model based on the catastrophe theory is constructed. Finally, this paper expounds on the preventive measures of Marine traffic safety based on the catastrophe theory from three aspects: humans, ships and the environment. To provide the theoretical basis for the subsequent Marine traffic safety risk assessment based on the catastrophe theory.*

Keywords: *Mutation theory; Maritime traffic; Security risks; Evaluation*

1. Introduction

Maritime traffic safety has always been a concern of people. Due to the deepening of world economic integration, the closer communication between countries in the world, and the increasing volume of international trade, maritime transportation has become increasingly busy, but the related accident risk also increases. How to minimize the risk and avoid accidents has been the focus of scholars, the shipping industry, governments and international organizations. Maritime transport has a complex operational and safety system. Most accidents occur because of deficiencies in human, ship and environmental systems. With the increase in tonnage of ships, the density of ships passing through important waters and waterways is also increasing [1]. Coupled with the construction of large-scale ocean engineering, this inevitably leads to the increasingly complex maritime traffic environment. Various maritime traffic accidents such as ship collisions, grounding, fire, explosions and sinkings occur from time to time. This not only causes serious economic consequences but also pollutes the Marine environment. With the increasing maturity and development of maritime transport channels, more and more research on maritime transport safety risks has been carried out [2].

There are some motion and change processes in nature that can be described by differential equations, but such regular and good behavior is very rare. On the contrary, many uncontrollable and unpredictable events occur in nature and society, which are non-calculable functions. Abrupt change theory is precisely the condition that can describe gradual changes in motion or abrupt changes. What the abrupt change theory wants to solve is the abrupt phenomenon of continuous change, so it is bound to be related to the qualitative theory of the solution of the differential equation, as well as to the topological characteristics, which can well predict and evaluate the occurrence of some events. Risk evaluation is the premise of risk prediction, and risk prediction is the core of risk evaluation. Through the study of maritime traffic risk assessment, the future safety situation of the maritime traffic safety system can be mastered, the level of maritime traffic safety can be predicted, and corresponding preventive measures can be taken to effectively control the risk of maritime traffic and reduce the casualties and property losses to the minimum or acceptable range [3].

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2. Research on Maritime traffic Safety Risk based on catastrophe theory

2.1 The principle of mutation theory

The potential function in the sudden change theory can be determined by the state variable and the control variable, where the state variable represents the behavior state of the system, and the control variable represents various factors affecting the state variable. Let f (x, c) represent the potential function of the system, where x is the state variable and c is the control variable; Then the critical point equation can be expressed as:

$$\frac{df\left(x,c\right)}{dx}=0 \tag{1}$$

Formula 1 is an equilibrium surface composed of all critical points, but the system is in an unstable state near the degenerate critical point, and a slight change in control variables may lead to abrupt change in the system. The critical point of degradation meets the following conditions:

$$\begin{cases} f^{'}\left(x,c\right)=0 \\ f^{''}\left(x,c\right)=0 \end{cases} \tag{2}$$

By eliminating the; c is the bifurcation point set equation, and the bifurcation point set equation is the total number of points where the form of the potential function changes. Through the bifurcated point set equation, the normalization formula can be derived. The normalization formula is to normalize the different quality of each control variable of the system into the same germplasm that can be compared, so as to carry out quantitative recursive operation on the system, and obtain the total mutation membership function value of the system, which represents the system state, and take this as the basis for comprehensive measurement. In this paper, the mutation model will be improved. According to the established mutation model (namely, the cusp mutation model), the recursive operation will be carried out layer by layer from the factor layer according to the corresponding normalization formula, which shall follow the "complementary and non-complementary principle". The overall calculation formula can be described as follows:

$$D_{ii_j}=x_{ii_j}^{\frac{1}{j+1}}(\mathrm{i}=1,2,3,\cdots,\mathrm{m}) \tag{3}$$

$$C_{pp_q}=\left(\frac{1}{m}\sum_{j=1}^{m}D_{ii_j}\right)^{\frac{1}{q+1}}(\mathrm{p}=1,2;q=1,2,3,\cdots,s) \tag{4}$$

$$B_R=\left(\frac{1}{s}\sum_{q=1}^{s}C_{pp_q}\right)^{\frac{1}{R+1}}(\mathrm{R}=1,2) \tag{5}$$

$$K=\frac{1}{2}\sum_{R=1}^{2}B_R \tag{6}$$

Where, Diij represents the mutation value of the JTH control variable of the ith mutation in layer D; Xiij represents the standardized original value of the JTH control variable of the ith mutation in layer D; n represents the number of mutations in layer D; m represents the i-th mutation control variable dimension of layer D; ij represents the JTH control variable of the ith mutation in layer D; Cp represents the coupling degree of the q th control variable of the p th mutation in layer C; pq represents the g th control variable of the p th mutation in layer C; s represents the control variable dimension of the p mutation in layer C; BR represents the coupling degree of the R th control variable of layer B; R represents the dimension of control variable of layer B; K represents the coupling degree of layer A, namely the final critical node risk coupling degree.

