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WORLD MARITIME UNIVERSITY

Dalian, China

Evaluation of the Factors which Affect the Safe Sailing of the Ships

By

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The People's Republic of China

A research paper submitted to the World Maritime University in partial Fulfillment of the requirements for the award of the degree of

MASTER OF SCIENCE

(MARITIME SAFETY AND ENVIRONMENTAL MANAGEMENT)

2014

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DECLARATION

I certify that all the material in this research paper that is not my own work has been identified, and that no material is included for which a degree has previously been conferred on me.

The contents of this research paper reflect my own personal views, and are not necessarily endorsed by the University.

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Title: Evaluation of the Factors which Affect the Safe Sailing of the Ships

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ABSTRACT

Transportation is the support of the national economic development. Safety, high efficiency, energy saving are the direction of transportation development, and safety is the most important one among them. How to make shipping safer and ocean cleaner has become the focus of global attention. However, there have high incidence of accidents at sea, not only affects the development of the economy, also threaten the people's lives and the safety of property at sea.

From the viewpoint of safety system engineering, using the combination of qualitative and quantitative method, this article detailed analyze and find out the factors which endanger people's life and property safety from three aspects include: human, ship and environment. And we established a factor structure chart on this basis, and then we use the analytic hierarchy process to analyze all factors about their quantities, and get the important degree of various factors according to the analysis results. Finally this article will put forward some suggestions on the measures of the various influence factors according to the analysis results to ensure the safety of maritime navigation, and provide the basis of qualitative and quantitative for maritime supervision agencies, shipping companies and ship driver assessment of ship navigation risk.

Keywords: navigational safety, human factors, shipping factors, environmental factors

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ABRREVIATIONS

NPC&CPPCC	National people's congress and Chinese people's political consultative conference
MSC	Maritime Safety Committee
MEPC	Marine Environment Protection Committee
USCG	United States Coast Guard
AHP	Analytical Hierarchy Process
SOLAS	Safety of Life at Sea
PSC	Port State Control
FSC	Flag State Control
IMO	International Maritime Organization
ISM code	International Safety Management code
PTP	Prevent Through People
GPS	Global Positioning System
ARPA	Automatic Radar Plotting Aids
GMDSS	Global Maritime Distress and Safety System

Chapter 1

Introduction

1.1 Background and Significance of research

The report of the 18th national party firstly proposed the construction of "powerful ocean country", and requested to improve marine resource development, develop marine economy, protect the marine environment, and resolutely safeguard national interests in marine construction. During the NPC&CPPCC in 2013, the State Council started reform plan, this plan proposed to re-establish the State Oceanic Administration, which indicated that the country attaches great importance to the overall development of China's marine construction. Security is a prerequisite of development. In order to build "powerful ocean country", protecting the safety of maritime navigation is a prerequisite.

Since the 21st century, with the acceleration of liberalization of world trade, economic integration and information globalization, the world shipping industry has been greatly developed, followed by the evidently trend of world's increasing merchant fleet tonnage, large size of the ships and high-speed of the ships. Meanwhile, the increasingly busy maritime traffic, great sailing density, narrow waterway, crowded port access, evidently increase the traffic accidents. So the deep study of factors affecting the safe navigation of the ship at sea is necessary, it not only conducive to the relevant personnel to understand the root cause of the ship accident, but also for the safe navigation of the ship at sea provides a theoretical

guarantee to the offshore supervisory authorities, shipping companies and seafarers.

1.2 research status of internal and external

Early analysis of factors affecting the safe navigation of the ship mainly reflected in the structure of the ship and research of the navigation environment. People constantly improve shipbuilding technology, invent advanced navigational equipment, improve navigation environment, and design the collision regulations and safety routes, in order to through these technical means to reduce the accident rate from the ship's equipment and maritime navigation environment aspects.

After a long-term analysis of various types of accidents occurring in the sea, IMO Maritime Safety Committee (MSC) and the Marine Environment Protection Committee (MEPC) jointly issued the "human factor unified terminology" on June 23rd, 1997, the term is divided into six major items of 45 small items. This six major projects are: ① Human error ② Dimishedhuman performance ③ Marine environment④ Safety administrations⑤ Management⑥ Mental action.**(Zhou, 2006)** Obviously we can see this uniform terminology highlights the existencedefects of the aspects of psychological and physiology of the human, human behavior, human capacity and natural environmentrelated to the safety of navigation. It marked the international shipping community of maritime safety research priorities from the previous "technology first" to now "human first".

As early as 1992, USCG began to study on human factors. Since 1994, USCG launched a long-term, systematic research program (PTP program), it is "designed to reduce shipwreck and marine pollution research methods through human-centered", through the systematic study of human factors to reduce or control the hazards of the factors to achieve traffic safety.**(J.Hagart 2001)** Until September 1996, PTP strategic plan had been finalized and began to complete the scheme. The U.S. Coast Guard is

responsible for PTP and its Quality Plan Action Group said: in the past the security research community always focus on marine equipment with a problem, and ignore reducing the possibility of the incidence of maritime by avoiding human error.

It also pointed out that the high incidence of maritime accidents are caused by these several main reasons: ① lack of root cause investigation of maritime accident and leading to no possibility to identify the specific human error cause of the accident; ② lack of systematic analysis to the higher risk operation; ③ lack of effective exploration and implementation measures to prevent human error; ④ lack of extensive cooperation when study human error problems

(Lu. 2005, P4).

In the recent 20 years, experts and scholars in other countries also made a lot of achievements for human factors, mainly focused on the crew conduct reliability studies and human physiology, psychology study characteristics.

In China, recent years, many experts and scholars also analyzed the main factors causing accidents at sea from different sides and pointed out that the human factor is a combination factors, the associated factors contact with each other. Early research on human factors only related to analysis of a personnel result, such as: ① improve education and training approach is the key point in the research. Especially in the action to avoid collision, when to take collision avoidance behavior, how to take collision avoidance behavior have closely connection to richness of the knowledge of crew, and the degree of understanding the rules, skills, experience, attitudes ② investigate the relationships between human factors and selection of new staff. Many

articles qualitative analyze the considerations of physical and psychological condition of the crew in the selection of personnel and staffing, especially the character, temperament, etc. personal factors which closed to ship operations, and made necessary psychological tests of seafarers③ study of fatigue. Depending on the global maritime statistics, for the cause of the high incidence of marine accident analyze, the results show that human factors play a major role in the maritime accident, and fatigue may be up to about 75%, and proposed the establishment of a reasonable working hours system is particularly necessary ④ through the crew collision avoidance behavior statistics and the tests of the crew personality to investigate the relationship between crew personality and their behaviors, get conclusions about its operating vessels behavior is different due to the different crew personality characteristics, further analyze the relationship with crew personality and its operation of the ship⑤ make the research of crew actions reliability models.

In the evaluation methods aspect, in October 8, 1990 the Ministry of Transportation Maritime Safety Supervision Bureau in Beijing held the third seminar order to improve maritime traffic, use maritime traffic safety evaluation method for the theme, invites relevant experts and scholars workers to discuss together. In the meeting, experts, scholars proposed AHP, Safety Index method, collision risk, the risk of navigation and maritime traffic micro-macro network simulation five main methods. These five methods proposed to solve the problem from different angles or different theories based on the basis of ideas and methods. With the development of science and in-depth research of technology, many scholars applied a lot of the new method up to this area. According to the research results by scholars in the field of maritime transport environmental assessment, we divided evaluation methods into three categories: one is the traffic simulation, including computer simulation and ship handling simulator two forms; one is the application of mathematical model; one is

the application of systems engineering method.**(Zhang. 2011)**

1.3 research content and methods of this article

Ship navigation system is a typically complex man - machine - environment engineering system, it has many constituent elements and certain level of relations, thereby there are a lot of factors affecting the safe navigation of the ship, and the various factors interact with each other, mutual restraint with each other, and also human behavior is quite uncertainty and the system environment is variability, it makes the factors which affecting the relationship of security of the system more complex. The choice of factors which affecting the safety should follow principles like completeness, independence, representativeness, comparability, operability, qualitative and quantitative. Therefore, the analysis of the factors affecting the safe navigation of the ship is significant, this paper depends on the systems engineering ideas as a guide, start from the view of regarding the system as a whole, gradually analyze and study. We start from the actual situation, sort out, classify and integrate these factors; we launched a comprehensive systematic study from human factors, ship factors, and environmental factors three areas.

