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A Review of Risk Assessment Methods for Maritime Traffic

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Abstract

Marine traffic safety assessment is an important indicator of navigation safety. At present, there are many kinds of Marine traffic safety assessment methods. In this paper, the existing Marine traffic safety assessment methods are classified and summarized, the main application results and characteristics of each research method are summarized, and the possible development direction of Marine traffic safety assessment in the future is proposed.

Keywords

Maritime Traffic Safety; Risk Assessment.

1. Introduction

For a long time, maritime traffic safety has been a very concerned issue in the shipping industry, the maritime countries in the world have done a lot of work in the field of safety, but also made a lot of progress. However, with the rapid development of the shipping industry and the rapid rise of the shipbuilding industry in recent years, more and more accidents such as collision, grounding, fire, explosion and pollution have occurred to ships around the world, resulting in more and more serious economic losses and casualties. Therefore, how to reasonably and effectively apply the key technologies and research results of modern science to shipping safety has become an important subject and focus of research in the field of modern water traffic safety. Safety assessment is usually built on the basis of investigating the history and the present situation, using appropriate methods, more comprehensive analysis of maritime traffic safety system security ties between each component and influence, at the same time, also for the implementation of the vessel traffic safety measures or waterway planning and design to provide important theoretical support. It can be seen that the evaluation method of maritime traffic safety directly affects the accuracy of the evaluation results and the practicability of the evaluation model.

2. Influencing factors of maritime traffic safety

2.1 Human factors

Eighty percent of maritime accidents are caused by human factors. With the large-scale, new-type and automation of ships, modern technology has been applied to the shipping industry, and the structural functions of the equipment and systems on board have been comprehensively refined, and the technological content and degree of automation have been improved. Therefore, high standards and high requirements have been put forward for seafarers in terms of theoretical knowledge, technical application, operation control and maintenance management. Literature [1] makes a more accurate assessment of human reliability by examining the uncertainty of working time at sea. Through dynamic analysis of the structure and subjective analysis of human activities under different weather conditions, a model is established to describe the uncertainty of human performance factors.

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The results show that the probability of human failure increases at the end of the voyage, but the large variation of human reliability is largely dependent on weather conditions. Literature [2] proposed a probabilistic method to estimate the fatality rate of fire accidents by comparing the available and required safe evacuation times in fire accidents caused by critical temperature and critical smoke.

2.2 Ship factors

The ship factor includes the ship itself and the ship management. The quality and seaworthiness of ships are the premise of safe navigation of ships. Of course, the factors of the ship itself also include the normal operation of various fire-fighting and life-saving equipment in the engine room, mechanical and electrical equipment, safety measures, navigation equipment in the cab and various automation systems. According to the literature [3], the design of ships emphasizes more and more on reducing life-cycle costs, which can be achieved by means of reducing the number of crew members, improving automation and adopting commercial practices. According to the literature, the current assessment standard focuses on performance, and it is unreasonable to build the ship system according to the different degree of acceptable risk, which will lead to underdesign or overdesign, and eventually the ship will end up with the strength of its "weakest link". Literature [4] discusses in detail the problem of maritime collision based on molecular collision theory, as well as the shortcomings of existing methods. At the same time, the calculation method is modified to obtain more real collision diameter. Literature [5] proposed a new fatigue damage assessment method. By introducing a reasonable model into the coupling dynamics of hull/mooring system, the influence of wave climate change and ocean corrosion on the fatigue damage assessment of mooring cables was considered. At the same time, this method is used to evaluate the fatigue damage of the mooring cable of the semi-submersible platform.

2.3 Environmental factors

Navigation environmental conditions include meteorological and sea conditions, Marine geographical environment, Marine traffic environment and Marine information environment. The meteorological and sea conditions that affect maritime safety include visibility, wind and waves, ocean currents and tides. The sea is a water area with free choice of shipping routes, but the width, depth, bend Angle, crossing condition of shipping routes, vessel traffic flow and navigation order of sea areas have certain influence on shipping safety. Literature [6] shows that the environment on board is a typically harsh environment, including extreme temperature and relative humidity conditions, especially in the engine room. Literature on a merchant ship on several sites of the temperature and relative humidity were monitored, and the actual monitoring data comparing with ISO design index, in order to obtain effective job hazard analysis, and calculated the maximum of the workers in the cabin stay the rest of the day time and must be in the control room, also puts forward the corresponding solutions.