2.2 Comparison of maritime safety risk assessment methods

There are many risk assessment methods for different aspects, and the common risk assessment methods mainly include analytic hierarchy process, N-K model, explanatory structure model, mutation progression method, etc. In order to select the method suitable for this study, the advantages and disadvantages of each method are compared in this paper, as shown in Table 1.

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Table 1: Comparative analysis of coupling risk measurement method.

Method name	merit	shortcoming
Analytic hierarchy	Comprehensive, Simple and practical, Less quantitative data is required	Measures that are too subjective and don't apply too much metric data
Interpret the structural model	The ability to decompose complex systems into clear subsystems	The process relies on subjective judgment and lacks objectivity
N-K model	Ability to measure the results of interactions between factors in complex systems	Complete historical data is lacking
Mutational progressional method	There is no need to consider the weight of risk factors, and comprehensively consider the relationship and impact of risk factors	Key risk factors need to be selected

In this paper, the results of risk factors at key nodes of maritime transportation should be measured. On the one hand, the risk factors themselves and the relationship between risk factors should be considered. On the other hand, the results of risk factors should be comprehensively considered. Although the N-K model can measure the results of the research problems in this paper, the processing process of the N-K model needs to completely rely on data and cannot consider the characteristics of the risk factors themselves. Therefore, the mutation progression method is the most consistent with the requirements of this paper [4].

Abrupt change progression method is a multi-criteria measurement method based on abrupt change theory, which can consider the characteristics of risk factors and coupling mechanism between key nodes of maritime transportation, and can establish a multi-level and multi-criteria measurement model of risk factor coupling effect. The mutation progression method can avoid the weight analysis of risk factors, but can take into account the importance of analysis factors. At the same time, the comprehensive effect value can be calculated according to the established hierarchical structure, which can be used as the basis for the overall comparison of risk size.

3. The risk assessment model of maritime traffic safety based on catastrophe theory is constructed

According to the measurement steps of catastrophe progression method, firstly, factor analysis method is adopted to establish and analyze the index system, and the hierarchical structure chart is finally established according to the calculated results, which can be specifically described as the form of Figure 1. Secondly, the mutation model of each part is established according to the established hierarchical structure and reference. Finally, the normalization calculation is carried out. In this part, the data should be standardized first, then the recursive calculation should be carried out according to the normalization formula of the mutation model, and finally the results should be adjusted according to the above formula.

(1) The hierarchical structure established by the factor analysis method adopted in this paper builds four layers as shown in Figure 1, in which layer A is the calculated value of the final risk coupling measurement of each key transport node. According to the coupling analysis of risk factors in Chapter 2, it is known that the final degree of risk coupling is determined by the vulnerability and adaptability indexes of key nodes of maritime transportation. Therefore, layer B is divided into two aspects: vulnerability and adaptability indexes. The number of factors in layer C, i.e. the value of n, is determined by the calculated contribution rate of cumulative variance. The number of factors contained in each factor in layer D, that is, the value of m, is determined by the calculated factor load. In addition, the importance of each layer decreases from left to right. For example, in layer C, factor 1 is more important than factor 2 to the vulnerability index or adaptability index, similarly, factor 2 is more important than factor 3 to the vulnerability index or adaptability index, and so on.

(2) During the establishment of the mutation model, the upper layer confirms the mutation model according to the lower layer, that is, layer A establishes the corresponding mutation model according to the number of factors in layer B. At this time, the factor in layer B can be regarded as the control variable, and its dimension determines the final mutation model. It can be seen from Figure 1 that it conforms to the cusp mutation. Similarly, the mutation model of each factor in layer B is determined by its corresponding number of risk factors in layer C.

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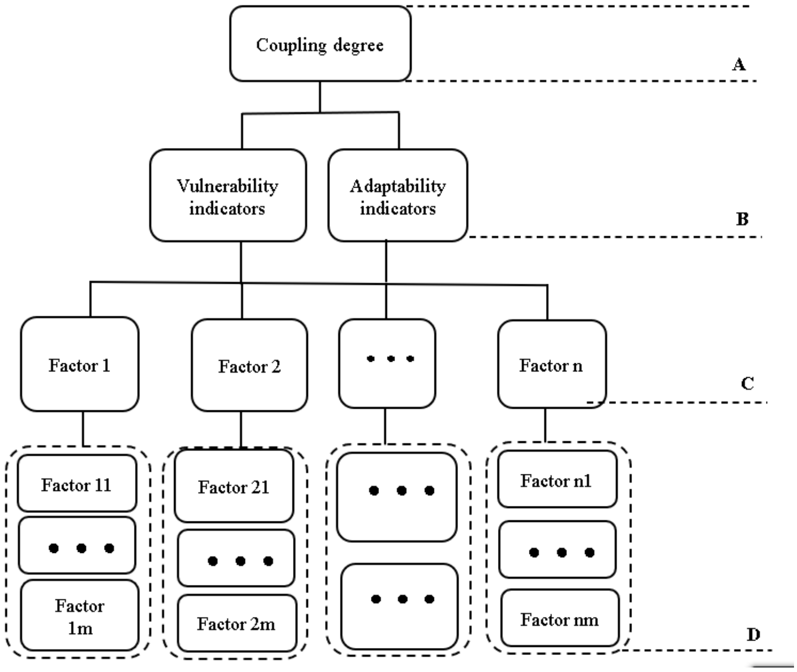

Figure 1: The diagram of hierarchical structure.