Establish the factors framework affecting the safety of navigation, shown in Figure 1

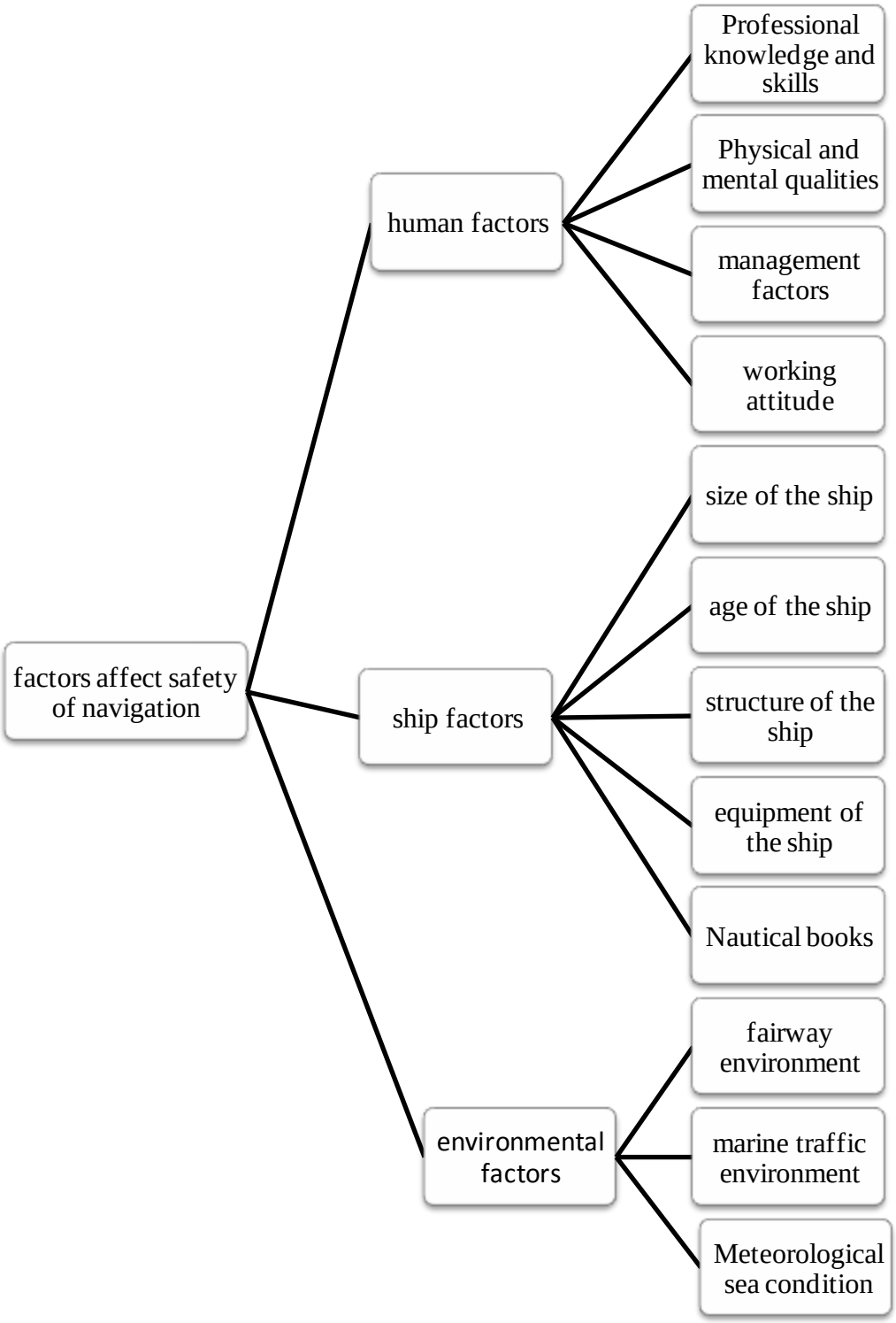


Figure 1-Factors framework affecting the safety of navigation

Source: the Author

Security systems engineering study often use qualitative and quantitative analysis methods. In many cases, a qualitative analysis is to determine the direction of the research, and a quantitative analysis provides the number indication of system behavior. Simple qualitative analysis or quantitative analysis is difficult to solve specific problems in science research. Therefore, this article uses both qualitative and quantitative analysis methods, and combines with each other, then make detailed analysis on the factors within the system

Due to the security itself is a vague concept, ship accidents not occuring do not indicate that the shipping system is safe, no incident does not indicate that person's behavior is safe, the factors involved in vessel traffic system have the diverse and complex characteristics, especially when it comes to human factors, it is difficult to fully quantitative, therefore, this paper started to analyze various factors from different angles, and then uses the AHP model to carry out quantitative research for all factors, finally makes the sequence depending on the degree of influence for the various factors affecting the safe navigation of a ship, which is the practical application of systems engineering methods of analysis and evaluation in this article.

Chapter 2

Safety system engineering

2.1 Overview of the safety system engineering

Safety System engineering is divided into narrow and broad safety system engineering systems security engineering, narrow safety system engineering combined with engineering theory using system principle views and methods to manage security, it is systems engineering applications in the field of security, and it is also a branch of systems engineering science. It is the principles and methods of application systems engineering, through controlling the process of a variety of related events in the systems, reducing the likelihood of accidents, so to reduce various losses due to security incidents, and guarantee protecting personnel and property safety and the marine environment

An advantage of the safety system engineering is that it can comprehensively analyze the security system, research the issues on the overall point of view, in order to avoid shortcomings, reduce the one-sidedness of the analysis. After analysis, the security weaknesses which exists in the entire system can be found, the analysis can help to identify areas where accidents may happen, and predict the consequences of the accident, find ways to avoid accidents, reduce accidents occurs, all of which can make safety system engineering approach pay less in terms of security investment to get the maximum effect. This method needs a variety of standard and data in the process of its assessment, which is also conducive to a variety of safety standard

formulated and related data collection. What is more, through the use of safety systems engineering approach, we can also improve business and management capabilities level of relevant staff.

2.2 Safety Assessment Principles

Safety assessment is a risk assessment for the system which can determine the level of risk. The approach may be qualitative analysis, and also can be quantitative analysis, through the analysis we can identify the weaknesses of system, determine what aspects can be dangerous, and if the danger does occur, how is the degree, how much the effect and losses will it cause, safety assessment is an integral part of the safety system engineering. By evaluating we can make the conclusions and identify the risk in advance, reduce the risk of occurrence, and reduce the losses of accidents. Although qualitative analysis can only roughly identify the degree of risk of hazard resources, it is still quite necessary. In order to understand the probability of accidents and severity of the consequences of the accidents more accurately, we need quantitative analysis. Using some mathematical method we can change qualitative identification into quantitative identification, thereby improving the accuracy of qualitative identification, validate the danger of system we need to repeatedly check to determine if there is a new danger, then we compare the quantitative results which are repeatedly checked with the allowable limit to determine the degree of risk, make further hazard assessment to the danger resources which still exist after complying control measures, and determine whether the risk is acceptable. The contents of the safety assessment and safety assessment program flow show in Figure 2 and Figure3 respectively. "

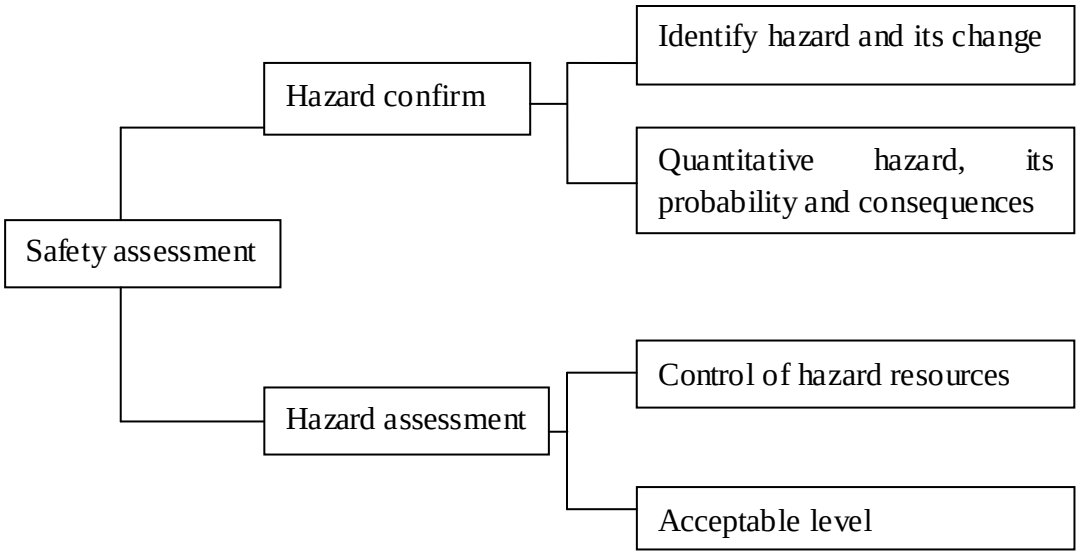


Figure 2- safety evaluation contents

Source: Zhao, X.J. (2010). The application of FSA in the evaluation of port area. Traffic information engineering and control of Dalian Maritime University, p10