2.4 Management factors

Management factors play an increasingly important role in modern shipping safety. A large number of accidents involve ship management, crew management, ship structure and equipment are also directly related to management; Shipping enterprises have weak awareness of production safety, weak safety system construction, unreasonable cargo stowage; The long-term operation of ships makes it difficult for enterprises to manage all ships and implement the safety management system comprehensively. Literature [7] discusses the effectiveness of traffic guidance systems (VTS) and the benefits of improved navigation. The literature uses a risk assessment tool developed for complex systems analysis (the Incident Sequence Precursor Method) to analyze related events. Literature [8] provides a methodology that can be used to develop risk-based system safety standards. The literature studies the relationship between risk and navigational standards from a managerial perspective.

2.5 Special influence factors

Ships in the course of navigation are not only affected by internal and external influences, but also by special influences in special areas or under specific circumstances. For example, literature [9]

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introduced the role of ship AIS equipment in ship navigation, collision avoidance, inter-ship communication and ship-shore communication, analyzed the possible unsafe factors caused by blind reliance on AIS, and focused on how to make full use of the characteristics of AIS to maintain the safety of water traffic. In reference [10], an evaluation model is built based on matter-element theory to improve the navigation environment of the port, and the service capacity of Ningbo port area is demonstrated, and good results have been achieved. Literature [11] proposed a framework of safety indicators based on accident severity, death rate and special indicators of maritime transportation to evaluate the risk level of busy waterways by analyzing the report data of ship traffic accidents in the western port of Shenzhen from 1995 to 2015. The safety index is composed of safety evaluation index (SEI) and safety warning index (SWI), which is derived from the proposed Chinese ship traffic risk criterion. Literature shows that risk criterion and safety index are feasible and effective in vessel traffic management. The method based on long-term accident data can significantly support risk analysis of busy ports and waterways from a macro perspective, SWI can be used as a threshold to trigger action, and SEI can be used as an indicator to measure safety status.

3. Methods for risk assessment of maritime traffic

There are many methods to evaluate the navigation safety of ships. The traditional evaluation method is to find the cause of the accident, sum up the experience and lessons, and take measures after the accident. Although this method plays a certain role in reducing the risk, it has many shortcomings. At present, the more advanced method is to carry out safety assessment before the ship sails, that is, to judge whether the index system of navigation safety meets the prescribed safety requirements before the voyage, so as to adjust or improve the elements in the system and control the probability of accidents within a certain level as far as possible.

3.1 Evaluation method based on probability theory and mathematical statistics

For many years, China has used five absolute number indexes of accidents, including "number of accidents", "direct economic loss", "number of deaths", "number of injuries" and "shipwreck rate", and one index of "safety overall" to evaluate the traffic safety status of water area or shipping enterprises. Most of these indicators are accident indicators, that is, after the occurrence of an accident, the maritime traffic safety situation can be investigated through the determined data. The limitation of this approach is that the safety situation cannot be comprehensively evaluated in advance. At the same time, the status of risk factors of the system is not fully considered, which makes the safety assessment of Marine traffic system stay in the stage of post-evaluation. Literature [12] collects and reviews a large number of literatures on probabilistic risk analysis of ship collision by using the method of probability statistics, and focuses on analyzing the stakeholders who may benefit from the study as well as the methods and standards adopted for collision risk. The literature identifies modeling aspects of interest to stakeholders (frequency estimation, causation analysis, etc.). At the same time, according to the technical characteristics of these methods, a classification system is proposed, and its representative methods are described and discussed in detail. At the same time, it is emphasized that these risk analysis methods need to be improved, such as the determination of collision candidates, the evaluation of collision probability of multi-vessel encounters, the evaluation of personnel and organizational factors. Literature [13] discusses an analytical approach to accident risk modeling when data for analyzing safety factors are limited or unavailable. The literature is based on Markov model and Markov chain Monte Carlo simulation, and takes shipping as an example to illustrate. Literature [14] adopted Bayesian network and Kafangfang method to analyze the accidents of fishing boats with a total length of 7 m and above from 2008 to 2018, and put forward suggestions for accident prevention. Literature [15] selected the data of total losses from global maritime accidents from 1998 to 2018, involving 16 ship types and 13 major navigable sea areas, and used the improved entropy weight topological model to calculate. The results show that in the statistical results of ship type and sea area, the main influencing factors of accidents are ship capsizing, grounding and explosion. Based on the Greek Ship Accident Database from 1992 to 2005, Literature [16] proposed