4. Maritime traffic safety precautions based on catastrophe theory

It is self-evident that maritime transport safety assessment plays an important role in maritime transport, and the constant change of its risk factors has an important impact on maritime transport safety. Therefore, it is very necessary to study maritime transport safety assessment from the perspective of risk factors. The following are maritime traffic safety precautions based on the catastrophe theory.

(1) Human factor is the focus of maritime safety work. The greater the mutation membership function value in the risk decision scheme, the safer the maritime traffic safety system. Therefore, according to the membership index of factors, preventive measures are proposed in aspects of education and training, crew selection, rest and rest system, psychological consultation and performance evaluation. Training institutions should strengthen the education and training of seafarers, especially the education of safety culture; In the selection and personnel arrangement of seafarers, the physiological and psychological conditions of seafarers should be mastered, and the suitability of seafarers should be investigated. Improve your sleep schedule. In the maritime industry where human factors play a major role, the proportion caused by fatigue is as high as about, so it is particularly necessary to establish a reasonable working time system [5].

(2) Risk prevention measures for ship factors. In port waters, ships are managed by ports and shipping companies at the same time. Only when ships, ports and companies perform their duties seriously can they ensure the safety of ships in port waters. Safety management should be strengthened. Strengthen the ability of transportation ships to resist safety mutations, comply with relevant treaties of the International Maritime Organization, and conduct fire drills to improve the management level of ship organizations[6].

(3) Risk prevention measures for environmental factors. For the transportation environment, improving traffic density. Reasonably schedule ships to avoid multiple ships entering and exiting the port simultaneously, and improve transportation methods. Choose a reasonable mode of transportation for ships entering and exiting the port, reduce the time spent staying in narrow channels of the port, and improve traffic management regulations. For the natural environment, it is necessary to strengthen the lookout in the frozen area, avoid drifting large ice cubes in time to avoid sailing near the area with thick ice, and try to prevent the ice from freezing the ship's risk prevention measures in the area of high wind and waves. Listen to meteorological forecasts in a timely manner, carefully analyze the weather situation, and formulate preparation measures for preventing and resisting strong winds and waves in advance. Before sailing, stability calculations should be carefully carried out to ensure compliance with stability requirements, correct prediction of typhoons, and appropriate analysis and evaluation, to accumulate experience in typhoon prevention and resistance.[7].

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5. Conclusion

Maritime traffic safety risk assessment refers to the estimation of the probability of occurrence, possible consequences, possible occurrence time and scope of influence of maritime traffic risks, which is the basis of prevention and control of maritime traffic risks. It can be seen that maritime traffic safety risk assessment has more practical significance than maritime traffic accident prediction. According to the abrupt change theory model of maritime traffic safety system, if the characteristic evolution curve of the system is larger than the singularity set, the more energy will be released by the system potential function, and the more serious the risk consequences will be. Therefore, the use of the system potential function model can well describe the abrupt change phenomenon of maritime traffic risk. Although the occurrence of accidents is random under the same environmental conditions, the analysis of the evolutionary mechanism of maritime traffic safety system can provide a necessary theoretical basis for the study of maritime traffic safety risk decision-making.

References

[1] Lili J, Minglu M. Analysis of Maritime Traffic Safety Based on Intrinsic Safety Theory[C]//Journal of Physics: Conference Series. IOP Publishing, 2021, 1827(1): 012040.
[2] Bi J, Gao M, Zhang W, et al. Research on Navigation Safety Evaluation of Coastal Waters Based on Dynamic Irregular Grid[J]. Journal of Marine Science and Engineering, 2022, 10(6): 733.
[3] Li L, Lu W, Niu J, et al. AIS data-based decision model for navigation risk in sea areas [J]. The Journal of Navigation, 2018, 71(3): 664-678.
[4] Han Y, Zhen X, Huang Y. Hybrid dynamic risk modelling for safety critical equipment on offshore installations [J]. Process Safety and Environmental Protection, 2021, 156: 482-495.
[5] Vassalos D. A Pioneer of Maritime Safety [J]. Ships and Offshore Structures, 2020, 15(5): 462-467.
[6] Ozbas B. Safety risk analysis of maritime transportation: review of the literature [J]. Transportation research record, 2013, 2326(1): 32-38.
[7] Park C, Kontovas C, Yang Z, et al. A BN driven FMEA approach to assess maritime cybersecurity risks [J]. Ocean & Coastal Management, 2023, 235: 106480.