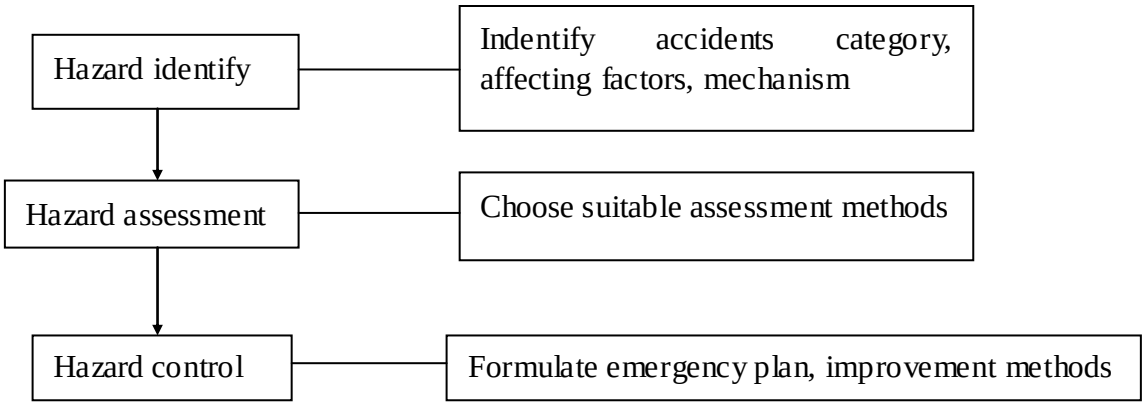


Figure 3- Safety assessment program flow

Source: Zhao, X.J. (2010). The application of FSA in the evaluation of port area. Traffic information engineering and control of Dalian Maritime University, p10

As can be seen from the safety assessment of the content and processes, safety systems engineering structure consist of four basic elements: human, machine, environment and management. In the safe navigation of the ship they correspond to the crew, ship, navigation environment, shipping companies and authority

management. To avoid or reduce the accidents, people must effectively control the people, machines, environmental factors and their relationships.

2.3 Principles of the choice of Safety Assessment Methods

When we select the method of safety assessments methods, in order to make the appropriate assessment method selected object, the following five principles must be followed of:

(1) Principle of adequacy

Before making the safety assessment for the system, we must get fully prepared, ready to fully analyze in advance, according to the characteristics of the system, make a full estimate, so as to choose the most reasonable, most scientific and most effective method for the safety assessment.

(2) Principle of adaptability

During the assessment process of safety systems engineering, the safety assessment methods must have adaptable object. For all the items in safety system engineering, we use different safety assessment methods adapt to its specific situation, which can make the evaluation more specific, and the results of the assessment more accurate.

(3) Principle of systematic

Systematic principle means to obtain credible results of the safety assessment; it must conduct a systematic research, using comprehensive data and information to analyze the system. The result of the assessments should be real, effective and comprehensive.

(4) Principle of direction

Principle of direction refers to the results of the assessment which should be targeted. When we choose the safety assessment methods, we must first determine the purpose of the evaluation, determine what we need about the results of the assessment, and then based on the results choose the safety assessment methods.**(Ma&Ren, 2002)**

The purpose of our assessment may be whether the system exists danger or the level of hazards, also can be determine the probability of the accident in order to reduce the possibility of accidents, it also may be identifying the cause of the accident and prevent accidents from hazards sources, focus on these different evaluation purposes, we should choose a adapted safety assessment method, so that we can get the assessment result that we want.

(5) Principle of rationality

Principle of rationality requires us to choose the most reasonable safety assessment methods when we choose the safety assessments. This assessment should be as simple as possible during the process of calculation. The data we need to provide should be as less as possible, which makes our assessment workload not too complicated and difficult. Of course, this assessment must first meet our safety evaluation purposes, and can get the results of the assessment that we need. In the assessment process we should try to avoid useless and unnecessary troubles as much as possible.

Based on these principle, until now we have developed a variety of assessment methods, including both quantitative assessment methods and qualitative assessment methods, in the end what kind of method should we use depends on how much information available for us during the risk assessment process. when the data is adequate for the evaluation, we can use quantitative assessment method; when the data is insufficient, we usually use qualitative assessment methods. There are a lot of relevant factors affecting the safety of navigation, there are external environmental factors, and ship factors, seafarers sailing experience and sailing skills factors, and ship company management factors. These factors are overlapped and many concept of factors are fuzzy, so only through an integrate assessment, a combination of qualitative and quantitative methods, so that we can get a more reasonable result.

Chapter 3

Analyze human factors which affect navigation safety

The former IMO Secretary Mr. O'Neil said at the World Maritime Day in 1994: human error accounted for over 80 % of all maritime accident causation, if we want to prevent the accidents, we should focus on eliminating human error. **(Lu,2005)**From this we can see, human factors have a non-negligible impact on the safety condition at sea. In order to protect the safety of marine navigation of ships, we must study the impact of human factors on marine safety.

The human factor is the main scientific facts associated with the human characteristics. This term includes all biomedical and social psychology consideration**.(Gu,2009)** In maritime studies, broadly speaking, the human factor refers to the all other relevant factors about persons except natural factors, which is the human error that directly results in the accidents. This means violating the operation rules or crew common practice, and then making the system failure or appearing poor performance events. From the narrow speaking, human factor refers to the shipping personnel factor. From the perspective of safety evaluation studies, the impact of the human factor in maritime safety include: professional knowledge and skills, physical and mental qualities, management factors and working attitude.

3.1 professional knowledge and skills

Crew's professional knowledge and skills from a broadly speaking is the general

term for crew's professional quality and work ability. From the narrow speaking, it refers to the professional knowledge and skills validated by the statutory technical crew qualification certificate. Crew technical quality certificate in our country consist of competency certificate, professional training certificate and special training certificate, through a review of the eligibility criteria, examinations and assessments to judge the professional knowledge and skills of the crew. This paper argues that the evaluation indicators of professional knowledge and skills are: knowledge, qualifications, practical skills and comprehensive skills.

3.1.1 Knowledge

Educational background to some extent can be able to objectively reflect the professional knowledge of a person. As the increasing complexity of ship's navigation equipments, communication equipments and communication tools, it requires a high level of the knowledge of shipping industry. GPS, ARPA and GMDSS and other advanced navigational instrument operation requires specially trained personnel. What is more, for other regulations, such as understanding the Collision Regulations also require the crew to have some qualifications. The practice shows that a large number of maritime accidents occur simply because the lack of understanding of the Regulations for Preventing Collisions by crew

Well knowing about the professional knowledge of the shipping is the most basic indemnification to the competency of seafarers, the country established a perfect system of examinations to judge the knowledge of crew. Currently, crew competency certificate exam is strictly accordance with the examination outline issued by the authority; the examination results can objectively show the professional knowledge of crew. Only by attending appropriate training to learn a certain amount of sailing knowledge and obtaining certificate through the appropriate exam, can we become qualified seafarers, and provide protection for the safety of navigation at sea.

3.1.2 Qualifications

Qualifications reflect a person's work experience. Seafarers sailing experience is closed to the safety of maritime navigation. In the marine accidents, due to the different situation of the human experience, length of work experience at sea and physiological conditions, it may cause different level of errors.

When the professional knowledge can not meet the requirements of safe navigation, it must have some sailing experience, which is decided by shipping industry. Sailing is a skill -based occupations. It needs some theoretical knowledge, but also needs some experience. Without theoretical knowledge to guide, the navigation will have a large blindness and dangerousness, and the lack of experience of sailing is also not acceptable. Experience is a direct contact knowledge of sailing through their senses in the long-term practice, and then through their own rational summary and repeated practice, the sailing knowledge and skills can be acquired. It grew with age of the sea, the longer working hours, the less likelihood of marine accidents, the more security of marine navigation. But by investigating the officers on the ship, it is shown that most of them upgrade quite fast, and has less time on the low level job service, and thus their sailing experience is not very rich, "STCW Convention" for issuing certificate with a mandatory requirement is that the crew must have certain seagoing service.**(STCW, 1978)**

3.1.3 Practical skills

Practical skill is the reality of the crew working condition. Sailing is a practical technology, there is a wide variety of mechanical equipments and instruments as well as goods on the ship, operation, using and maintenance all need " hands-on " operation by crew, the ship itself is also a big machine requiring safe operation, so the practical skills of crew is very important. In order to improve practical ability of crew, "04 rule" stipulates that the crew applying for competency certificates must be

assessed by the evaluating project. Shipping company's safety supervision department and maintenance department also have responsibility to check and record the safe operation by crew.

3.1.4 Comprehensive skills

Comprehensive capacity refers to the ability to use both knowledge and skills to work according to the specific circumstances. Sailing is a practical technique across a variety of subjects, which requires the seafarers to learn and acknowledge rich and extensive knowledge and skills, including astronomy, geography, fluid, mechanical, chemical, meteorological, management, legal and other aspects. The seafarers need to make the most reasonable action based on the actual situation. Facing unexpected situations under special circumstances is also a reflection of the comprehensive ability.

3.2 physical and mental qualities

After a long analysis of the accidents, IMO Marine safety Committee and maritime Environment Protection committee jointly issued the "human factor unified terminology" on June, 23, 1997, highlights the subjective and objective defects of psychological and physical behaviors of the human.**(Wang,2009)**

Sailing far away from shore, and separating from society and family, all of these decide that the crew life is monotonous, boring, lack of stimulation and information. Meanwhile, working on the ship may bear the big noise, high temperature, and pollution produced by oil and chemical things. These all increased the physiological, psychological pressure of the crew, affecting the health of them.

