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Analysis of human factors in ship collisions based on accident investigation reports

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ANALYSIS OF HUMAN FACTORS IN SHIP COLLISIONS BASED ON ACCIDENT INVESTIGATION REPORTS

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.

(Signature): ....

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ABSTRACT

Title of Research paper: **Analysis of Human Factors in Ship Collisions Based on Accident Investigation Reports**

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Based on maritime accident investigation reports, this dissertation investigates human factors in ship collisions using the Human Factors Analysis and Classification System(HFACS) framework, which originated in the field of aviation safety and has since been introduced to other fields, including railroads and maritime transport.

21 ship collision investigation reports that occurred in China in 2020 are examined in a case study, in which human factors are described and analyzed in detail at four levels, namely organizational influences, unsafe supervision, preconditions for unsafe acts and unsafe acts. This study finds that the direct and obvious factors of unsafe acts are fully demonstrated in the investigation reports, but the potential, non-direct factors of organizational influence and unsafe supervision are not sufficiently revealed in the investigation reports, although these factors play an important role in causing accidents.

This paper suggests that human factors remain difficult to address, most notably because it is a systemic problem. Mitigating this problem requires a system approach, rather than a person approach. Not only does regulation need to be effectively implemented, but the maritime culture of efficiency/economy over safety needs to be changed. To do this, the top down structure of shipping companies must be changed to empower crew members to participate in making decisions that affect their safety and interests. In addition, automation technologies cannot be expected to eliminate the human element; at best, they only allow it to change places and forms. Last but not least, the world is still suffering from the Covid-19 pandemic. The shipping industry, governments, and international organizations must work together to address the challenge of crew change and dispatch, as well as the physical and mental health of seafarers in order for the industry to remain viable in the future.

KEY WORDS: Human factor, Ship collision accidents, HFACS, Investigation reports

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

AIS	Automatic Identification System
ANP	Analytical Network Process
BN	Bayesian Network
BRM	Bridge Resource Management
COLREG	International Regulations for Preventing Collisions at Sea
CRM	Crew Resource Management
DCPA	Distance of Closest Point of Approaching
FAHP	Fuzzy Analytical Hierarchy Process
HFACS	Human Factors Analysis and Classification System
HFACS-MA	Human Factors Analysis and Classification System for Maritime Accidents
HOF	Human and Organizational Factor
ILO	International Labour Organization
IMO	International Maritime Organization
LNG	Liquefied Natural Gas
NTSC	National Transportation Safety Commission
SMS	Safety Management System
STCW	Standards of Training, Certification, and Watchkeeping
TAN	Tree Augmented Network
TCPA	Time to Closest Point of Approaching
VDR	Voyage Data Recorder
VHF	Very High Frequency

1 INTRODUCTION

1.1 Background

Research on maritime accidents have shown that ship collision accidents are the most common type among all kinds of maritime accidents. A study by Zhang et al. (2021) on global maritime accidents between 2003 and 2018 found that ship collisions accounted for the highest proportion of maritime accidents at 19% (see Figure 1). According to the same authors, ship collisions in East Asia, including China and Japan, accounted for 40.33% of all maritime accidents, 30% higher than groundings, which were in the second place.

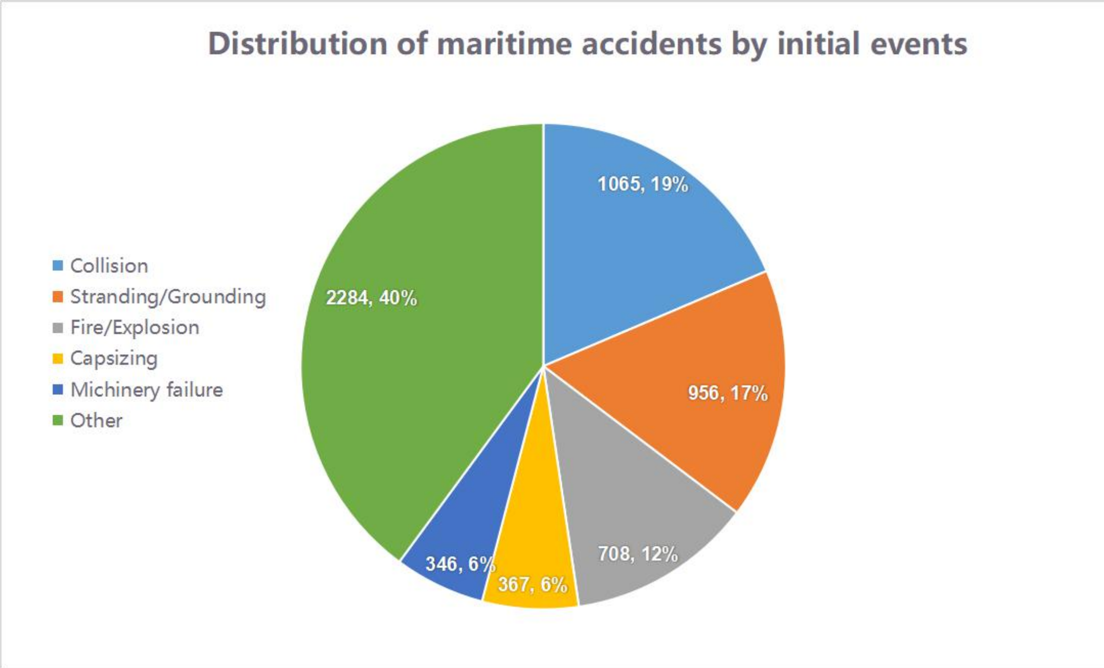

Figure 1 - Distribution of global maritime accidents by initial events.

Source: Adapted from Zhang et al. (2021).

Among the many factors that contribute to ship collisions, human factors are the most important. Numerous studies have shown that human error accounts for more than 90% of all ship collisions. More and more efforts are being made to improve marine transportation safety, with the development of better ship design and advanced shipbuilding technology, as well as state-of-the-art navigational equipment on ships. It is expected that the continuous improvement of hardware and software of ship systems will enhance the safety of shipping safety. And indeed, ship collisions caused by defects in ship design or shipbuilding, or equipment failure (rudder failure, main engine failure, etc.) have been greatly reduced. However, collisions caused by human factors are not.

1.2 Review of previous research

Through literature review, this paper describes the research of human factors of ship collision accidents, and the Human Factors Analysis and Classification System (HFACS) in transportation safety analysis, including in aviation, railway and the maritime industry.

1.2.1 Human factors in ship collision accidents

Many scholars have carried out a lot of research work in the study of human factors in ship collision accidents. Using data mining technology, Liu & Wu (2004) established the relationship between human errors and their influencing factors (including human factors, environmental factors, ship factors and organizational factors) based on 100 ship collision accident investigation reports of the world's major maritime countries during the 10 years from 1993 to 2002. The research established the correspondence between human errors and their inducing factors in the process of ship collision. This paper is one of the earliest studies on human factors based on accident investigation reports in China. However, the study was based on data from 20 years ago, when technology and the shipping industry were very different, which means it may not be well suited to the current situation. In addition, the study itself notes that their efforts to extract better information and data on human factors from these accident investigation reports are weakened by the limited quality of the investigation reports on which their conclusions are based.

Hetherington et al. (2006) reviewed a number of studies that investigated navigation safety from three perspectives: themes in accidents, human error, and safety interventions. Their analysis identified the role of humans and organizations in shipping accidents, and an improvement in shipping safety is possible if human factors problems can be detected and corrected. Celik & Cebi (2009) generated an analytical HFACS based on the Fuzzy Analytical Hierarchy Process (FAHP) to determine the role of human error in shipping accidents. Chauvin et al. (2013) used the HFACS model to determine the contributing factors of 39 ship collisions and concluded that most collisions were caused by poor decision making, highlighting the importance of Bridge Resource Management (BRM) when navigating in restricted waters and that correct decision making by the master in an emergency situation in open water can prevent most emergencies, while non-compliance with Safety Management System (SMS) will lead to more emergencies. Strauch (2015) explored the main causes of fatigue and how it disrupts cognitive performance and affects safety, arguing that fatigue is one of the most important human factors contributing to accidents and proposing a systematic approach to determine whether fatigue adversely affected the performance of seafarers in accidents. The authors remind investigators to be aware of seafarers' errors related to their fatigue in accident investigations and that different measures should be used to determine fatigue and its causal relationship with the accident.

Research by Galieriková (2019) offers another example of how to incorporate human factors into accident investigation programs. The HFACS was used in this study as a taxonomy for human factors for accident investigation. The author claimed that the fundamental issue of the HFACS is the coding process, which is comprised of nineteen sections. The author used Reason's (1990) Swiss Cheese Model to classify the types of human errors into three main categories: unsafe acts, unsafe supervision, and organizational factors， presented recommendations on how to classify causal factors of marine transport accidents.

A study by Coraddu et al. (2020) argues that marine accidents are complex events, and analyzing how humans factor into a collision is particularly difficult. HFACS, human reliability assessment, and simple statistical analysis, they claim, are not always effective because they rely on human experts and are subject to limitations, biases, and high costs. Using historical maritime incident databases, the authors suggest a data-driven approach to identify the most influential human factors. Chen et al. (2020) identified the main factors associated with 3976 total-loss marine accidents in the past 20 years. A total of 11 variables were also chosen as independent variables to analyze and forecast the probability of deaths due to total loss marine accidents.

Based on the International Maritime Organization (IMO) database, Paolo et al. (2021) identified and categorized causal themes from 1079 sea accidents, and found fatigue, stress, work pressure, and poor communication were often important factors in accidents in the 24-hour environment of shipping, where ships and crews are routinely pushed to the limit. Fan et al. (2020) used a data-driven Bayesian Network (BN) to investigate the effect of human factors on maritime safety. Tree Augmented Network (TAN) was used to model the inter-dependency among the risk influencing factors, and it was validated by both sensitivity analysis and past accident records. According to their findings, age, operation, voyage segment, information, and condition of the vessel are among the critical risk factors for all accident types.