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a method to determine the occurrence probability of ship grounding by means of accident limit state analysis and combining with the Greek Ship Accident Database from 1992 to 2005.

3.2 Logical reasoning method

3.2.1 Accident tree analysis

The accident tree analysis method takes the analysis target as the top event, analyzes its possible causes and events to the basic events layer by layer, establishes the accident tree with logical symbols according to the logical relations among the causes and events, and analyzes and evaluates the accident by simplifying and calculating the accident tree. FTA is also widely used in ship accident evaluation and ship safety management. Literature [17] using fault tree analysis method to evaluate oil tanker collision probability, based on this, advances an improved cognitive reliability based on fuzzy bayesian network error analysis method for human error evaluation, provides a higher degree of results can distinguish between sex, at the same time, considering the weight and the quantitative impact of environmental factors.

3.2.2 Safety Evaluation Method Based on Bayesian Network

Bayesian network can well represent the uncertainty and correlation among variables, and carry out uncertainty reasoning. Ship traffic accident is the result of the comprehensive action of man-machine-environment-management and other factors, and each influencing factor has randomness, uncertainty and interconnection. This ensures the feasibility of Bayesian network in evaluating the application of ship traffic safety. Literature [18] used dynamic Bayesian network (DBN) to conduct dynamic assessment of natural environmental risks at key nodes of the Arctic Northwest Passage. The literature specifically discusses the index selection and data processing, the determination of key navigation nodes, the calculation of evidence-based reasoning and the verification of DBN model. In Literature [19], the concept of FSA and Bayesian network technology are used to evaluate the navigation risk along the Yangtze River. Meanwhile, the risk matrix method is used to consider the probability and consequences of accidents, establish a navigation risk model, and conduct scenario analysis on the model. Literature [20] established a new risk model applicable to the Northern Sea Route (NSR) by using Bayesian network (BN) to discuss the possibility of collision, sinking and grounding of ships at sea.

3.3 Evaluation method based on ambiguity and other uncertainties

3.3.1 Fuzzy comprehensive evaluation method

Fuzzy comprehensive evaluation method is a feasible method to analyze and deal with the phenomena or things with fuzziness by applying fuzzy transformation principle and quantitative mathematics method. It is also widely used in ship traffic. In Literature [21], the method of fuzzy evaluation was used to obtain the AIS data collected by the automatic identification system equipment installed by Kobe University in Japan and the University of Johor in Malaysia. The risk identification was carried out first, and then the safety assessment was carried out. The data used were processed through failure mode and effect analysis, including occurrence (O), severity (S), and detection (D) risk factors, which were finally analyzed by fuzzy evaluation. Literature [22] used fuzzy evidence reasoning method to deal with the uncertainty of the failure mode of a liquefied natural gas transportation system, and studied its safety risk level. Literature [23] evaluates the reliability of personnel in the operation process of ship emergency fire pump. According to the literature, the fuzzy processing method can be applied to the ocean-specific error generation conditions. Therefore, the research results of the literature provide contributions for safety managers and supervisors to monitor fire safety management and crew reliability performance. Literature [24] combined geospatial technology with multi-criteria decision making, and proposed a spatial fuzzy multi-criteria evaluation method for maritime transport risk. Fourteen criteria from three risk categories (risk, vulnerability and exposure, and mitigation) were selected for assessment in the literature and transformed into spatial levels using geospatial techniques. According to the fuzzy analytic hierarchy process, each index is weighted, and the risk component diagram is generated. A risk map is then generated by combining the risk,