3.2.1 Physiological quality

Physiological factor is the most fundamental factor to ensure safety performance of the crew on their duties, the most important two indicators are the degree of health

and physical fatigue.

The level of health reflects physical fitness of the crew. Obviously, if there is no good physical condition, then we can not guarantee the security of maritime activities. Particularly in the long-term shipping at sea, work pressure is very high. It not only requires the crew to continue a long time operating work, but also requires the crew to afford different climate caused by the changeable navigation zone, so the health of the crew will certainly produce a direct impact on their job security. Although before obtaining the corresponding competency certificate, the crew has already received medical research, but due to the illness with characteristic of suddenness, it is difficult to keep the health of the crew without any change. In addition, due to the poor living conditions on board, crew's depression and other complex causes may lead to the disease of the crew. Thus the health of the crew is the most basic physiological factors content.

Fatigue is another aspect. For the driver driving in a long time on the ship in a complex environment, it is easy to produce fatigue. And the symptom of the fatigue is slow behaviors, inaccurate action and insensitive mood, they may be also very easy to feel boring and can not concentrate the mind. Therefore, the fatigue reduce the level of work, and make the body and mind with slow reaction, and it also weaken the ability to make a reasonable judgment, the result will inevitably lead to an unsafe behavior, and easy to result in accidents.

3.2.2 Psychological qualities

Psychological qualities affect the potential of human in various forms, and ultimately affect the entire population and affect to achieve organizational goals. When the drivers are on the duty, they always follow an activity rule like

stimulus-feel-judgment-action, when the people in a bad psychological state, such as nervous, over exciting, lonely, it is easy to cause perceived errors for the outside stimulus, wrong judgment, or operation error. The maritime industry have noted that in sailing theoretical knowledge, practical operation skills and psychological qualities three elements, the psychological quality is the dominant, playing an important role. Because the application of theoretical knowledge, good practical skills are based on certain psychological qualities, leaving the psychological quality, it will affect acknowledge and apply of theories, and seriously affect the operation skills

3.3 management factors

IMO pointed out in the ISM Code, about 80 percent of the occurrence of accidents at sea due to the human factors, and in the human factors, about 80% can be controlled through effective management, which means strengthen the internal management of the shipping company and improve ship's safety management. D.J.Mackenzie considered that in order to improve the safety of navigation of the ship, we must ensure that there is a complete management system.**(Chen,2002,P26)** Only by establishing a comprehensive management system, through effective management, we can make a good coordination among the various departments of the company, and enhance the cohesiveness and working efficiency

With the rapid development of shipping industry. There are more and more ships put into use, so it inevitably brings adverse effects on management, the mainly perform are followed:

Crew team expanded rapidly, but the overall quality declined. Development of shipping industry creates large number jobs, but the people who quickly enter into

the team of seafarers have a only short term training. The crew graduated from a formal training institution only accounted for a small proportion of the crew team, so the overall quality of crew is declining.

The deterioration of the navigation environment. Although the state has invested a lot of money on environmental improvement, it can not avoid the deterioration of the navigation due to the market competition and the lack of comprehensive management. Deterioration of the environment brings an effect which can not be ignored by marine safety

Thus, the country's major policies and macro-control agencies of the safe navigation of a ship at sea is very important, and the security management in the company is a prerequisite for the safe navigation of the ship.

3.4 Working Attitude

Attitude is an important part of the crew quality. Crew working attitude reflects personal beliefs, worldview, political stance, style of thinking, policy level and so on. Correct and positive attitude is quite helpful for the crew to do their work. Ships are always sailing on the sea for a long time, staying away from their loves, and the life is monotonous in poor working conditions, and often encountered storms, if they do not have good quality and strong ideological quality, it is easy to produce sense of fear for their jobs, make their mood depressed, and let them loss enthusiasm of the life, and it may become impossible to continuously learn new technology to improve their professional level, and more importantly, they can not concentrate their mind, and can not effectively perform their duties. In the practical work, there are many accident cases which are caused by the bad attitude of the crew

3.4.1 Professional ethics

Professional ethics refers to occupational behavior standards which need be followed during the professional activities. Crew professional ethics refers to rules and guidelines to conduct the care among the people during the process of transportation. For example, loving the shipping industry, working together and help each other, devoting to duty and so on. Crew professional ethics also reflects the degree of dedication and love for their work.

3.4.2 Safety Attitude

Safety attitude is an external reflection for the security awareness, and it is also a practical performance of people's security feeling and psychological processes. Crew's correct attitude is the basic conditions to ensure the safety of the ship, only when the crews have the proper safety awareness, then they can have a good safety attitude to achieve the control of human behavior, and make their action safe and reliable; If the crews do not have a good safety attitude, then it will pose a great threat to security.

3.4.3 Enterprising

Enterprising can produce enthusiasm and creativity during the operations. Enterprising is one of the key factors that affect the quality of the thought of the crew. A seafarer with great enterprise will continue to learn, and humbly ask the experienced crew, desire to promote their positions through their own efforts and training, so they can make the better serve for the company. Conversely, if a seafarer is lack of enterprising, he will reduce the requirements of themselves, which is not conducive to the safe navigation of the ship.

Chapter 4

Analyze the ship factors which affect navigation safety

Maritime traffic engineering believe that human, ships and environment are three elements that constitute environmental transport system, if one of three elements has problems, it could lead to accidents, so as one of the elements, the ship is an important part in maritime security. Ships factors include many aspects such as size of the ship, age of the ship, ship structure, and ship equipments and so on; many marine accidents have the relationship with the ship factors.

Numerous ship factors bring great damage to people's lives and property. According to statistics, the manipulation of large ships in the harbor due to the large inertia, is difficult to control, if the rudder suddenly fails, it may often lead to significant loss.

In short, due to the poor conditions of the ship which cause marine accidents are quite stable.

4.1 Size of the ship

In the analysis of vessel size, we mainly consider the index from the length of the ship and tonnage of the ship two aspects. In fact, the length of the ship has relationship with the tonnage of ship, the longer the length of the ship, the greater the tonnage of the ship. So generally we can use the tonnage of the ship to indicate the size of ship

According to statistics, the incidence of marine accidents is affected by the size of ship. Japanese maritime experts found in a long-term study of marine traffic accidents, under the same conditions, the larger of the ship, the higher probability of the marine accidents. Because the bigger of the ship, the greater of its inertia, but the less of maneuverability, the greater affected by the channel width, water depth and other factors, at the same time, the large of the ship, the number of subsystems of each ship will also become more complex, so the frequency of occurrence of marine accident is higher. According to maritime statistics, the rate of ship collision's average change with the tonnage of ship can be expressed as **(Chen,2002,P14)**

$$\text{Collision rate} = 0.0014 \log_{10} T + 0.009 \qquad (4.1)$$

The formula means: greater of the tonnage the higher rate of the collision.

Therefore, we can not ignore the impact of the size of the ship to the maritime transportation security; and also the tonnage is an important part of the safety evaluation index system of the sea.

4.2 Age of the ship

Ship's age is a big factor affecting the safety of the ship, because with increasing of the age of ship, the ship structure and ship equipment technical condition will decline, and increase the probability of occurrence of marine accidents, especially for the ships more than 15 years, generally entered into the inefficient period, due to aging or corrosion and other reasons, the failure increase year by year.

Statistics show that from 1990 to 1994, there are 25 bulk carrier accidents which

caused the loss of lives among the world, the minimum age of ship is 14 to 16 years, the maximum is 22 to 26 years, among this more than 18 years of age of ship accounted for the majority.

(Chen,2002,P16)

Of course, some of the ship although have a high age, but due to the good maintenance, it also maintain a high state of technology, but general speaking, the greater the age of the ship, the higher the rate of loss, for example, the losing rate of the different ages of the ship fully illustrates this point. Like Table 1 and Table 2 show.

Table 1-relationship between ship's age and losing rate

Ship age	0 ~ 4	5 ~ 9	10 ~ 14	15 ~ 19	20 ~ 24
Losing rate	1/769	1/625	1/323	1/162	1/76

Source: Dong, J.H.(2004). Ship state assessment standards and computer evaluation system implementation. Modern ship management of Shanghai Maritime University.P31

Table 2-marine accidents statistics for bulk carrier during 1990～1996

Age of ship	0 ~ 4	5 ~ 9	10 ~ 14	15 ~ 19	20 ~ 24
Total numbers of losing ships	1	3	6	24	29
Total numbers of ship	772	737	1188	785	821
Probability of marine accidents	0.02%	0.11%	0.07%	0.44%	0.5%

Source: Dong, J.H.(2004). Ship state assessment standards and computer evaluation system implementation. Modern ship management of Shanghai Maritime University.P31

Obviously, more than 15 years of age of the ships are quite dangerous, in the PSC

inspection, among the ships which found the problem and even stranded, high age of ships accounted for a large proportion, and it indicate that the aging boat brought insecurity**.(Chen,2002,P16)** At present, China Classification Society pay more attention to the age of the ship during the inspection and enhancing safety assessments to adapt the strict requirement of international maritime community for the management of old ships, so we can take the age of ship as an important indicator for safety evaluation.