1.2.2 HFACS in transportation

Analyzing civil and military aviation accidents, Shappell & Wiegmann (2000) found that 70 to 80 percent of them are caused by human error. They found most accident reporting systems did not address human error with any theoretical framework, making most accident databases unsuitable for traditional human error analysis, as well as making establishing intervention strategies difficult. Therefore, they developed a comprehensive Human Factors Analysis and Classification System, a general framework for human error investigation that can be used to design new investigation methods and reorganize existing accident databases. Today, the HFACS framework is used in military, commercial, and general aviation to examine potential human factors and improve aviation accident investigations.

In large part, HFACS is based on Reason's (1990) Swiss Cheese Model and provides a tool to assist investigators and to improve training and prevention efforts. With HFACS, investigators can identify potential and active failures within an organization that ultimately lead to an accident. HFACS does not seek to assign blame, but rather to understand the cause of an accident.

The HFACS framework (see Figure 2) describes human error at each of the four levels of failure. These include:

1. Unsafe acts of the operator,
2. Preconditions for unsafe behavior,
3. Unsafe supervision,
4. Organizational influences.

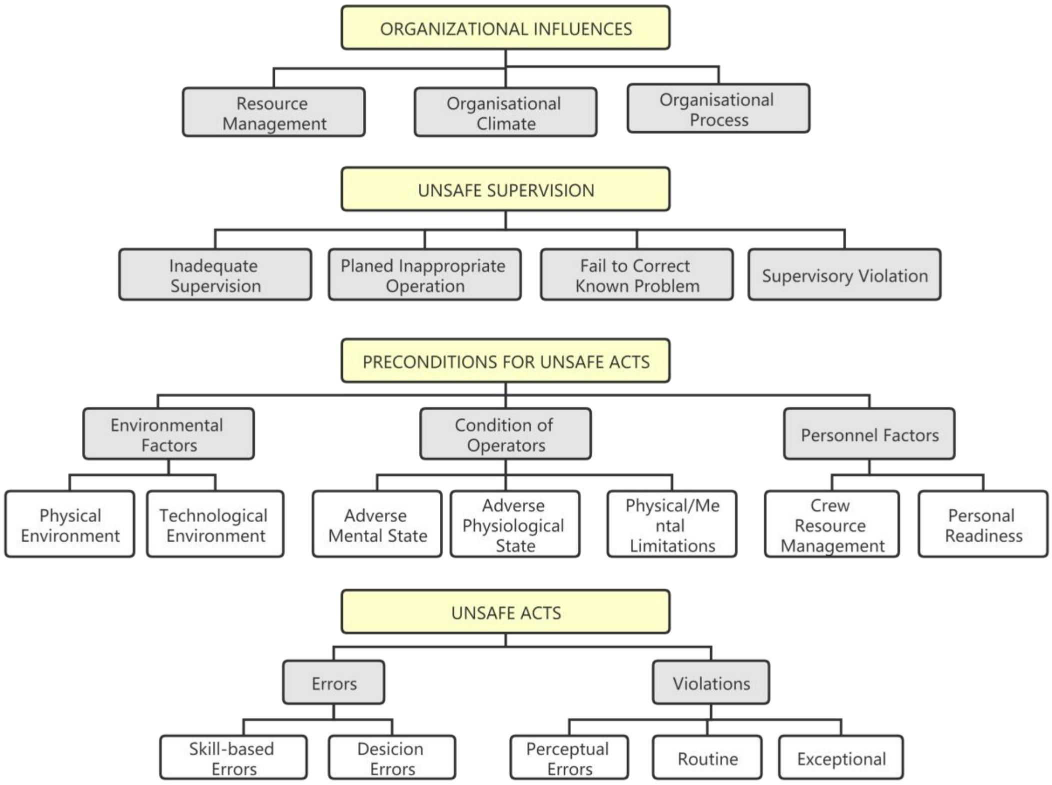

Figure 2 - The HFACS framework originally used for human factors analysis in aviation safety.

Source: adapted from Shappell & Wiegmann (2000).

HFACS develops causal categories to identify active and potential failures at each level. An adverse event can be caused by a failure at every level, and will be prevented if one of the failures leading to it is corrected at any time.

Since its introduction, the HFACS model has been used extensively in the investigation and analysis of human factors in the field of aviation safety, and has been tested to be an effective method in practice. Subsequently, the model has been gradually extended to other fields, including in the fields of navigation, railway, coal mining, construction, chemical industry, etc. Researchers have carried out a number of research work on human factors based on HFACS in these areas.

Dambier & Hinkelbein (2006) used the German National Aircraft Accident Analysis Department's reports to classify aircraft accidents in German general aviation using the HFACS model and to identify their possible causes. The underlying causes were categorized as follows: pilot error, organizational factors, ergonomic factors, aeromedical problems, and crew resource management. They found the majority of accidents occurred during approach and landing (53%) caused by pilot error (84%). Thus, pilots should train on approach and landing to achieve higher proficiency. Wiegmann et al. (2005) argued that HFACS can be reliable in identifying human causal factors in aviation accidents, helping to identify general trends in human factors and pilot errors that are responsible for accidents involving civil aircraft, as well as being able to analyze human errors and contribute to the development of interventions to prevent accidents in the future.

Daramola (2014) applied the HFACS framework to assess Nigerian aviation accidents from 1985 to 2008 and found that Nigeria's accident and fatality rates were higher than the global average in most years. The analysis concluded that skill-based errors, physical environment and poor supervision were the most common causes categories of air accidents and concluded that the most likely causal chain in Nigerian aviation accidents was considered to be regulatory violations - crew resource management - decision errors. Yan & Histon (2014) examined 267 safety investigation reports from North American commercial airlines between 2006 and 2010, and concluded that unsafe acts and the preconditions of unsafe acts continue to be the most significant human factors risks. In addition, the study identified Crew Resource Management (CRM) as a primary causes of accidents and recommended that safety departments increase training and develop risk-mitigation methods to enhance aviation safety. KiLic & GÜMÜŞ (2020) concluded that operational problems faced by pilots while performing night flights (e.g., night vision, blinkers, black hole illusions, and reflections) pose a threat to flight safety. HFACS was used to study 30 nighttime commercial aircraft accidents that occurred during the past five years. They found the physical environment to be the most important causal factor, while skill-based errors were the second most important contributor, and perceptual and decision errors to be the third most important factors.

HFACS was later introduced by researchers in other industries, such as rail transport. Baysari et al. (2008) applied the HFACS model to 40 Australian rail safety accident investigation reports and found that nearly half of the accidents were caused by equipment failure, which was most likely due to poor maintenance and monitoring. Most of the other accidents were caused by inattention coupled with decreased alertness and physical fatigue. Almost all safety incidents involved organizational influence level factors, demonstrating the benefits of improving resource management, organizational climate, and organizational processes in order to reduce rail safety incidents. Iridiastadi & Ikatrinasari (2012) analyzed nine accidents with fatalities using HFACS based on the data provided by the National Transportation Safety Commission (NTSC) of Indonesia. The results indicated that 72 factors were closely related to these accidents. Although train drivers play an important role in accidents, interventions aimed at them alone are not sufficient. The four dimensions of HFACS should be used to create a comprehensive approach to accident prevention. Madigan et al. (2016) used HFACS to examine 78 minor safety incident reports on UK railroads involving five accident types and found that these reports focused strongly on active failures, particularly those related to work-related distractions and environmental factors, with little mention of underlying factors. The study suggests that particular attention should be paid to potential factors at the level of organizational influence and unsafe supervision when investigating minor rail accidents.

A growing number of studies in maritime transportation safety also have adopted this analytical framework. Kim et al. (2011) reviewed the root cause classification system for maritime accident investigation and outlined some typical human error analysis methods used in shipping. They proposed a human error analysis method based on the cognitive process model, the maritime HFACS model, and the chain of causality of maritime accidents, and tested its efficacy using real-world data. Chen et al. (2013) developed a framework of Human and Organizational Factors (HOFs) specifically for maritime accident investigation and analysis, called the Human Factors Analysis and Classification System for Maritime Accidents (HFACS-MA). They combined it with the Why-Because Graph for accident analysis to provide a complementary measure for the practical application of HFACS. The paper used the Herald of Free Enterprise disaster as a case study to show that a more comprehensive understanding of accidents can be obtained through HFACS. Akyuz (2017) combined HFACS with Analytical Network Process (ANP) to construct a hybrid approach for assessing safety factors in cargo ship accidents. HFACS provides a diagrammatic conceptual framework for investigating and analyzing the role of human error in maritime accidents, while ANP illuminates the causal chain of accidents and shows the feasibility of the hybrid approach using a real-life example of a LPG ship spilling accident.

According to Kim et al. (2017), a human factors investigation process can provide maritime accident investigators with a guide for identifying and classifying human error-induced factors as well as development of safety actions for minimizing maritime accident risks. The case study illustrates that human factors investigations can identify potential factors and contribute to developing safety actions to prevent similar accidents in the future. Yıldırım et al. (2019) examined collisions and grounding accidents by using HFACS and examined the frequency and distribution of causes, and analyzed unsafe acts and preconditions for unsafe acts according to the bridge crew structure. It was found that decision errors, resource management deficits, violations, skill-based errors, and communication errors were the most important human factors for ship collisions and groundings.

1.3 Comments on existing research

Through the above review, this paper finds that the current research on human factors of ship collisions presents the following characteristics:

(1) The data of the research works are mainly based on the investigation reports of maritime safety accidents. Through analyzing the maritime safety accident investigation reports collected, useful information such as the types and frequencies of factors leading to accidents are extracted and used as the basic data for the research work. However, the accident-causing factors extracted in previous studies mainly focus on the factors reflected in the process of ship collision, such as the crew's error in the collision avoidance process and the weather and sea conditions at the time of the collision. The hidden factors at the level of organization and management, supervision and guidance are not fully utilized in the report.