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vulnerability, and exposure levels with the mitigation capability risk component map. Literature [25] proposed a Marine accident learning technology based on fuzzy cognitive map (MALFCMS). MALFCM uses fuzzy cognitive map (FCMS) to model the relationship between accident factors by directly using information from the accident database and combining with expert opinions. Thus, the results are more realistic and objective, and the subjectivity of the results is eliminated or controlled, which overcomes the main shortcomings of FCMS. The literature [26] based on the fuzzy analytic hierarchy process (quantificating and expert system (ES), through to the automatic identification system (AIS) acquisition of data analysis, selection of the external environment and internal factors significantly influence factors, and then using the method of quantificating modeling hierarchy and determine the weight of each factor, finally, ES algorithm are used to get the sorted sequence and the corresponding traffic command of the ship. According to the literature, this method can significantly improve the efficiency and accuracy of ship traffic scheduling, and can improve the channel capacity by reducing the voyage time.

3.3.2 Grey theory evaluation method

Vessel traffic system can be as a grey system, a dynamic system in both the people known to determine information (such as ship parameters, etc.), there are also unknown and uncertainty of information (such as driver's psychological status and inner mechanism of various factors of traffic system, etc.), so you can use grey system theory and method to study the vessel traffic system. Literature [27] uses grey theory and fuzzy theory to prioritize the main factors affecting ship manoeuvring decisions. According to the literature, the influencing factors of autonomous ship manoeuvring-decision constitute a typical grey system, which is suitable to be studied by grey correlation analysis method. Based on the experimental data of experienced sailors at Waigaoqiao Wharf in Shanghai, a reasoning model based on grey and fuzzy theory is proposed by using the simulation platform. The model selects the main influencing factors of ship handling decision from a variety of factors (overall and partial natural environment factors, ship movement, mechanical parameters, position, etc.), and sets up a specific ship handling scenario for the priority of Marine traffic safety research decision.

Grey system modeling requires a relatively small number of samples, simple principle, convenient operation and multi-level processing. However, it has specific requirements for sample data: sample data must be easy to obtain and can be accurately quantified, and conform to smooth discreteness. In the process of vessel traffic safety evaluation, the determination of weight or evaluation matrix will be interfered by expert opinions.

3.4 Evaluation method based on neural network

Artificial neural network modeling is a branch of artificial intelligence research, it has strong parallel processing, self-adaptation and self-organization ability, therefore, it has high modeling ability and good data fitting ability in the complex nonlinear system. In literature [28], a collision risk model was established according to human-machine-environment-pipe and other factors, and BP neural network was used to train and learn a large number of samples, which could ideally realize the identification of collision risk level affected by multiple factors. Literature [30] applies the neural network machine learning method to collision risk assessment and navigation safety. Literature [31] analyzed maritime accidents that occurred in Istanbul Strait, and proposed quantitative and qualitative assessments of maritime accidents. An analysis of Marine accidents in the Istanbul Strait using neuro-fuzzy and genetically optimized fuzzy classifiers has been carried out in the literature. It is concluded that when severe weather conditions prevail in the strait, the severity of accidents increases regardless of ship size. Therefore, solutions to reduce unnecessary incidents should give priority to weather conditions and ship capacity.

3.5 Evaluation method based on AIS data

Automatic Identification System (AIS) is composed of shore-based (base station) facilities and shipboard equipment. It is a new type of digital navigation aid System and equipment integrating