4.3 structure of ship

The ship structure is an important factor in the ship indicators, in the accident of ship losing, there is a large part caused by insecurity of the ship structure.

In 1990 there are 23 bulk carrier hull damaged. In 1991 there are 14 loosed due to damage of the hull. According to statistics of 6075 classed ships by Japanese maritime committee in 1997, for the hull damage, in the total number damage, abrasion accounted for 66.8%, deformation accounted for 9.9%, cracking accounted for 22.4%.

(Chen,2002,P17)

Deformation damage is the internal skeleton of the hull and the outer plate fission occur deformation, primarily concerned with the strength, and it is caused by the collision, stranding, waves shock and heavy cargo which make the part of the structure too much press. And then it seriously influences the safety of the ship

Abrasion and cracking of the hull are increasing with the age of the ship. We can

now prove that: more deterioration of the shell, the older of the ship. According to the feedback from the ship in 25 accidents, 44 percents have been tested the varying degrees of structural damage before the accidents, due to the strength of hull can not resist large waves, so the accident is inevitable, because the smaller of thickness of the hull, it also means a reduction in safety. No matter how insignificant cracks are, they are not allowed to have any slightest negligence. Because the crack will become a focal stress point once it exists, causing cracks expand, and leading to general corrosion loss.**(Wang,1993)** Therefore, in the PSC inspection, there are checks about hull plates, beams, ribs and other projects, and fully reflects the importance of hull of the in the ship safety.

We can see from the form of manifestation and practical threat maritime consequences to human life, property and the marine environment, the structural integrity of the hull is very important because most marine damage associated with ship hull. It not only causes the lost of human life, significant damage of property, but also produces more serious marine pollution. According to Lloyd statistics, from 1994 to 1995, hull damage of the ship is the most important reason in marine accidents. Therefore, the complete structure of the hull is a prerequisite for the ship to realize various capabilities such as stability and anti- sinking.

4.4 ship equipment

The so-called ship equipment failure refers to failure of ship technology system, failure of turbines or engine, failure of communications equipment and so on. In the maritime analysis, it is not difficult to find a considerable part of accidents which were caused by a defective condition of the ship equipment, such as the damages of steering equipment, propulsion, power supply systems, and so on. And many accidents like collisions, grounding, stranding incidents mostly caused by sudden

failure of steering or the failure of other equipments

According to the traffic accident statistics from 1997 to 2007, the accidents due to the failure of the ship technical equipment account for 7% of total accidents. Our country's statistics of causes of accidents also fully illustrates this point, as shown in Table 3.

Table 3-statistics of the causing of accidents in part of ports

ports	Qingdao Port (1996～2003)	Dalian Port (1992～1999)	Huangpu Port (1991～1998)	Xiamen Port (1991～1998)
Percentage of accidents due to equipment problems(%)	6.75	7.24	4.50	7.54

Source: Chen,C.Y.(2002). Analysis on safety of water transportation in our country and study on the prediction about the traffic accidents. Transportation planning & management of Dalian Maritime University,P18

4.5 nautical books and materials

Nautical books and materials are the main tools of sailing. "SOLAS" Chapter V Regulation 27 - Nautical charts and nautical publications says:

Nautical charts and nautical publications, such as sailing directions, lists of lights, notices to mariners, tide tables and all other nautical publications necessary for the intended voyage, shall be adequate and up to date.

(Convention of STCW)

Whether ships can meet the above requirements of SOLAS, directly decide whether the ship is seaworthy. It is related to the whole sailing process of safety of ships, which is also required for port state control(PSC) and flag State control(FSC). According to statistics, the accidents due to the failure of nautical chart or maritime materials account for 2.0%, and it is also a main reason of ship grounding. We can also found that in the maritime inspection, it is common to see the nautical books and materials are not up to date. In fact, this is one of the main reasons that the ship being stranded in the port State. Therefore, it is necessary to regard this as an important indicator to evaluate the safety of the ship.

Chapter 5

Analyze environmental factors which affect navigation safety

With the development of port shipping industry, the scale of the port construction is expanding all the time, port navigable environment varies greatly. On the one hand the proportion of large tonnage vessels are increasing rapidly, and make the port traffic more complex; on the other hand, open-deepwater pier construction, increasing the impact of natural conditions like wind, waves and currents, such changes provide a higher requirement on navigation environment of the port and maritime safety management. Therefore, making the research on navigation environment has the practical meaning of significance. This paper studied environmental factors including fairway environment, maritime traffic environment and meteorological sea condition.

5.1 fairway environment

Directly impacts on the safety of navigation of fairway environmental factors mainly are radius of curvature of the fairway, fairway width and fairway depth.

5.1.1 Radius of curvature of the fairway

In recent years, Russia made a statistical analysis for the traffic accident in different radius of curvature in the fairway; we can see that, the curvature of fairway directly affects the safety of navigation, and the statistic data are shown in Table 4.

Table 4- traffic accident statistics due to the different radius of curvature in fairway

radius of curvature R_1	Number of curved fairway n_R	Number of accidents n	Number of relative accidents $K_i = n/n_R$	Accident rate (%) $\lambda = K_i/k_{total}$
About 500m	51	102	2.00	38.7
About 1000m	72	88	1.223	23.6
About 2000m	61	73	1.197	23.2
About 3000m	24	18	0.7	14.5

Source: Gan, L.X.(2001). The effect of channel condition on ship navigation. Navigation of china.No2,P56

Through the above statistics, we can see that the smaller the radius of curvature, the greater likelihood of the accident. According to the regression analysis theory we can use the formula $K_R = a / R + b$, according to the least square method we can get regression coefficients a and b, then gets the relationship between the curvature of fairway and relative number of accidents: **(Gu,2009)**

$$K_R = 682 / R + 0.64 \qquad (5.1)$$

From the above analysis we can see, the larger the radius of curvature, the smaller the relative number of accidents, the greater the reliability of navigation. The results of the statistics have some impacts on a and b. Through the statistical data we can see, when the beam of the ship and the deep of the water are suitable, for large ships, the radius of curvature may not less than 300m, the number of relative accidents K_r should less than 3, then we can guarantee the reliability of navigation.

5.1.2 Width of fairway

When Ships travel in the narrow fairway, it is easy to occur shore push, shore absorption and wave loss. Then it will easily result in collision, shore touch, and other kinds of accidents. The encounter rate and collision rate of different sizes of vessels in the same width of fairway will be different. Usually we regard the ratio of ship width and channel width as an indicator of the degree of danger. According to statistical theory, analyze the statistical data, we can get the relationship between ship accidents and the width of the ship fairway, normally the width of fairway need three times greater than the width of the ship to ensure the reliability of the ship sailing.**(Gan,2001,P56)**

5.1.3 Depth of fairway

Ship's draft is closely related to the depth of fairway, it will directly determine whether the ship will ground, make the study of the relationship between channel depth and the ship's draft is an important topic to ensure navigation safety. Depending on the accident statistics of different ship draft sailing in different depths of water, we can know from the statistical data

In general, the ratio of the depth and draft which may influence the maneuverability of ship is $h / d \leq 2.5$, the obvious impact on the maneuverability of the ship is $h / d \leq 1.5$.

(Zhou& Zheng,2006,P54)

When the ship is sailing in the shallow areas or the areas near shore, we should pay particular attention to poor maneuvering performance and increasing dynamic draft, the likelihood of ship grounding will increase, in this time the ship should sail with the safe speed.

5.2 Marine traffic Environment

Waters areas which are 10 miles from offshore would easily cause the maritime accidents. One of the reasons is due to poor fairway conditions and the majority of shoals, reefs, wrecks, etc. which located in coastal areas, making it difficult in ship handling and cause accidents. Another important reason is that the density of vessel traffic in coastal water areas is heavy, and it causes the probability of ship collisions increasing. Ship track distribution, traffic volume and ship speed are important indicator of maritime traffic environment.

5.2.1 Vessel Density

Ships density refers to the number of vessels per unit area. It not only reflects the degree of vessel density in the water, but also reflects the degree of busy and degree of danger of the ship traffic in the water.**(Wu&Zhu,2004)** Allegedly, the numbers of ship collision accidents are quadratic of ship density. Control of the density of ships will help improve the efficiency of vessel traffic and reduce the risk of vessel traffic. At the same time, we must control the density distribution of the ships. The density of ships may be larger but with a reasonable distribution, then the vessel traffic in this area may neither blocked nor occurs accidents, on another hand, the density of the ships may not be large but the distribution is not quite good, then it might result in traffic jams or accidents.

5.2.2 Track Distribution

Vessel's track is the record of ship movement line. All the tracks in one water area show the characteristic form or traffic routes of marine traffic. The concept of track distribution is a little bit similar with the ship density distribution, the former is the line spatial distribution, and the latter is the point spatial distribution. The more ship tracks in per unit area of the water for a given period of time, the greater of the vessel density. Thus, the track distribution also reflects the degree of traffic congestion and the degree of risk in one water area.