(2) The research method mostly uses HFACS, Bayesian Networks, Tree Augmented Network and other uncertain knowledge inference methods. The purpose is to use historical data to find the most likely causal chain leading to the accidents. The specific approach is often driven by the collision results for reverse inference, looking for the highest probability of the upper level of factors, and finally come up

with a most likely causal chain. It can be said that the research work on how unsafe behaviors lead to ship collisions has been carried out adequately, and a large number of research results have been achieved.

But few studies are developed on how deeper hidden factors, such as the structural issues behind human factors, influence unsafe behavior. And obviously there is a lack of in-depth discussion on the impact of automation technology and the Covid-19 pandemic on the human factors of maritime accidents. In a word, HFACS can be a very powerful tool for digging deeper into the hidden factors of an accident, as the categories of factors can be exhaustively and rationally classified through a clear framework.

1.4 Objective of this study

So far most of the research work on human factors in ship collision accidents has been carried out by many researchers, and there are many research methods and tools used by them. Among them, HFACS has been widely used in analyzing human factors in accidents, and with good results. This research paper will apply the HFACS model to the study of human factors in ship collisions based on the currently available investigation reports of maritime accidents in China in 2020, which will help to further understand the human factors in ship collisions, as well as to come up with effective intervention measures to prevent accidents, protect human lives, property, and the environment.

Furthermore, while the significant impact of human factors has been recognized, researchers and stakeholders in the shipping industry have addressed human factors with a disproportionate focus on the crews themselves, believing that the negative effects of human factors can be mitigated or eliminated through better education and training of crews and strict adherence to operational procedures. However, if we delve into the real mechanisms by which accidents occur, and not just the actions or inaction of crew members, we will find that attributing accidents to the actions of seafarers is usually an oversimplified understanding of a complex system. Ship safety is a complex system involving not only the ship and crew, but also the environment, shipping companies, authorities, laws and regulations. Members of the crew, who operate the ship directly, are only one component of a ship's safety system. Despite their impact on the system, they are also affected and constrained by other aspects of the system. In order to understand the human element, we need to analyze structural aspects of the human factor within the context of an industry's operations, not only looking at their behavior and consequences, but also at the drivers of their behavior.

With the development of automation technology, ship manning requirements are decreasing. In the foreseeable future, ships will become more automated, and some even believe that the large-scale application of unmanned ships will become a reality. The impact of these technological developments on human factors is also worth exploring in depth.

Last but not least, the global Covid-19 epidemic that started in late 2019 still shows no signs of ending after a year and a half, but has already had a serious impact on the shipping industry. In particular, it has had a huge negative impact on crew members both physically and psychologically that cannot be ignored. This may also make the human factors of maritime accidents more complex, which will be analyzed in this paper.

2 Ship Collision Accidents in China

Before analyzing the ship collision accidents, it is necessary to make a brief introduction to this topic, and understand the definition and the process of the occurrence of the ship collision accidents. Since the study of this paper is based on the investigation reports of ship collisions, it is also necessary to elaborate on the accident investigation and investigation reports. The paper examines ship accidents within Chinese jurisdiction, using the definition and understanding of those accidents by Chinese laws, regulations, authorities, and researchers.

2.1 Definition of ship collision accidents

There are a variety of definitions for ship collisions provided by different scholars. Ship collisions may occur between ships and ships, or between ships and other floating or fixed objects, such as icebergs, offshore platforms, bridges, whales, etc. This study focuses on ship-ship collisions. Chinese scholars Si & Wu (1995) defined the broad concept of ship collision in their book *Ship Collision Law*: ship collision in the broad sense refers to mutual contact between ships resulting in damage to one or both parties. Zhao & Wang (1995) defined ship collision as an accident in which a ship collides or touches another ship while sailing or at berth, causing damage to the ship. In Chinese maritime law, a ship collision is an accident in which a ship comes into contact (with other ships) at sea or in navigable waters connected to the sea, causing damage.

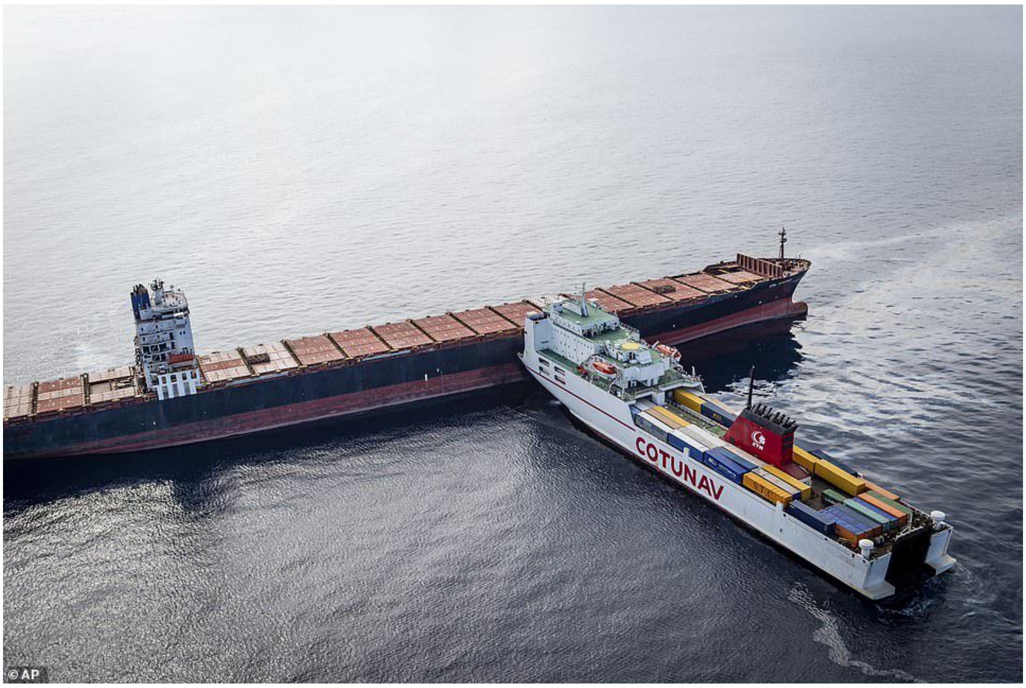

Figure 3 - A ship-ship collision accident: a Tunisian vessel carrying trucks rammed into another ship off Corsica in clear conditions in October 2018.

Source: Associated Press

Based on the above definitions, the following three conditions are necessary to constitute a ship collision in Chinese law and practice.

(1) The subjects in the accident must be ships. In other words, the collision must occur between two ships. A collision with the port, reef, iceberg, or any other non-ship subject cannot be considered a ship collision accident. According to the regulation, no matter the ship is in navigation or at berth, it should keep normal watch, indicating that the subject in the ship collision accident should have the ability

to actively identify the collision hazard and take collision avoidance measures in time.

(2) There is direct physical contact. It means that at the time of the accident part of both vessels occupied the same physical space (see Figure 3). It excludes the case when the waves raised by the ship acted as a force for causing damage to other ships, but the ships did not make direct contact with one another.

(3) Damage has indeed been caused. The occurrence of a collision causes damage to both vessels in the accident or to a single party, resulting in economic loss, human casualties, environmental pollution and other consequences. If there is only physical contact between ships but no damage is done, it is not considered a collision.

All of the ship collisions studied in this paper meet the above three conditions.

2.2 Process of ship collision accidents

There are four stages to the process of ship collisions, according to the actions that are permitted or required by each ship (Zhao & Wang, 1995).

Stage 1: Free movement. At this point, the two ships are far apart and there is no danger of collision. The action rules related to collision avoidance are not yet applicable, and the vessels are free to act without restraint. In practice, at this stage two ships usually do not take collision avoidance action, but if it is expected that they may encounter a difficult situation of avoidance, some ship pilots will also take appropriate action at this stage, which is worth considering.

Stage 2: Collision hazard. Generally speaking, when the Distance of Closest Point of Approaching (DCPA) of two ships is less than the safe meeting distance, and the Time to Closest Point of Approaching (TCPA) is limited, there is a danger of collision between two ships. At this stage, one of the vessels has the duty and responsibility to give way to the other vessel according to the collision avoidance rules. In this stage, according to the rules, the give-way vessel's avoidance action should be carried out early and should be substantial to keep well clear. The other vessel should maintain her course and speed according to the rules.

Stage 3: Close-quarters situation. When the action of the give-way vessel alone cannot ensure that the two vessels are sailing at a safe distance, it is considered that the two vessels are in a close-quarters situation. In practice, a close-quarters situation is often caused by the failure of the give-way vessel to take timely and effective action in accordance with the requirements of the rules at the collision hazard stage.

Stage 4: Immediate danger. When the two ships are so close that the collision cannot be avoided by the action of the give-way ship alone, or so close that the action of the two ships cannot keep clear at a safe distance, it is considered that the two ships are in the stage of immediate danger. At this point, the two vessels should take advantage of every opportunity to avoid collision. If it is impossible to avoid collision, they should take the necessary measures in order to reduce the damage from collision. Of course, the International Regulations for Preventing Collisions at Sea 1972 (COLREGs) also provides that, in construing and complying with its Rules dueregard shall be had to all dangers of navigation and collision and to any special circumstances, including the limitations of the vessels involved, which max, make a departure from its Rules necessary to avoid immediate danger.

Under normal circumstances, when two ships are about to meet at sea, the watchkeepers of both ships should have proper situation awareness, assess the danger of collision, communicate on collision avoidance actions, and take appropriate avoidance actions in time to keep clear of each other. If one or more of the links fails in this process and is not corrected in time, it may eventually result in an accident. Figure 4 illustrates how an individual ship collides or avoids a collision with another ship.