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network technology, modern communication technology, computer technology and electronic information display technology. AIS system can cooperate with global positioning system (GPS) will position, speed, rate of change course and course of ship dynamic combined with the name of ship, call sign, draft and dangerous goods ship static data by very high frequency (VHF) channel to the waters near the ship and coast station broadcasts, leaving nearby ship and coast station can timely grasp all ships near the surface of dynamic and static information, be able to immediately call to coordinate each other, take necessary collision avoidance action, of great help to ship safety. The functions of AIS include :(1) identifying ships, (2) assisting in tracking targets, (3) simplifying information exchange, and (4) providing other auxiliary information to avoid collisions. AIS can strengthen the measures to avoid collisions between vessels, to enhance the ARPA radar, vessel traffic management system, the function of the report, on the electronic chart shows all ships visual information such as course, routes, name of vessel, improved the function of maritime communications, and provides a by AIS recognition method for voice and text communication, to enhance the global awareness of the ship. Based on the analysis of the behavior of incoming vessels at Kaohsiung Port, literature [32] used two approaches to navigation safety assessment methods (cross line method and Monte Carlo method) based on automatic identification system (AIS) to quantitatively evaluate the grounding risk of the incoming channel and the inner channel, and the grounding probability results obtained by the two methods were consistent. Literature [33] studied the evaluation index system of automatic identification system (AIS) information extraction and analysis of relevant data and the theory of multi-objective multi-layer fuzzy optimization, and established the navigation risk decision-making model (multi-objective multi-layer fuzzy optimization model) for different sea areas. The result of the decision model is basically consistent with the actual traffic condition of Chengshantou water area and the result of the fuzzy comprehensive evaluation model, which proves that the decision model is scientific and practical. Literature [34] proposed a method to evaluate vessel traffic performance at the current speed by using the automatic identification system (AIS) big data of 4923 ships in Shanghai section of the Yangtze River. Key elements of the method include data acquisition, error elimination, combined with the AIS of geocoding system and channel data characteristics of traffic flow modeling, the estimated speed and the correlation between the congestion level, and the results show that currently Shanghai Yangtze river section of the speed limit is reasonable, further proves that the model can be calculated in the other channel or navigation channel the rationality of the speed limit. Document [35] studied the risk of ship collision off the coast of Portugal based on the data of the Automatic Identification System (AIS) recorded and maintained by the Portugal Coastal Vessel Traffic Management Center (CCTMC). The literature develops an algorithm to assess the risk profile and relative importance of harbor-related routes, and proposes a collision risk calculation method that estimates future distances between ships based on their position, heading and speed, and compares these distances to determined collision diameters.

3.6 Other methods

After years of development, there have been many safety assessment methods that can be applied to different types of ships in different scenarios. Literature [36] proposed a potential risk ship domain model with a clear meaning of risk degree. Based on the concept of ship domain, the area around the ship is established by using the kernel density algorithm. The PRSD model was used to analyze the effects of ship length and speed as well as sailing conditions on the size and shape of the ship area. Meanwhile, the ship area size and potential collision risk index of each risk level were determined by comparing with the existing models. In Literature [37], the normal distribution of ship traffic is used to calculate the risk of ship collision based on the characteristics of traffic flow. In this paper, the collision probability is simulated by estimating the best-fitting distribution function of ship traffic flow at Busan Port, the largest cargo loading and unloading port in South Korea. In Literature [38], environmental stress and collision risk models are used to assess ship collision risk. In the literature, the Collision Risk (CORI) model of moving the existing ship domain to CPA was adopted to compare the collision risks according to the navigator's perception of the conditions encountered by the ship.

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The paper [39] used data from the Vessel Traffic Service (VTS) system of the Coast Guard of Mexico to estimate possible shipbuilding accidents using the International Association of Lighthouse Authorities Waterway Risk Assessment Program (IWrap) model, and calculated the geometric collision number (the number of collisions in different circumstances) and the causal probability.

4. Conclusion

(1) the maritime traffic safety evaluation is based on a large number of accidents on the basis of the analysis of, and the accident data collection, statistics and analysis of all difficulties, many accidents are difficult to get a complete data, so the corresponding accident analysis is not accurate enough and fully, can further improve and build the maritime traffic accident database;

(2) At present, there are many models and methods for Marine traffic safety assessment, but it can be seen that the general trend has gradually changed from "post-accident analysis" to "pre-accident prevention". The birth of FSA is a good example.

(3) At present, unmanned ships and intelligent ships are developing rapidly, and the corresponding laws, regulations and collision avoidance rules are not perfect. At the same time, the corresponding ship safety assessment system also has a considerable space for development. In the future, the ship safety assessment system may develop towards the direction of "few people" or even "unmanned".

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