Track distribution is also an important concept to express the actual condition of marine traffic. It is like the ship density distribution, is one of the basic elements of ship traffic. The study of the ship distribution is the basis for the establishment of traffic track flow model, it is also important for introduction of fixed-line system and the suitable use of the ship in this water area. Track distribution help people understand the general situation of the encounter of ship, such as place of encounter, the situation of encounter and the encounter rate, then it can also help people understand the degree of collision risk, and make evaluations of the safety of maritime navigation.

5.2.3 Traffic volume and the numbers of the ships which go in and out of the port

Traffic volume is an essential item to express a certain amount of traffic conditions in the water area. The size of the traffic volume directly reflects the scale of the traffic and its degree of business, and also reflects the degree of vessel traffic congestion and dangerousness

When studying the vessel traffic in the port, there is a similar concept with traffic volume, called the numbers of ships entering and leaving the port, and often makes a classification statistics according to the nationality of ships and the species of ship. This kind of data statistics generally involve in the ships which loading and discharging in the harbor, and does not fully reflect the actually traffic conditions in the port area, especially in the harbor where the fishing boats, construction vessels and other non-transport ships often working in. So the numbers of ships entering or leaving the port can not be the same as traffic volume

However, it is still a very important data that may have a great value in the investigation analysis

5.2.4 Speed of the ship

From the object of the studies of maritime traffic engineering, the so-called ship's speed does not mean a single ship's speed or maximum speed, but refers to the all the ship's speed distribution and the average speed in one water area. The average speed is one element of the ship traffic flow model, the purpose of research of ship's velocity distribution is to predict the probability of overtaking or encounter among the ships through the traffic flow model. Acknowledge the velocity distribution and the developing trend of the speed in a certain water area, we can reasonably determine standard of speed limits and traffic control design index, at the same time provide the situation for the analysis of accident causes and the effectiveness of traffic improvement measures. As we know, fast speed is an important reason of marine accidents. However, if we want to maintain and improve traffic efficiency, slow speed can not satisfy our requirement. Therefore, investigation of ship speed and analysis of speed control is a guarantee for the efficiency of the sailing and safety of navigation.

5.3 Meteorological sea condition

5.3.1 Visibility

The weathers which cause invisibility are fog, snow, rain and hail. Among above the fog may affect most. According to the statistics, the numbers of accidents K have an exponential relationship with visible distance D (km), the regression equation is$K = 90 \times D - 0.8$.**(Li&Zheng&Chen,2007,P342)**When visible distance is less than 4 km, there might be am impact on the safety of navigation; when the visible distance dropped to 1 km, the numbers of accidents increase sharply.

5.3.2Factor of wind

Effect of wind on the sailing ship has many related elements. When the wind is stronger, then the deflection and drift become larger. The direction of the ship

deflection under the wind was decided by the direction of Wind dynamic pressure transshipment moment M_a and hydrodynamic torque moment M_w . Ship's wind-caused drift is closely related to the speed, the lower the speed, the greater the drift and the speed of drift. To avoid the drift, must reserve wind pressure in advance. When designing the fairway, we should take full account of the impact of wind -induced drift amount.

5.3.3 Factor of wave

Impact of waves on ship navigation and manipulation include two aspects, one is swing moments due to change of waves, the other is the drift force on the ship by the wave, causing the ship sailed off route or fairway.**(Wu&Zhu,2004)** Waves also bring difficult to the direction of the vessel control, speed control and position control. When the ship hit the cross waves, it is easy to occur resonant motion, Ships sway exacerbated which make waves rush on the deck and directly endanger the safety of the ship, at this time we can adjust ship speed to change the wave encounters cycle, and avoid resonant motion. When the ship encountered the downstream waves, it is likely to appear stern flooding, instability direction of heading. Therefore, in order to maneuver the ship in the big storm, we should take measures to reduce the sway of the ship, and reduce the impact of the waves as much as possible to minimize the degree.

5.3.4 The impact of water flow

Water flow has some impacts on the ship maneuverability such as speed of vessel, stroke, and rudder efficiency. When the ship sailed down the river, the actual speed increases, ground stroke increases but the efficiency of the steer get worse. When the ship sail up to the river, the actual speed reduce, ground stroke decreases but the efficiency of the steer gets better. When the ships enter or leave the fairway in the port, they will generate the drift due to the effect of mixed flow. In the procedure of designing the fairway, we should take full account of flow-induced drift ΔB_W,

$$\Delta B_W = V_C \times T\sin\alpha,$$

Where: V_C means the speed of water flow (m/s); α is flowing pressure angle; T is the time of drift (s). **(Wu&Zhu,2004)**

Chapter 6

Using AHP method quantitatively analyze the factors affecting the safe navigation of the ship

Safety condition of ship sailing is influenced by many factors, and the various factors interacted with each other, which makes it difficult to make the quantify study for the system security impact by various factors. Due to the limited capacity of the research, only from the perspective of exploration, drawing previous research results, try to use analytic hierarchy process method quantitatively analyze the factors which affect the safety of navigation. Because I can not invite so many experts to discuss the judgment of matrix assignment, I can only through access a lot of literature and information about the AHP method, and with the help of my tutor to make the assignment study, and I also ask some captains, some officers from MSA, some seafarers and some professors and teachers in DMU, they all give me great help about the influence of all these factors. So the findings result may offer reference to some other correlation studies.

6.1 The basic principle of AHP method

AHP method (Analytical Hierarchy Process) is presented by the American scholar T.L.Saaty. His basic idea is to put a number of complex issues into orderly hierarchical level, and based on the judgment of objective phenomenon; make a relative importance representation for the high-level factors in respect of each hierarchical arrangement elements, which means construct a comparative judgment

matrix on each level. Then, according to the eigenvalue of maximum and eigenvectors, determine the order of weight of each factor's relative importance on each level, and finally, through the analysis of each level to obtain the total weight of the sort of the question.

(Deng&Huang,2011,P480-482)

The mathematical principle is, assuming a problem has n affecting factors, the degree of importance of each factor about the issue were$W_1, W_2, \ldots W_n$, constitute the weight vector

$$W = [W1,\ W2,\ \ldots Wn]^T \qquad (6.1)$$

Make pairwise comparison among factor W_i in vector$W$, then we can obtain the comparative judgment matrix$A$ for amount n factors

$$A= \begin{bmatrix} W_1/W_1 & W_1/W_2 & \ldots & W_1/W_n \\ W_2/W_1 & W_2/W_2 & \ldots & W_2/W_n \\ \ldots & \ldots & \ldots & \ldots \\ W_n/W_1 & W_n/W_2 & \ldots & W_n/W_n \end{bmatrix} = \{a_{ij}\} \qquad (6.2)$$

Obviously,$a_{ii} = 1,\ a_{ij} = \frac{1}{a_{ji}}$, $a_{ij} = a_{ij} \times a_{ki}$, i,j=1，2，3，…n and also

$$AW= \begin{bmatrix} W_1/W_1 & W_1/W_2 & \ldots & W_1/W_n \\ W_2/W_1 & W_2/W_2 & \ldots & W_2/W_n \\ \ldots & \ldots & \ldots & \ldots \\ W_n/W_1 & W_n/W_2 & \ldots & W_n/W_n \end{bmatrix} \begin{bmatrix} W_1 \\ W_2 \\ \ldots \\ W_n \end{bmatrix} =nW \qquad (6.3)$$

From (formula 6.3) we can see, n is an Eigenvalue of the comparative judgment matrix$A$, vector W is an eigenvectors from which A corresponding to the n.

For most cases, we do not know each factor of the vector$W$, but requires taking the values of all factors. Therefore, this boils down to the question whether we can take

W if A satisfy to certain conditions, under the conditions of A with complete consistency, through solving the eigenvalue λ_{max}

$$\lambda_{max} W = AW \qquad (6.4)$$

So we can get very factors' degree of importance in amount n factors.

Judgment matrix A usually comes from checking information or some relevant experts, then we can obtain subjective evaluation for the ratio of the degree of importance for each two factors. Whether A is consistency, it is determined byA's maximum eigenvalue λ_{max}, general