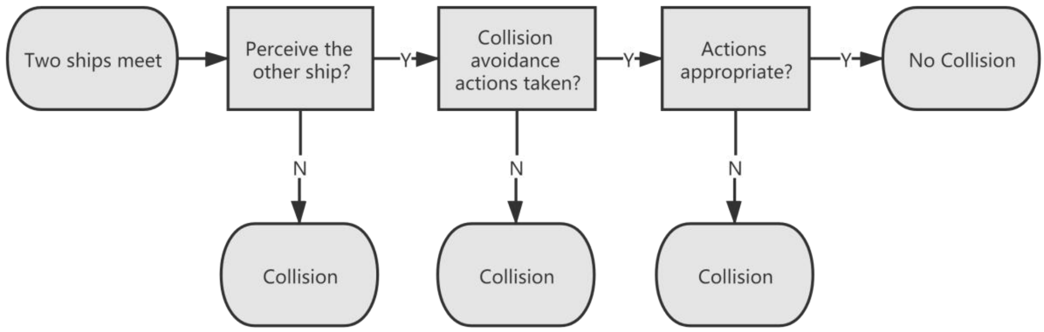

Figure 4 - The simplified process of a ship collision accident.

Source: adapted from Zheng (2000).

According to the above description of ship collisions, the most practical way to prevent collisions is to cut off the links that lead to them. According to Zhao and Wang (1995), there are a few steps one can take to avoid a ship collision.

(1) Observe and perceive other ships, and gather information.

(2) Determine the risk of a collision.

(3) Determine whether avoidance action are needed.

(4) Decide on avoidance actions and timing.

(5) Take proper collision avoidance actions.

(6) Resumption of navigation.

This requires the ship's watchkeepers to keep regular lookout as required by the rules, so as to observe the other ship early when the ships meet, including the perception of the other ship through visual and acoustic senses, as well as the information of the other ship's course, speed and bearing obtained by using radar, AIS and other navigation aids. Based on these information, both ships analyze the encounter situation, accurately calculate the DCPA and TCPA of the two ships, and then judge whether there is a danger of collision. If there is a real danger of collision, they should communicate and coordinate the collision avoidance actions according to the requirements of collision avoidance rules, and take effective actions as early as possible, until finally sailing through to keep each other clear, and then return to the planned routes. Even if there is no danger of collision between the two vessels, watchkeepers should also pay attention to the environment around their own ships and the planned routes.

2.3 Investigation reports of ship collision accidents

A ship collision accident investigation report is a conclusive report based on the thorough investigation of the accident by the professional investigators of the Maritime Authorities following the collision accident. An accident investigation report should include an overview of the accident and investigation, the ship, crew, and cargo profiles, the navigation environment and ship's situation, details of the accident, rescue and salvage, damage and loss, accident causality analysis, and advice on safety management(see Figure 5).

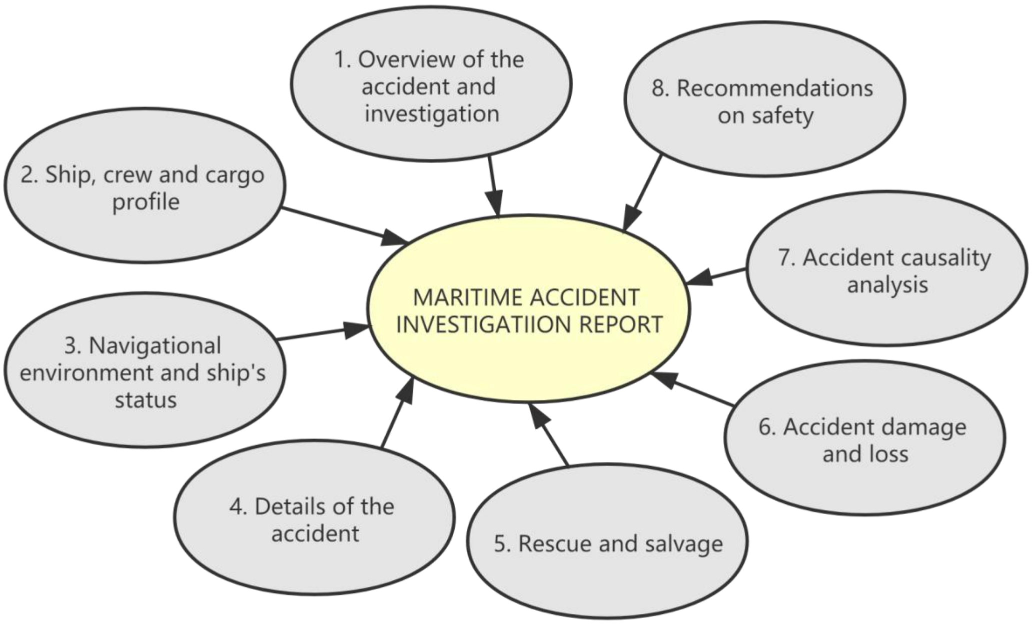

Figure 5 - Main contents of a ship collision investigation report in China.

The following is a brief description of the eight elements of China's maritime accident investigation report:

(1) Overview of the accident and investigation. A brief description of the accident including time, location, ships involved, consequences of the accident, main causes, etc. The investigation overview includes the organization involved in the investigation (e.g. Maritime Authorities), the accident investigation method (questioning of parties, access to records and documentation, etc.), and the investigation target (crew member, shipping companies, etc.).

(2) Ship, crew and cargo profiles. The ship profile includes the type, tonnage, main engine and other information of the ship, and the ship's manning, including the minimum safety manning requirements that the ship should meet according to the rules and the actual manning of the ship at the time of the incident, the number qualification of crew members. The cargo profile includes whether the type of cargo

carried by the ship matches with the type of ship, whether the ship is overloaded, and whether the cargo is reasonably loaded and whether effective safety protection measures are taken for special cargo, such as dangerous goods.

(3) Navigational environment and ship's status. The navigational environment includes hydro-meteorological conditions (wind, waves, currents, visibility, etc.), as well as the channel conditions around the location of the accident and nearby waters, such as traffic density, channel width, channel depth, islands, shoals, reefs and other conditions. Ship's status includes ship's certificate, survey and inspection history, and the ship's equipment and facilities, as well as the ship's operator/owner.

(4) Details of the accident. The detailed descriptions of the accident that are established by investigators based on the statements of the crews, AIS, VDR, shore-based radar data, VHF recordings, etc. The accident is often recorded in the report in chronological order, starting from the start of the voyage of the two ships to the end of the collision, elaborating the implementation of navigation plan and watchkeeping, navigation methods, communication between vessels, collision avoidance actions and emergency measures taken by both vessels during this period.

(5) Rescue and salvage. This describes the distress information received by the search and rescue center after the collision, the situation of self-rescue by the involving vessels, rescue team's efforts, and the final result of rescue (including the rescue of personnel and salvage of the wreck, etc.).

(6) Accident damage and loss. The casualties and missing persons in the accident, the economic loss caused by the damage of the ship/equipment and the loss/damage of cargo, the environmental pollution caused by the oil spill and the leakage of harmful substances.

(7) Accident causality analysis. The conclusion given by the professional accident investigation team to synthesize all aspects of the information of the collision. The purpose of the report to analyze the cause of the accident is not to

pursue responsibility, but to summarize the experience and lessons, and help to avoid the occurrence of similar collisions in the future. The causes of accidents are often divided into two categories: direct causes and indirect causes, where direct causes generally include the decision errors of the ships leading to the collision, including improper collision avoidance actions, etc, which are often obvious and easier to identify. Indirect causes mainly include training of crew members, management loopholes of shipping companies, etc., which are often more complex to identify.

(8) Advice or recommendations on safety management. Recommendations and advice provided to the parties involved in the accident in order to avoid the recurrence of similar accidents.

An investigation report is an authoritative and comprehensive data source for the study of ship collisions. Many researchers have conducted corresponding studies based on such data, and many results have been obtained in constructing causal models of ship collisions and tracing a causal chain. However, the current research on human factors in ship collisions mostly focuses on the specific collision avoidance behaviors and the objective navigation environment in the accident investigation report, without paying special attention to other parts. HFACS was used in this paper in order to delve deeper into the information in each part of the ship collision investigation report, including the sections about organizational influence and supervision factors.

2.4 Chapter summary

The chapter describes the definition, mechanism, and process of ship collisions, as well as contents of the accident investigation reports, according to the Chinese regulations, authorities, and researchers' understanding of ship collisions. As a result, a solid foundation is established for further analysis of human factors in ship collision accidents based on accident investigation reports.

3 Human Factors in Ship Collision Accidents

3.1 The HFACS model

The HFACS model emerged from the field of aviation safety. At the end of the twentieth century, aircraft themselves were quite reliable and humans themselves had become an important factor in flight accidents. More and more aviation safety researchers began to study human error in flight accidents. This has led to a variety of human error analysis models and corresponding human error investigation programs. Douglas A. Wiegmann and Scott A. Shappell summarized and analyzed six previous perspectives that have been proposed to study human factors in flight accidents, and found that most of these perspectives were not supported by theory and data, but were proposed based on intuition. Consequently, models based on these perspectives are either too simplistic to analyze hidden factors in depth or too abstract to be understood, let alone used in practical investigations (Wiegmann & Shappell, 2000). Therefore they revised James Reason's model of accident causation theory (i.e., the Swiss Cheese Model), and based on this model they extracted the human factors in a large number of aircraft accident reports, comprehensively analyzed the deep-seated causes of accidents, and reasonably classified each layer of factors into specific categories, and then proposed the HFACS model. The generation of this model provides a practical tool for the investigation and analysis of human factors in flight accidents, and also provides a reference for the expansion of human factors research into other areas.

HFACS is based on the Swiss Cheese Model and defines the "holes" in the "cheese" in detail, so that the abstract concept is expressed as a concrete and specific content. It divides accident-causing factors into four levels of failure, namely, the organizational influence level, the unsafe supervision level, the preconditions for unsafe acts level, and the unsafe acts level. To further clarify the attribution of each factor, in practical application HFACS also lists the specific content of each subcategory. For example, the category of inadequate supervision under the unsafe supervision level includes failure to track qualifications and performance, failure to provide guidance and oversight. These detailed definitions and categories provide a convenient and practical way for researchers and investigators to conduct accident investigations quickly and accurately, and also provide a reference for applying HFACS to the study of human factors in other areas.

It is safe to argue that HFACS is one of the most mature methods for human factor analysis and classification, and has achieved many good results in practical applications. Some scholars have combined the characteristics of their respective research fields and made appropriate modifications to HFACS, which makes this model effectively applied in a wider range of fields, including in ship collision accidents. There are a large number of similarities between maritime traffic and air traffic, as well as between ship collisions and aircraft collisions. The following paragraphs describe five similarities:

(1) The operators of both aircraft and ships are highly specialized, with high requirements for skills, and strict standard regulations for operators' education, training, and qualification assessment and certification.

(2) The supporting navigation instruments and equipment on board are abundant and complex. With the development of science and technology and the increasing attention to safety, more and more advanced instruments and equipment are integrated into ships and aircraft to assist the pilot to maneuver and improve the safety level of the system, but this also further increases the requirements for the pilot's capacity.

(3) Merchant ships and aircraft are often used for long-distance transportation, have fixed routes, and are prone to accidents due to the relatively heavy traffic flow at the end of the voyage and at certain convergence points. On most of their routes, traffic is sparse, so pilots/captains often use automatic piloting during this phase.

(4) Unlike road transportation, ships and aircraft encounter collisions relatively less; but when they do, the resulting damage is often huge. Detailed voyage plans are made before the voyage begins. Weather conditions play a huge role in the occurrence of a ship/aircraft accident. Traffic control agencies and the operating companies of ships and aircraft have a greater impact on the occurrence of accidents.

(5) The investigation following an accident is done by professionals, resulting in a report that provides all relevant data and causes of the accident. These accident investigation reports also serve as a valuable data source for research and provide lessons learned to prevent recurrence of similar accidents.

Of course, in addition to the similarities listed above, we should also continue to analyze the differences between ship collisions and aircraft collisions in order to reach a comprehensive understanding, these include five aspects:

(1) Speed. The sailing speed of a ship is much slower than an aircraft's flight speed. As for the collision, the ship sailing at sea can be considered a two-dimensional plane movement, and the aircraft flying in the air is a three-dimensional movement. The ship can reduce its speed to zero or reverse its course during navigation, while the aircraft cannot. Moreover, large ships are less capable of changing speed direction, and airplanes are more maneuverable in this regard.

(2) Space. When a ship is moving on the surface of the sea, if its speed is 0, the ship can stay on the surface of the sea by virtue of the buoyancy of the sea without accident, while the aircraft cannot reduce its speed to zero while flying.

(3) The role of traffic control agencies. For the role of traffic control agencies in the collision avoidance process, it’s less important in the ship collision avoidance process. While traffic control may remind ships of their situation and the environment, the coordination of avoidance action and the specific collision avoidance maneuvers are at the discretion of the ship's pilot based on the actual situation. When a plane is in danger of colliding in the air, traffic control gives more frequent and specific instructions.

(4) Results of collision accident and rescue. In the event of a ship collision accident, if the speed is low and the damage is not severe, the ship can be repaired by itself or sailed to a safe position with the assistance of tugboats. In spite of serious consequences like sinking, it is generally possible to reduce collision losses by starting the emergency plan to organize the crew and passengers on board to escape through lifeboats, allowing them to be rescued by nearby ships or rescuers. However, once aircraft collide, the final result is often the total destruction of the aircraft, often with no survivors.

(5) Accident investigation. In light of the above differences, when examining a ship collision, the information that can be referred to is not only that provided by the

ship's VDR, AIS, and other instruments and equipment, but also that provided by the survivors of the accident. In contrast, the investigation of aircraft collisions, in most cases, does not have the opportunity to interview survivors since few people survive a collision.

Based on the above comparison of ship collisions and airplane collisions, it is reasonable to introduce the HFACS model, which is well established in aviation accident research, when studying the causes of ship collisions. To obtain a HFACS model that is applicable to ship collisions, it needs to be modified with the specific characteristics of ship collisions.

3.2 Analyzing human factors in ship collision accidents with HFACS

The human factor or the human element is a complex multidimensional issue that affects maritime safety, security and marine environmental protection and involves the full range of human activities performed by ship's crew, shore-based managers, regulators and others (International Maritime Organization, 2021). In the maritime context, the term "human factor" includes anything that affects the interaction between a person and any other person, system or machine on board. The HFACS framework breaks down the factors that affect maritime safety at four levels: organizational influences, unsafe supervisions, preconditions for unsafe acts and unsafe acts. Some researchers add to these four categories a fifth top-most level named "Outside Factors", which includes the regulatory environment as well as the economic, political, social, and legal environments (Chauvin et al., 2013). The author of this paper believes that such a level is not essential for the study of human factors and therefore excludes it from the discussion.

Based on the previous research findings and the analysis of ship collision accident investigation reports, the authors carefully reviewed the 21 reports collected, identified nearly all the human factors involved in the accidents, and classified them according to the HFACS framework.

3.2.1 Organizational influences

Organizational influences are implicit factors of ship collision accidents, which mainly result from the failures or defects of shipping companies and crew management companies in the process of managing ships and crew for the purpose of preventing accidents and ensuring safety and environmental protection. The organizational influence level has 3 categories of factors, which are resource management, organizational climate, and organizational processes, as shown in the Figure 6.

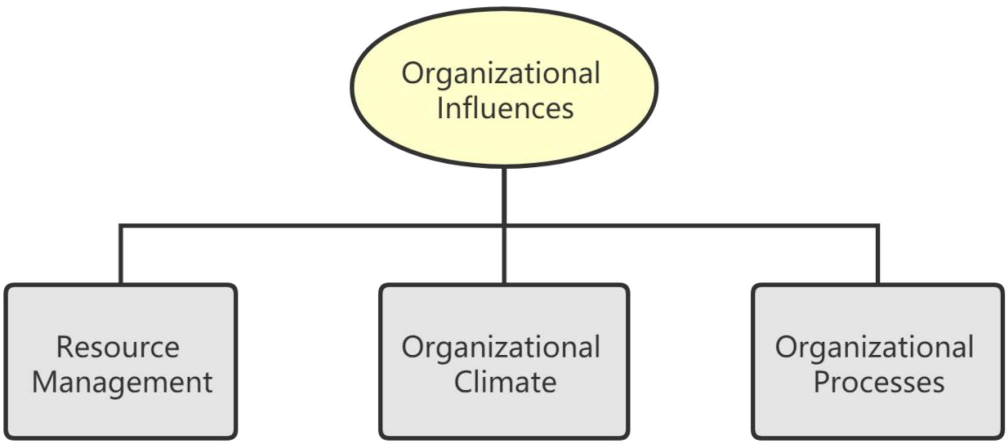

Figure 6- Human factors at the Organizational influences level.

Resource management is the process of allocating and organizing resources such as crew, training, finance, equipment, etc. throughout the course of a ship's operation. Resource In the shrinking shipping market, especially during downturns, resource management is often faced with the conflict between safety and profit. In that case, it is easy to compromise on safety in order to reach profit. This category includes the following three factors.

A. *Insufficient manning.* According to regulations, the minimum safe manning requirements of a ship shall be sufficient to ensure the safe navigation, berthing and operation of the ship and prevent the ship from polluting the environment. The minimum safe manning shall be adapted to the type and main engine power of the ship. When the actual manning on board does not meet the requirements of the Ship's Minimum Safe Manning Certificate or its equivalent documents held by the ship, it is regarded as insufficient manning. Furthermore, the ship can add additional crew members if necessary, but not more than the authorized manning standard for life-saving equipment.

B. *Inadequate training.* A shipping company should provide sufficient training to the crew before them work on board a ship, including theoretical knowledge and practical operation, in order to ensure that they are competent to perform the tasks on board. The training provided should meet the requirements of STCW Convention or other domestic regulations. Nevertheless, some shipping companies in reality reduce or cancel crew training due to short crew schedule cycles, which negatively impacts the safe operation of ships.

C. *Inadequate equipment, facility and financial support.* The ships put into operation by the shipping company are either not built to standards or later appear unsuitable for further use. This includes the ship's hull structure, power equipment, navigation systems, and sound and light signals. In order to increase the revenue, a ship company may cut the capital that should have been invested by reducing the crew, lowering the training time and shortening the inter-voyage cycle. The profit-centered operation ideology is evident in many aspects of the accident investigation despite not being identified in the accident investigation.

Organizational climate in this context refers to the working atmosphere within the organization, including culture, policy and command structure, which can also be considered as the working atmosphere of the personnel involved in the ship operation process. These factors include the inadequate work done by the shipping company in setting up a safety culture and raising the safety awareness of employees, including not conducting sufficient safety training and not following through with promoting safety knowledge. The value of safety first is not established when interests and safety conflict. Moreover, there are deficiencies in administrative management, such as in the management of personnel files, recruitment, training, and assessment, as well as unreasonable delegation of authority relating to safety issues in vessel operations. In addition, there is poor information communication, especially when it comes to transferring information about navigation safety between the upper and lower management levels at a shipping company as well as between the company and the ship, including planning voyages, senior crew scheduling, and special situation notices.

Organizational process refers to a series of administrative decisions and rules formed by the shipping company in implementing the ship safety management system, including the development of standard operating procedures involving ship safety, the management and assessment of crew work, etc. These factors include an incomplete safety management system. A shipping company's safety management system should include these elements: safety and environmental protection policy, instructions and procedures to ensure safe operation of the ship and environmental protection in accordance with relevant international and flag state legislation, authority of ship and shore personnel and channels of communication between them, reporting procedures for accidents and non-compliance with rules, internal review and management audit procedures. If the safety management system does not meet these requirements, it will pose a hidden risk to the safe operation of the ship.