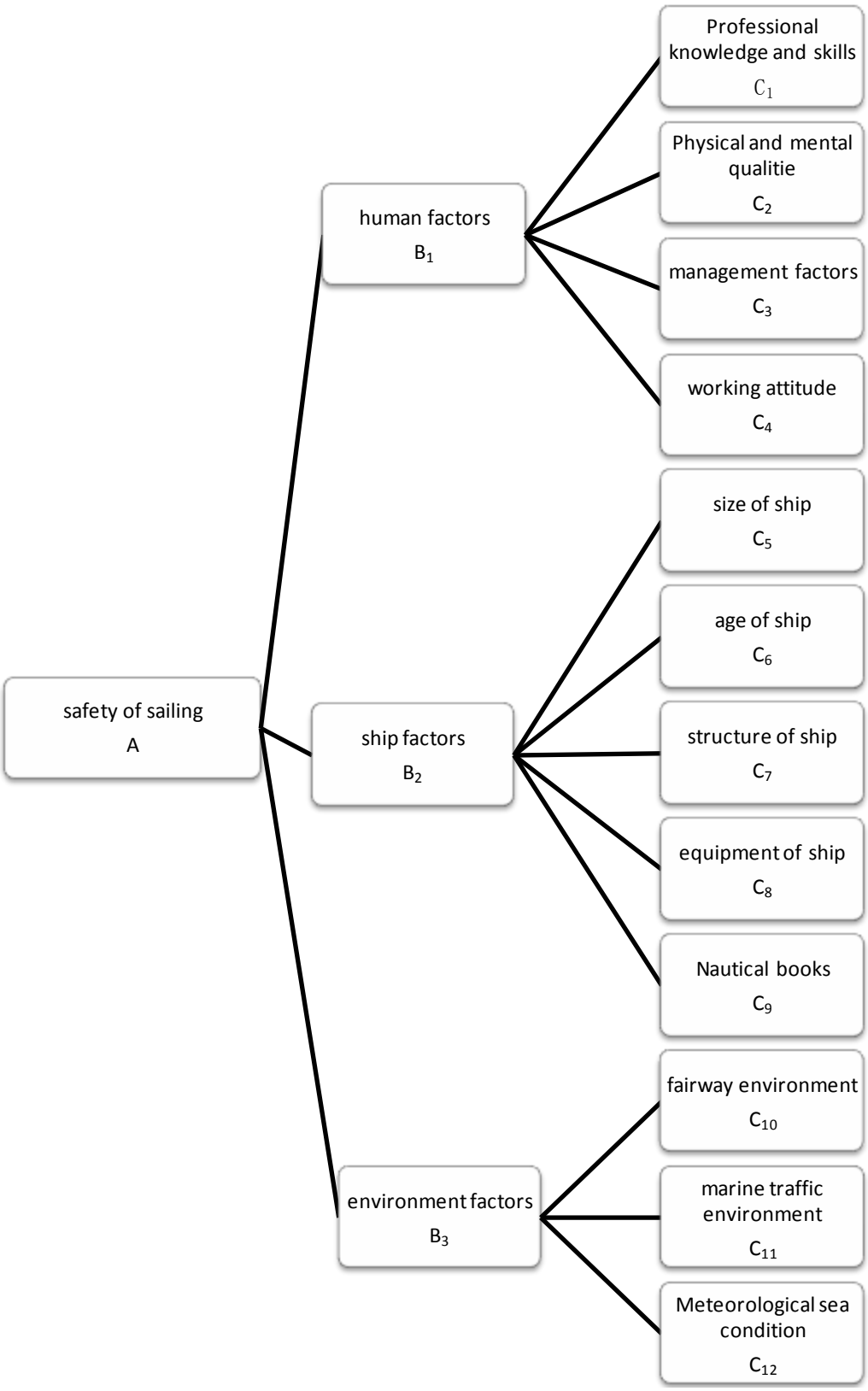
λ_{max} Need greater or equal to n

$$\lambda_{max} \geq n \qquad (6.5)$$

When$\lambda_{max} = n$, and other eigenvalues are zero, then A has a complete consistency; when λ_{max} is greater than n and other eigenvalues are closed to zero, then A has a satisfied consistency. The AHP method only can apply under the condition of A has complete consistency or satisfied consistency.**(Xu,1988)**

6.2 Using AHP method to analyze various factors affecting the safe navigation of ships

6.2.1 Establish a hierarchy structure



High level middle level low level

Figure 4 -hierarchy structures of factors affecting safety of sailing

Source: The Author

6.2.2 Construct judgment matrix at all levels

Structural principles

The first step of construct judgment matrix is to list the accumulation portfolio, so called accumulation portfolio simply means a combination of associated factors both in the former level and the next level. Like figure 4, system running A's accumulation portfolioR| running factor isR| Run factor $=\{B_1, B_2, B_3, B_4\}$. The second step is the assignment structure matrix, shown in Table 5, vertical and horizontal bar items are gathering tables are low level objectives factors in the accumulation portfolio; left upon corner is the target factor of high level; C_{ij} is the ratio of degree of importance of C_i and C_j for the target factors B_i, usually take 1, 2 ... 9, and its reciprocal, such as 1/2, ... 1/9. The meaning of these figures is relative to the same objective factor B_k.

Table 5- form of judgment matrix

B_i	C_1	C_2	⋯	C_n
C_1	C_{11}	C_{12}	⋯	C_{1n}
C_2	C_{21}	C_{22}	⋯	C_{2n}
⋮	⋮	⋮	⋮	
C_n	C_{n1}	C_{n2}	⋯	C_{nn}

Source: The Author

When C_i is same important as C_j, C_{ij} is 1

When C_i is little more important than C_j, C_{ij} is 3

When C_i is more important than C_j , C_{ij} is 5

When C_i is much more important than C_j, C_{ij} is 7

When C_i is extremely more important than C_j, C_{ij} is 9

Construct judgment matrix

According to the above principle, construct four judgment matrixes with objective factors: A, B_1, B_2, B_3 respectively

Table 6- judgment matrix with objective factor A

A	B_1	B_2	B_3
B_1	1	3	5
B_2	1/3	1	3
B_3	1/5	1/3	1

Source: The Author

Table 7- judgment matrix with objective factor B_1

B_1	C_1	C_2	C_3	C_4
C_1	1	5	5	3
C_2	1/5	1	1	1/3
C_3	1/5	1	1	1/3
C_4	1/3	3	3	1

Source: The Author

Table 8- judgment matrix with objective factor B_2

B_2	C_5	C_6	C_7	C_8	C_9
C_5	1	1/3	1/5	1/5	3
C_6	3	1	1/3	1/3	5
C_7	7	1/3	1	1	7
C_8	7	1/3	1	1	7
C_9	1/3	1/5	1/7	1/7	1

Source: The Author

Table 9- judgment matrix with objective factor B_3

B_3	C_{10}	C_{11}	C_{12}
C_{10}	1	1/3	1/5
C_{11}	3	1	1/3
C_{12}	5	3	1

Source: The Author

6.2.3 Consistency test to strike weight vector, maximum eigenvalue and judgment matrix

Strike weight vector and maximum eigenvalue:

Because it is complexity and not necessary for accurate calculation, we use the simple calculation, the idea to simplify the calculation: consistent array of any vectors are all feature vectors, positive and negative anti-column array vector with good consistency should approximate to eigenvectors, and get average result under some sense.

When using the simplified calculation to strike the weight vector and the maximum eigenvalue, we can first normalized the column vector in judgment matrixA, then sum the row and then again normalize, then we can strike the weight vector W, so that obtained AW, and then using formula:

$$\lambda_{max} = \frac{1}{n} \sum_{i-1}^{n} \frac{(AW)_i}{Wi} \qquad (6.6)$$

Get approximation maximum eigenvalue λ_{max}

Now strike weight vector and the maximum eigenvalue from judgment matrix A

$$A = \begin{bmatrix} 1 & 3 & 5 \\ \frac{1}{3} & 1 & 3 \\ \frac{1}{5} & \frac{1}{3} & 1 \end{bmatrix} \xrightarrow{\text{Normalize the column vector}} \begin{bmatrix} 0.652 & 0.692 & 0.556 \\ 0.217 & 0.231 & 0.333 \\ 0.131 & 0.077 & 0.111 \end{bmatrix} \xrightarrow{\text{Sum the row, and again normalize}}$$

$$\begin{bmatrix} 0.634 \\ 0.260 \\ 0.106 \end{bmatrix} = \text{W（weight vector）use（6.3）getAW} \qquad \begin{bmatrix} 1.944 \\ 0.789 \\ 0.319 \end{bmatrix} = AW$$

According to (formula 6.6) we can get λ

λ=1/3(1.944/0.634+..789/0.260+0.319/0.106)=3.037

So, the approximate weight vector of matrix A is $W_A = \{ 0.634 \ \ 0.260 \ \ 0.106 \ \}^T$

The approximate maximum eigenvalue $\lambda_{A.max} = 3.037$

Similarly,

We can obtain approximate weight vector of matrix B_1 $W_{B_1} = \{ 0.618 \ \ 0.084 \ \ 0.0940.214 \}^T$

The approximate maximum eigenvalue of matrix B_1 $\lambda_{B1.max} = 4.090$

The approximate weight vector of matrix B_2 $W_{B_2} = \{ 0.091 \ \ 0.308 \ \ 0.289 \ \ 0.265 \ 0.047\}^T$

The Approximate maximum eigenvalue of matrix B_2 $\lambda_{B2.max} = 5.19$

The Approximate weight vector of matrix B_3 $W_{B3} = \{ 0.106 \ \ 0.261 \ \ 0.633\}^T$

The Approximate maximum eigenvalue of matrix B_3 $\lambda_{B3.max} = 3.040$

Consistency testing:

Due to the complexity of objective things, diversity awareness and possible one-sidedness, the judgment matrix may not be exactly the same or satisfied, and

therefore we need to do the consistency test. If the relationships between the various factors in the judgment matrix keep as following:

$$C_{ij} = C_{ik} / C_{jk} \ (i, j, k = 1,2, \ldots n) \quad (6.7)$$

Then we can see the judgment matrix has complete consistency. The general method to test consistency of judgment matrix is to use a random proportion consistency of judgment matrix CR when

$$CR < 0.10 \quad (6.8)$$

We can consider judgment matrix with satisfactory consistency, the judgment matrix can be used to make analytic hierarchy, otherwise we should do a relative importance of re-evaluation, then reassign C_{ij} until the judgment matrix has satisfactory consistency. For the first, second step judgment matrix, need not be tested because they are always exactly the same.