3.2.2 Unsafe supervision

The human factors at the unsafe supervision level are also implicit in the HAFACS framework and include four main categories: inadequate supervision, planned inappropriate operations, failure to correct problems, and supervisory violations, as shown in Figure 7.

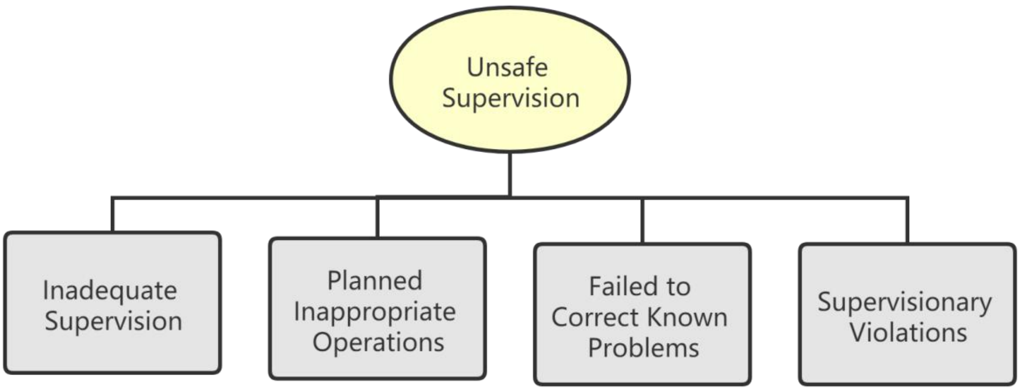

Figure 7 - Human factors at the Unsafe Supervision level.

Inadequate supervision. Supervisors in the safe operation of ships mainly include shore-based management supervision and master supervision. Whenever supervision and inspection are not conducted according to the appropriate procedures, the possibility of detecting safety problems may be lost, which adversely affects the ship's safety. Factors in this category are specifically defined below.

A. *Failure to track qualifications and performance.* Before recruiting crew members and placing them on board, shipping companies do not verify their competency certificates or do not confirm their skill levels according to the job requirements. Crew certificates of competency have expired, there are mismatches between the individual and the certificate, and the holder of the certificate does not meet the requirements of the actual vessel's navigational zone. Also, crew on LNG vessels, tankers, etc. do not obtain the required additional certificates. The ship's master does not monitor the work or performance of the crew.

B. *Failure to provide guidance and oversight.* This includes not providing the operating vessel with appropriate publications (e.g. charts, route guides, port guides, sailing notices, etc.) by the shipping company and the master. Procedures and rules are not provided or are inadequate. Crew members' behavior on board must be guided by various safety operation rules and procedures involved in shipboard operations. A complete set of operation rules and procedures can help new crew members become familiar with the operations on board as soon as possible. The staff will be more likely to skip some steps in order to save time if the shipping company does not provide appropriate operating rules and procedures or does not provide them adequately. Failure to monitor the crew's work implementation.

C. *Failure to identify and control risk.* Risk factors affecting navigational safety, such as defects in documentation, crew training, a ship's seaworthiness, etc., that cannot be identified and controlled in a timely manner.

Planned inappropriate operations refers to a situation where a ship is exposed to risks due to a lack of adequate and reasonable consideration beforehand, leading to an unsafe plan. Such factors include improper crew scheduling, and an inappropriate operation plan and mission.

A. *Improper crew scheduling.* Proper crew scheduling differs from the above two factors of insufficient crew and the lack of assessment of crew's capability, which is the deployment of crew members without considering the integration of new crew members with the existing crew or not allocating the work in accordance with the crew's qualification. As an example, a crew member who did not speak English well was assigned to work on a ship with all crew members speaking English, and a mechanic was assigned to watchkeeping. Or fail to schedule crew rest and work hours appropriately.

B. Inappropriate operation plan and mission. The navigation and operation plan should take into account the ship's condition, cargo conditions, hydro-meteorological conditions near the route, port traffic conditions, and choose the appropriate route, speed, and time to reach the key route points and ports in accordance with the principle of both safety and economy. When plans are too oriented toward economic efficiency and benefits, safety may be compromised and accidents more likely to occur.

Failure to correct known problems. Not reporting unsafe trends is part of this. Those situations that already exist or that will occur and are detrimental to the safe operation of the ship should be brought to the attention of the shipping company and the ship's personnel in time to prevent or minimize the damage. In the absence of corrective action, these risks may continue to increase. Specifically, these situations consist of a failure to discover certain behaviors or events that may have a negative impact on a ship's safety, or noticing problems but not taking action to address them as soon as possible.

Supervisory violations are more serious than inadequate supervision category. Inadequate supervision occurs when the supervision is not in place or details are missed due to negligence, while supervision violations are behaviour done despite knowing that they are against the rules, especially the safety management system.

3.2.3 Preconditions for unsafe acts

The level of preconditions for unsafe acts has three categories: environmental factors, condition of operators, and personnel factors. These factors explain the causes of unsafe acts, and there are both implicit and explicit factors at this level(see Figure 8)

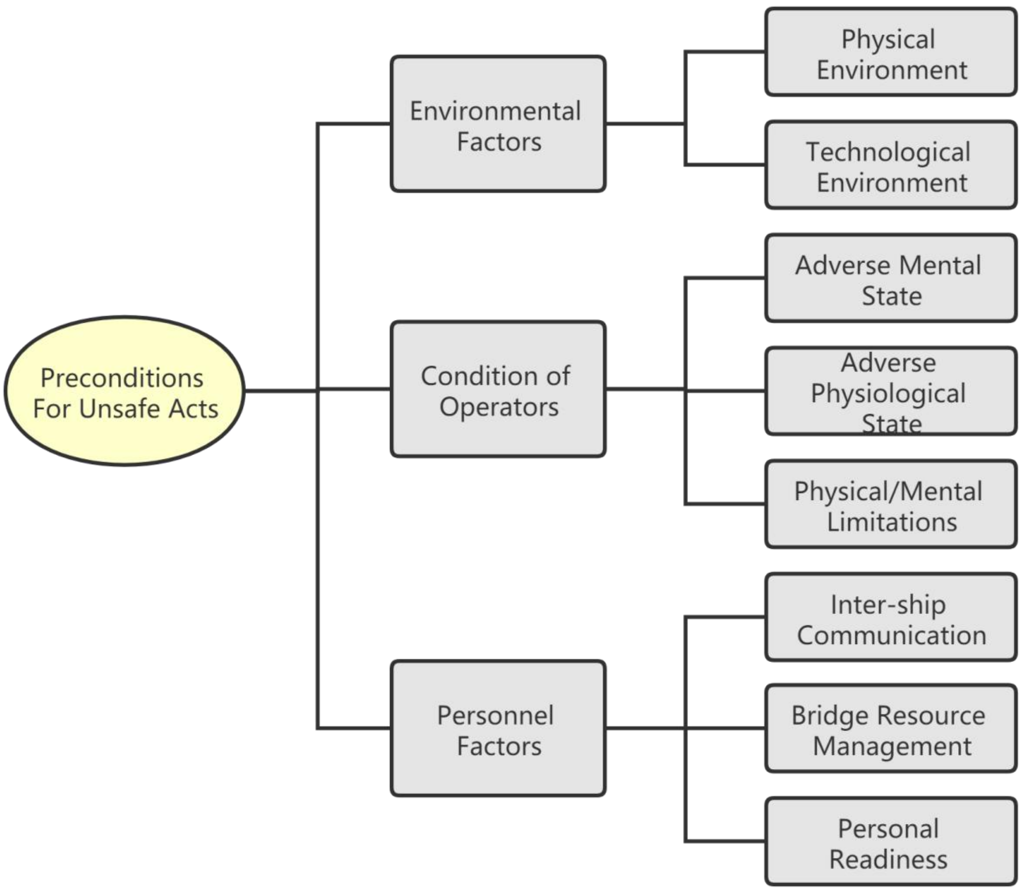

Figure 8 - Human factors at the Preconditions For Unsafe Acts level.

Environmental factors include the physical environment and the technological environment. Physical environments include wind, waves, visibility, lighting, channel conditions, and traffic density. Lookout and collision hazard judgment can be affected or limited by fog, night, and external lights. Ships' safe passage will be affected by the width of the channel, water depth, traffic density, and the condition of lighthouses, buoys, and other navigation aids. In narrow channels, vessel maneuverability can be greatly restricted by these factors, especially when collision avoidance is required. The technological environment is mainly the problem of defective design and construction of the ship and the bridge, or the failure of the equipment and facilities equipped by the ship that do not meet the safety standards. The performance of a ship's main engine, rudder, anchor, and other equipment affects the ship's speed and effectiveness when taking collision avoidance measures. Ship-to-ship communication and coordination depend on reliable communication equipment. In the aftermath of a ship accident, fire-fighting and life-saving equipment play a big role in damage prevention. Moreover, the nature of the cargo and the loading condition of the ship also contribute to the safety of the vessel.

Condition of operators refers to the mental and physical state of the crew, as well as their ability and experience. A crew member in poor condition may not be able to take full and proper collision avoidance action. This includes poor mental state, adverse physiological state, fatigue, and physical/mental limitations.

A. *Adverse mental state.* Loss of situation awareness, mental fatigue, attention deficits, circadian rhythm disorders, and complacency are all adverse mental conditions that disrupt one's performance.

B. *Adverse physiological state*. A performance-impacting physiological, pharmacological, or medical abnormality. A crew member who is fatigued due to excessive work intensity, insufficient rest periods, etc., will not be physically able to perform the tasks of their normal shift.

C. *Physical/mental limitations.* These include situations where individuals do not have the knowledge, ability, skills or time to process information safely. For instance, when a ship sails along a new route, the crew may be inexperienced in understanding the risks associated with the route.

Personnel factors include inter-ship communication, bridge resource management (BRM), and personal readiness failures

A. *Inter-ship communication.* Communication is a prerequisite for accurate information transmission. A ship's failure to communicate with other ships, as well as with shore, can adversely affect its safety. It is impossible to understand the intention of the other ship when communication is nonexistent or ineffective.

B. *Bridge Resource Management.* BRM is the responsible operation of a ship based on effective utilization, application, and coordination of all the available human resources and technologies, together with the skills and experience of the bridge team. In ship collisions, lack of timely reporting, lack of teamwork, and a lack of effective communication are the main human factors involved.

C. *Personal readiness failures.* This occurs when individuals are not physically or mentally prepared for the task, for instance, violation of crew rest requirements, excessive physical training, self-medication, and being under the influence of alcohol.

3.2.4 Unsafe acts

Unsafe acts are the explicit factor level of the HFACS framework that often leads directly to an incident or makes the consequences of one more severe, and includes skill-based errors, decision errors, perception errors, and violations(see Figure 9).

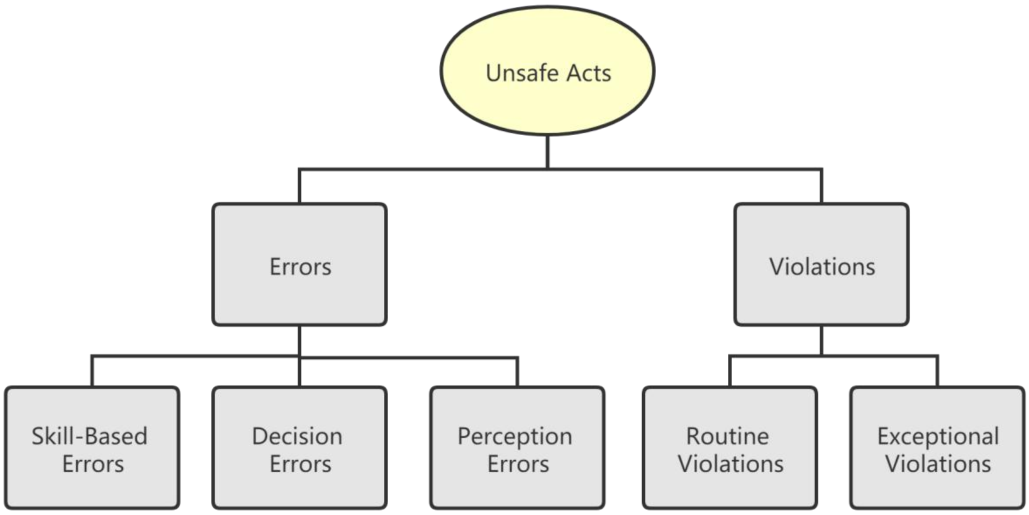

Figure 9 - Human factors at the Unsafe Acts level.

There are three kinds of errors.

A. *Skill-based errors* occur with little or no conscious thought. They are associated with automatic behavior. An example could be an inadvertent activation of the rudder on a vessel.

B. *Decision errors* are conscious, purposeful decisions to carry out an action as designed, however, the actions are not appropriate for the situation. It includes errors in deciding the course and speed of the ship as well as errors in deciding what to do when the ship encounters a special situation. For example, avoiding collisions is not appropriate in a dangerous situation. Or the emergency measures taken in the case of a collision are ineffective, resulting in the accident causing more damage. As an example, when the bow of one ship crashes into the cabin of another, causing the latter cabin to break, the former immediately reverses and backs up, causing seawater to quickly fill the cabin, causing the latter ship to capsize.

C. *Perceptual errors* refer to the situation where the pilot on watch does not perceive the other vessel or perceives it too late. It may be that the pilot does not maintain a regular lookout or is restricted by other factors, such as low visibility or vessels near the route not turning on their navigation lights at night. Wrong judgment of collision hazards, including errors in the pilot's judgment based on the current course and speed of own vessel and other vessels, and errors in anticipating the dynamics of own vessel and other vessels and resulting in collision hazards.

Violations are acts of willful disregard for regulations, and they can be divided into *routine violations* and *exceptional violations*.

3.3 Case study

In this section, based on the HFACS model, a case study of human factors was performed by drawing data from 21 collision investigation reports in China in the year 2020, which were publicly available on the China Maritime Safety Administration website (China Maritime Safety Administration, 2021). The factors involved in each collision for both vessels were classified and counted, and the results are shown in Table 1.

Table 1- Distribution of human factors in 21 maritime collision incidents, according to investigation reports.

	Number of reports where the factor is mentioned and percentage, N=21
Organizational Influences	14 (66.67%)
Resource Management	12 (57.14%)
Insufficient manning	9 (42.86%)
Inadequate training	4 (19.05%)
Inadequate equipment, facility and financial support	0
Organizational Climate	0
Organizational Process (incomplete SMS)	3 (14.29%)
Unsafe Supervisions	13 (61.90%)
Inadequate Supervision	6 (28.57%)
Failure to track qualifications and performance	3 (14.29%)
Failure to provide guidance and oversight	1 (4.76%)
Failure to identify and control risk	2 (9.52%)
Planned Inappropriate Operations	6 (28.57%)
Improper crew scheduling	3 (14.29%)
Inappropriate operation plan and mission	3 (14.29%)
Failed to Correct Known Problems	1 (4.76%)
Supervisory Violations (non-compliance with SMS)	6 (28.57%)
Preconditions For Unsafe Acts	17 (80.95%)
Environmental Factors	16 (76.19%)
Physical environment	12 (57.14%)
Wind, visibility or lighting	2 (9.52%)

Channel conditions and traffic density	10 (47.62%)
Technological environment	4 (19.05%)
Ship and bridge defects, equipment failure	4 (19.05%)
Condition of Operators	3 (14.29%)
Adverse mental state	1 (4.76%)
Adverse physiological state, including fatigue	2 (9.52%)
Physical/mental limitations	0
Personnel Factors	7 (33.33%)
Inter-ship communication	4 (19.05%)
Bridge resource management (BRM)	3 (14.29%)
Personal readiness failures	0
Unsafe Acts	21 (100%)
Skill-Based Errors	3 (14.29%)
Decision Errors	18 (85.71%)
Perceptual Errors	10 (47.62%)
Violations	4 (19.05%)

Analysis of the data in Table 1 shows that the majority of accidents involve human factors at all four levels: organizational influences (66.67%), unsafe supervisions (61.90%), preconditions for unsafe acts (80.95%), and unsafe acts (100%). Every accident report mentions unsafe acts since they are the direct causes of the accidents and are the ones investigators focus on when doing investigations. According to the HFACS model, unsafe acts are the last barrier to prevent collisions between ships, and once this layer is breached, collisions cannot be prevented. Unsafe acts include errors and violations. Only a minority of accidents are caused by violations (19.05%).

Most incidents are directly caused by errors, particularly decision errors (85.71%) and perceptual errors (47.62%). Perceptual errors are mainly a failure of situation awareness, where crew members do not perceive other vessels early enough due to poor lookout, until it is too late to act to avoid a collision. Therefore, the key to preventing accidents is to help crew members manage and control errors.

Preconditions for unsafe acts were cited in 17 of 21 incidents (80.95%), 16 of which involved environmental factors. The most common environmental factors are complicated channel conditions and high traffic density, as ten incidents are associated with these conditions. The challenge for the authorities is to improve the conditions of the waterways, and to ensure that a large number of vessels in limited waters can navigate safely.

At the level of unsafe supervisions, improper crew scheduling, inappropriate operation plan and mission, violations of SMS were the causal factors for a few incidents, each were mentioned in 6 investigation reports. In order to reduce the impact of these factors, the shore-based management of the shipping company and the captain of the ship will have to do a better job of supervising on board.

Organizational influences were mentioned in 14 incidents, 12 of which were related to resource management. Inadequate manning was a prominent issue, with 9 of the 21 ship collision accidents affected by this factor, including insufficient crew numbers and crew members not holding the proper certificates of competency. The majority of these situations are caused by shipping companies' cost-cutting efforts. To reduce this irresponsible behavior that threatens maritime safety, punitive measures should be taken against these companies. This will have a deterrent effect and increase the cost of their violations.

3.4 Chapter summary

The chapter reviews the history of the HFACS framework, which is an effective method to analyze human factors in aviation safety. In light of the similarities between the maritime and aviation industries, it is feasible, appropriate, and beneficial to use the HFACS framework in maritime safety incident analysis, once appropriate modifications are made. The specific causes of maritime accidents are examined at four levels: organizational influences,unsafe supervisions, preconditions for unsafe acts, and unsafe acts, which are further illustrated by a case study of 21 ship collision investigation reports. In this case study, human factors distribution was quantified at each of the levels of the HFACS model, to show how many incidents were caused by each factor.

4 Addressing Human Factors

4.1 A systemic problem

Human factors are responsible for the majority of maritime accidents. It is essential to address human factors and reduce human errors in order to reduce accidents, protect human life and property, and protect the marine environment. Human factors/errors can be addressed in two different ways: the person approach and the system approach. A person approach focuses on the mistakes made by individuals, blaming them for forgetfulness, inattention, or moral weakness. A system approach, on the other hand, involves building defenses against errors or mitigating their impact by addressing the conditions under which people operate. Rather than change the human condition, countermeasures are based on the assumption that conditions in which humans work can be changed (Reason, 2000).