When the judgment matrix is greater than the second step, CR is the ratio of consistency index of judgment matrix CI and same step of average random consistency indexRI, which is:

$$CR = CI/RI \quad (6.9)$$

and

$$CI = (\lambda_{max} - n) / (n - 1) \quad (6.10)$$

We can check the 1- 10 steps' judgment consistency index RI in (table10)

Table 10- 1-10steps average consistency index（RI）

matrix steps	1	2	3	4	5	6	7	8	9	10
RI	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

Source: Hong, Z.G & Li, Y. & Fan, Z.H.(2002). Calculation on high-ranked RI of analytic hierarchy process. Computer engineering and application. Retrieved May 26, 2014 from the World Wide Web: http://www.docin.com/p-714429175.html

Therefore, we can check the judgment matrix A、B_1、B_2、B_3 according to the formular6.9,6.10 and table 6.6.

For the consistency check of judgment matrix A, we can know that A is three steps judgment matrix, therefore, we get $n = 3$, $CI = (\lambda_{A.max} - 3)/2$, $\lambda_{A.max}$ is calculated above, $\lambda_{A.max} = 3.037$, so, $CI_A = 0.0185$, check the table we can get $RI_A = 0.90$, therefore:

$$CR_A = CI_A / RI_A = 0.021 < 0.1$$

So, judgment matrix A passes the consistency text

With the same principle

We can get $CR_{B1} = 0.033 < 0.1$, judgment matrix B_1 pass the consistency text

$CR_{B2} = 0.042 < 0.1$, judgment matrix B_2 pass the consistency text

$CR_{B3} = 0.034 < 0.1$, judgment matrix B_3 pass the consistency text

6.2.4 Total Sort of the level:

Single sort of the level:

Before the total sort of the level we need single sort of the level, the single-sort of level is to calculate maximum eigenvalue λ_{max} and the weight vector W in accumulation portfolio's judgment matrix, therefore the weight of i

$$w_i = \frac{\sqrt{Mi}}{\sum_{j=1}^{n} \sqrt{Mj}}, \quad i=1,2, \ldots n \qquad (6.11)$$

Among it

$$Mi = \prod_{j=1}^{n} a_{ij}, \quad i,j=1,2,\ldots n \qquad (6.12)$$

From the above two formulas we can get the weight of the middle level, which means the weight of level B $w_A = \{0.7548 \ 0.1949 \ 0.0503\}$

Using the same principle, get the weight of lowest level C:

B_1's nest level factor weight is $W_{B_1} = \{0.7336 \ \ 0.0306 \ \ 0.0306 \ \ 0.2052\}$

B_2's nest level factor weight is $W_{B_2} = \{0.0826 \ \ 0.1025 \ \ 0.3904 \ \ 0.3904 \ 0.0341\}$

B_3's nest level factor weight is $W_{B_3} = \{0.0503 \ \ 0.1949 \ \ 0.7548\}$

Total sort of the level:

After obtain the results of all single sorts at the same level, and then we can further calculate the degree of importance of the weight for all the factors in this level to the above level, so that we can obtain the total sort of level. The total sort of level should come from the high-level to low-level gradually.

Assumed that all factors A_1, A_2 ... A_m's total sort of level of the above level A has been determined, the weight of each factor were a_1, a_2 ... a_m, with the weight of a_i factors A_i corresponding to the next level of factor B B_1, B_2 ... B_n 's single sort of level is

$$[b_1^i, \ b_2^i, \ \ldots b_n^i] \quad (6.13)$$

Total sort of level B is

$$\sum_{i=1}^{m} a_i \, b_j^i \quad (6.14)$$

Therefore, we can get the total sort of level table according to the single sort of level (Table 11)

Table 11- Total sorts of factors affecting safe sailing of ship

Level B / Level C	**B_1** 0.7548	**B_2** 0.1949	**B_3** 0.0503	C level Weight of total sort
C1	0.7336	0	0	0.5537
C2	0.0306	0	0	0.0231
C3	0.0306	0	0	0.0231

C4	0.2052	0	0	0.1579
C_5	0	0.0826	0	0.0161
C_6	0	0.1025	0	0.0209
C_7	0	0.3904	0	0.0761
C_8	0	0.3904	0	0.0761
C_9	0	0.0341	0	0.0087
C_{10}	0	0	0.0503	0.0045
C_{11}	0	0	0.1949	0.0098
C_{12}	0	0	0.7548	0.0380

Remark: If B_j has no relationship withA_i, thenb_{ij} is 0。

Source: The Author

6.2.5 Total sort consistency text

The consistency index of total sort of level is

$$CR = CI/RI$$

Among it $$CI = \sum_{i=1}^{m} a_i \, CI_i \qquad (6.15)$$

CI_i is the consistency index of judgment matrix in level B corresponding to a_i

$$RI = \sum_{i=1}^{m} a_i \, RI_i \qquad (6.16)$$

RI_i is the random consistency index of judgment matrix in level B corresponding to a_i

According to the above formula, we can get

$$CI = 0.0183,\ RI = 0.8957$$

$$CR = 0.0204 < 0.1$$

So through the consistency test of total sort, the data in Table 6.7 is valid.

According to Table 6.7 we can get the sort of the degree of importance about the factors in C-level, descending orders are

$C_1 > C_4 > C_7 = C_8 > C_{12} > C_2 = C_3 > C_6 > C_5 > C_{11} > C_9 > C_{10}$, which means:

The factors which affect the safety of navigation sort from high degree to low degree according to the degree of their importance:

Professional knowledge and skills > working attitude> structure of ship= equipment of ship> Meteorological sea condition > physical and mental quality= management factors > Age of ship> size of ship> marine traffic environment> Nautical books> fairway environment.

6.3 Suggestions to safeguard safety of navigation

Based on analysis of factors affecting the safety of navigation, we proposed some recommendations to protect the safety of navigation as follows:

1. Strengthen the quality of the crew, improve the management system

Human factor is the focus of preventing the current marine accident in the safety of navigation, so we need to strengthen all aspects of prevention, strengthen physical and mental qualities through crew training, and improve management system. First, in the selection of drivers, we should pay attention to psychological factors of candidates. Crew companies should know very well about the psychological factors of their crew. So to a certain extent we can reduce the errors caused by psychological factors. Second, we should reduce the impact of fatigue on driving, establish a reasonable rhythm of work and live, let the crew have adequate rest and sleep, rich leisure life of the crew, strengthen labor time management and improve operational efficiency of ships in order to reduce marine accidents. Third, reduce errors due to the skill factors by drivers. Establish crew training, certification and tracking management mechanisms, strengthen the safety management system audit, strengthen training management, improve the quality of training, and strengthen the requirement of examination and assessment of certification, focusing on the update of their knowledge and requirement of qualifications, so as to improve competency skills of the crew. Also we need to improve the management capacity of head officers. People who engage in ship management not only need to have rich practical experience, but also need to acknowledge the theory of modern international

shipping management, which have good overall quality.

2. Pay attention to the maintenance of ship hull and ship safety inspection, ensure the seaworthiness

Ship owners and ship managers should pay attention to the maintenance of the ship hull and ship equipments, do the inspection and maintenance regularly, and update nautical books and related equipment to enable the ship with a good working condition. Maritime authorities should improve the security inspection of the ship, if the ships do not comply with seaworthiness standards, appropriate measures should be taken to reach certain standards to ensure the ship is seaworthy all the time, and avoid the accidents due to the hull or ship equipment problems.

3. Improve navigation environment

Government should increase investment in safety of maritime navigation, maritime authorities should organize relevant departments and shipping companies' safety management department, seriously make a specialized research of China's coastal navigation environment, complex trade area and response measures. Fully play the role of supervision functions of government department, and strengthen the supervision of ship reporting system, strengthen the guidance of safety of navigation. In China's coastal areas, especially complex navigation area and area which may easily cause accidents establish and improve maritime traffic separation schemes and VTS traffic supervision and guidance functions, timely release information of density of ship traffic area, fishing density, meteorological sea condition and traffic separation schemes, timely inform the suspected ship which have collision risk. So that we can reduce the collision accidents and the casualties, marine pollution incidents, hence ensure safety of navigation.

Conclusion

There are mainly three aspects affecting the safety of navigation: human factors, shipping factors and environmental factors, we can see that all of them are very important for the navigation, we can not ignore any of them, but there still exist the sequence of importance, after using the AHP method, we can find from the result that the human factors are on the top of the list, then is the shipping factors, and last is the environmental factors, and it is basically similar with the suggestion from the people who I ask, and it is also quite fitful for the fact which human factors may be the main causing of the accidents, and with the rapid development of the shipping technology, shipping factors become less and less important.

So, if we want to improve the safety of the navigation, human factors are the key aspect that we should concentrate on.

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