A primary way to minimize the negative impact of human factors is to improve the working conditions of crews. Nevertheless, improving crew working conditions is not as simple as it may seem, since this is a structural issue. The International Maritime Organization, for example, has tools to reduce crew fatigue and protect seafarers from overwork. Resolution A.772(18) addresses fatigue factors in manning and safety, while Resolution A.1047(27) integrates three core concepts for fatigue mitigation. The IMO fatigue guidelines came into effect in 2019. In addition, ILO Convention No. 180, adopted in 1996, sets mandatory standards for minimum and maximum working hours. However, this issue has yet to be resolved due to the following six deep-rooted issues:

(1) A problematic maritime culture. In this culture, priority is given to keeping the ship running. In order to maximize every penny invested in their ships, managers on shore often expect seafarers to work until work is done, even if crews are exhausted. Charterers are also keen to have their influence exerted so that ships run on time, regardless of weather or emergency. There is also the problem of six-on/six-off watch schedules, without effective regulations on rest hours, unlike other industries. This is not only a problem of regulation, but also a problem of culture.

(2) Culture of adjustment. Seafarers often lack the rest time they need on board although regulators and inspectors try to make sure they do so, as a result of a “culture of adjustment", under which a large number of seafarers tamper with their work and rest records to avoid non-compliance in official inspections (Baumler et al., 2021). Due to employment concerns and job insecurity, seafarers are subject to this "adjustment culture" because they have no other choice. The current regulatory framework does not address the fact that rules and regulations are only followed on paper. The port states and flag states are well aware of the problem, but inspectors rarely assess the accuracy of records. Even when they wish to verify rest time, they lack a robust process compared to their robust ability to assess the accuracy of other records, such as oil records. It is difficult to ignore the systemic failures in the implementation of regulations related to work/rest time.

(3) Changes in the shipping industry. Ships are becoming larger and more complex, and more operations are being automated. But it also leads to the ironies of automation: automation technology was thought to be able to do the job better than humans, so it was developed and adopted. Ironically, automation requires human monitoring to ensure that the system is doing its job correctly (Baxter et al., 2012). The physical work of the crew may be reduced due to automation, but it requires more monitoring of equipment and systems, as well as requiring concentration for longer periods of time. The result is a greater likelihood of mental fatigue. Moreover, the number of crew members on ships has sharply decreased, from hundreds in times of sailing ships and steam ships to only about 25 on modern ships due to technological advances, including containerization. Having fewer deck officers on watch will result in longer hours and fatigue.

(4) Shortened port turnaround. Port time has been reduced dramatically in the past decades, from 2 to 4 weeks in port to less than 24 hours, mainly due to containerization. As a result, the crew no longer has as much time as they once did to go ashore and relax while the ship is docked.

(5) Open registry. To reduce cost and maximize profit, shipowners tend to register their ships in open registry countries due to their lax laws on safety and working conditions for crews, and a lack of protection of crew rights.

(6) Supply chain pressure. Although it was expected that pressure from supply chain would improve working conditions for crews, the opposite has occurred. Tanker operators and managers often request that their crews work longer hours in exchange for approval of compliance by Oil Majors such as Shell, Texaco, and Exxon (Bhattacharya & Tang, 2012).

These problems result from the fact that modern shipping companies are a top-down structure, in which the crew can only accept decisions, requests and instructions from management, without any right or ability to participate. Crew members do not even dare raise their concerns about unreasonable orders with the company for fear of losing their contracts. In order to solve the issues mentioned above, the power structure needs to be changed so that crew members may bargain collectively and participate in decisions that affect their interests.

4.2 Technology and human factors

The study by Hanzu-Pazara et al. (2008) shows that simulation, modeling and web-based simulation training can reduce human factor-caused accidents at sea by improving crew capabilities, and ensuring that innovation delivers on its promise of improved activity. In addition, the authors recognize that, while automation can help operators of complex systems to reduce workloads or free up resources for other tasks, it also can cause problems for the control of the system, since it increases risks of unintentional human errors leading to accidents at sea.

The development of technology cannot eliminate the human element. Design, development, operation, and maintenance of technical systems all require humans. At present, unmanned ships still seem to be a distant reality. Even if they become widely used in the future and do not have any crew on board, a large number of system operators will still be required on shore. Wahlström et al. (2015) argued that unmanned operations of vessels face many of the same challenges as those of aviation, subways, space stations, and other industries. The need for human understanding in local knowledge and object differentiation (e.g., differentiate between help-seekers and pirates), and the information overload and boredom, mishap during changeovers and handoffs are a few examples. To achieve the goals of safer shipping and better working conditions for crew, the application of technology in the design, construction and operation of ships must be human-centered (Praetorius et al., 2015).

4.3 Impact of Covid-19 pandemic

More than a year and a half after the COVID-19 pandemic began, there is still no end in sight. One of the groups most affected by the outbreak is seafarers, who risk contracting the Coronavirus while carrying food, clothing, electronics and more around the world. However, due to closed borders, travel restrictions, and quarantine policies implemented by countries to stop the virus spreading, crew changes have become very difficult, or even impossible. As a result, roughly tens of thousands of seafarers are stuck on board ships and have to work much longer than their contracts require them. In many cases, shore leaves have also been denied, leaving crew members unable to purchase supplies and seek dental/medical services. Crew members are very exhausted and under great stress due to long and extended contracts. Not only the crew members are facing a physical and mental health crisis, the chances of maritime accidents caused by human errors have also increased greatly.

For the sustainable development of the shipping industry and for the recovery of the world economy, governments, international organizations and shipping companies around the world must protect crews. Most important is to make crew changes possible in as many countries as possible, so that seafarers can leave ships and return to their families. To make this happen, the most helpful step is to define seafarers as essential workers so that they can be exempt from travel restrictions. However, many governments that list pilots, cabin crew, and truck drivers as essential workers have refused to do so for merchant seafarers. Secondly, seafarers should be allowed to go ashore during port calls to purchase essential supplies and seek medical services. With the help of personal protection equipment and practicing social distance, the chance of spreading the covid-19 virus by seafarers going on shores will be very limited. It’s also necessary to pay attention to the mental health of seafarers during the pandemic. Of course the most effective measure would be allowing stranded seafarers to go home. Besides, governments and charitable groups could set up helplines to provide them with psychological counseling. Last but not least, seafarers should be protected from the virus. They should be provided with timely updates on the pandemic, practical health procedures, and adequate personal protection equipment. Port states should provide shore side medical assistance to crew members when them need it.

4.4 Chapter summary

Identifying meaningful human factors and addressing them require a system approach. In order to reduce human errors, it is crucial to not only build crew capacity and monitor their operation, but more importantly address the underlying systemic difficulties. In the maritime industry, the culture of prioritizing ship operations over safety must be changed so that the working environment and labor conditions of crews are actually protected, not just ‘adjusted’ to meet compliance on paper. This requires that regulatory authorities enforce regulations that protect the interests of crew members, and that crew members are empowered to participate in decision-making processes that affect their vital interests.

The development and application of automation technology in the shipping industry will not eliminate the human element from the process. In the best case scenario, they will be transferred to another place, i.e. on shore, in another form. In utilizing technology, there should be a human-centered approach, so that the technology serves both the crew and safety.

Hundreds of thousands of crew members have been forced to work on board longer than their labor contracts because of the Covid-19 pandemic, causing severe fatigue and affecting their mental health. It is a major threat to maritime safety and the environment, as well as the welfare of seafarers. To resolve this serious problem, governments, international organizations, and the shipping industry must work together.

5 Summary and conclusions

This paper reviews the history and current state of research on human factors in maritime accidents and introduces research methods like HFACS, Bayesian Networks, and Tree Augmented Networks. In an effort to analyze the human factors in ship collisions based on Chinese ship collision investigation reports, this paper presents Chinese understanding of ship collisions, and analyses the human factors in ship collisions using the HAFCS model, which was first proposed in aviation safety. A feasibility study of HFACS for analyzing human factors in maritime accidents is derived from comparing the same and different aspects of two different industries, air and maritime transportation. Four levels of HFACS are analyzed in detail in order to analyze human factors in ship collisions: organizational influences, unsafe supervision, preconditions for unsafe acts, and unsafe acts.

In the analysis of the 21 collision accidents, the human factors were classified and analyzed. It was found that the factors at the level of unsafe acts accounted for the highest proportion of human factors in all the accidents and should be the basis for preventing ship collision accidents. Human factors of ship collision accidents can be effectively explored in depth using HFACS, which expands the application scope of accident investigation reports for accident causation research.

This paper is limited in its scope, and a larger sample size would be necessary to obtain a more in-depth understanding. Maritime accident investigation reports contain a wealth of information that can be used to better understand maritime safety and accident prevention. China's maritime accident reports, however, tend to focus on direct and explicit factors that cause accidents and neglect indirect and potentially dangerous factors, such as organizational climate and processes.

This paper argues that in order to mitigate the human factors, we cannot take a person approach, i.e., interventions that are only directed at unsafe acts and preconditions for unsafe acts, and must find solutions from unsafe supervision and organizational influences. To achieve this, authorities and industry must adopt a system approach, change the maritime culture of efficiency over safety and the rigid, top-down corporate management structure, and empower crew members to be involved in policy-making. Only then can we truly improve the labor conditions of crew members, rather than merely complying with crew protection regulations on paper.

A growing number of stakeholders in the shipping sector are taking an interest in automation technology on board ships, particularly technology for unmanned ships. Even if commercial unmanned ships were to become a reality, the human factor would still have to play an important role. As such, the human factor could merely be shifted to other places in different forms. To improve safety and efficiency through technology, the development and application of technology must be human-centered, because technological systems require people to operate, monitor, and maintain them. A misuse of technology can have the opposite effect.

The Covid-19 pandemic has been ongoing for a year and a half, and has had wrought havoc on the shipping industry. As a result of government measures to contain the outbreak, including border closures, travel restrictions, quarantine requirements, and other measures, crew changes have been extremely challenging and in many cases have been impossible. Many crew members are forced to work on board for longer periods beyond their contracts, leading to fatigue and psychological and mental stress, which has a negative impact on human life and property at sea. International organizations, governments and shipping industry need to collaborate to protect and assist crews while safeguarding the sustainable growth of the international shipping industry.

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