8-26-2018

Formal safety assessment on inland self-unload carriers in the Pearl River Delta

Weijun Zhang

WORLD MARITIME UNIVERSITY

Dalian, China

FORMAL SAFETY ASSESSMENT ON INLAND SELF-UNLOAD CARRIERS IN THE PEARL RIVER DELTA

By

ZHANG WEI-JUN

China

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

MASTER OF SCIENCE

(Maritime Safety and Environment Management)

2018

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): Zhang Wei-Jun

(Date): June 29, 2018

ACKNOWLEDGEMENTS

I am grateful to Dalian Maritime University, World Maritime University and China MSA for offering me the opportunity to study in this program. My gratitude also goes to all the teachers from WMU and DMU for their hard-working teaching, especially to Professor Skjong for his teaching knowledge about the methodology of formal safety assessment which is so useful in my job. This research paper stems from the idea of applying FSA to my daily work.

Thank my supervisor Professor Xie Hong-Bin, Deputy Dean of Navigation College of DMU, for giving me so many useful suggestions in writing this research paper. When I wanted to give up my idea for the difficulty of collecting and arranging data, he encouraged me to overcome obstacles and do some research useful in daily work rather than just cope with the task of dissertation. His strict research attitude and spirit of hard work will benefit me a lot in the future of my life.

Thank all my colleagues in China MSA. My leaving for study leaves them additional burden of work. Moreover, I cannot finish this research paper without their help of collecting data.

Finally, I want to give my thanks to my parents, parents-in-law and my dear wife. They encouraged me to join this program and offered their full support in the period of study. They never blamed my long absence from family for studying in Dalian.

ABSTRACT

Title of Research Paper: **Formal Safety Assessment on Inland Self-unload Carriers in the Pearl River Delta**

Degree: **MSc**

The research paper is a study on the application of FSA methodology to inland self-unload carriers in the Pearl River Delta (PRD).

Both quantity and tonnage of inland self-unload carriers in the PRD have increased in the last decade. It is significant to analyze the risk of inland self-unload carrier since it has become a typical ship type in the PRD. FSA has been proved to be a structured, systematic and useful methodology in evaluating and reducing risks in marine industry. The risk of research object is analyzed under the framework of FSA.

Hazards of inland self-unload carriers are identified, ranked and analyzed via data analysis, risk matrix, event tree analysis (ETA) and fault tree analysis (FTA). After verifying risks' being in As Low As Reasonable Practical (ALARP) area, several risk control options (RCOs) are put forward. Cost-effectiveness analysis (ECA) of one of the RCOs is conducted and NCAF of the RCO is calculated. Suggestions are given based on the Acceptable NCAF ($NCAF_A$). Direction of further research is recommended.

KEY WORDS: FSA, Inland Self-unload Carrier, Pearl River Delta, ALARP, NCAF.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

ARPA	Automatic Radar Plotting Aids
CEA	Cost-Effectiveness Analysis
DWT	Deadweight Tonnage
PRD	Pearl River Delta
ETA	Event Tree Analysis
FSA	Formal Safety Assessment
FSC	Flag State Control
FTA	Fault Tree Analysis
GCAF	Gross Cost of Averting a Fatality
GT	Gross Tonnage
HAZID	Hazard Identification
IACS	International Association of Classification Society
ICFTU	International Confederation of Free Trade Union
IMO	International Maritime Organization
NCAF	Net Cost of Averting a Fatality
$NCAF_A$	Acceptable Net Cost of Averting a Fatality
PLL	Potential Loss of Life
QRA	Quantitative Risk Assessment
RCM	Risk Control Measure
RCO	Risk Control Option

1. INTRODUCTION

1.1 Research Background

The fast development of real estate industry in China generates heavy demand of river sand. The demand is even bigger in the PRD since it is one of the three biggest economical circles in China. Inland self-unload carriers are designed to transport sand, broken stones and other bulk building materials. There are more and more inland self-unload carriers operated in the PRD for their high efficiency of unloading without reliance on unloading device from port terminals. It is a relatively new type of bulk carrier, so the regulation is not as mature as other normal cargo ships in the PRD, resulting in higher frequency of accidents. According to statistics, there are 408 accidents which happened in the PRD from 2006 to 2015. Accidents involving inland self-unload carriers account for about one fourth of all accidents while the rate of inland self-unload carriers to all ships operated in the PRD is far less than one fourth from the perspective of both quantity and tonnage. In certain scenarios like ships' colliding small boats, the risk of inland self-unload carriers is even higher than other ships. Surveyors, FSC (Flag State Control) officers, investigators gave many suggestions on how to improve safety level, but none of them did systematic and structed analysis to the overall risk.

FSA is a systematic and structured methodology adopted by International Maritime Organization (IMO) in evaluating regulations on maritime safety and marine environmental protection via risk analysis and cost-benefit assessment (IMO, 2013). In recent decades, there are so many successful applications of FSA in marine industry and other industries, proving the availability of FSA in evaluating risk and making regulations. The application of FSA to inland self-unload carriers in the PRD is significant in understanding the overall risk and instructive for decision-making.

1.2 Literature Review

Relevant literatures were widely reviewed beforehand. Pu illustrated the widely existed overload and free liquid surface after loading, leading to decreased stability (Pu & Xia, 2002). Accumulated water in the cargo hold area is unavoidable because of the loading method of self-unload carriers. The process of loading is not operated in a wharf but in the waterway. Sand dredges transfer wetted sand to self-unload carriers directly. The content of water varies from 10% to 20% and water needs time to exude from sand. Even seafarers pump out water in and after the process of loading, still there will be some accumulated water exuding from wetted sand. Pu recommended a method to calculate the effect of free liquid surface on stability. Though the risk control measure on free liquid surface has been adopted in 2004, hazards due to the loading method are not just free liquid surface. Some seafarers are accustomed to sailing before water is pumped out completely enough, resulting in overloaded voyage, which is far more risky than free liquid surface according to the casualty statistics. Still the method of supervising overload is selective check which is inefficient. This paper brings forward a more intelligent option to supervise overload of inland self-unload carriers in the following text.

Chen figured out the poor quality of inland seafarers and the loose management of inland shipping company in the PRD, coming up with some administrative suggestions (Chen & Wang, 2008). Unlike ocean-going seafarers, the highest diploma of most of Chinese inland seafarers including captains and chief engineers is lower than senior middle school. In China, individualized ship operation without establishing a company is illegal. However, there are so many individual shipowners owning only one ship which the shipowner also works on. It is uneconomical for each of them to establish a company, so they join a company and pay a little money. Many inland shipping companies just have notional ownership of these ships for the convenience of individual shipowners' joining companies, without actual control of ships.

Hu pointed out the poor radar operational skill of inland seafarers in China and advised the administration to enhance training of how to use radar (Hu, 2008). English instruction of imported radar is an obstacle for inland seafarers' understanding of some functions. Cao recommended the introduction of ARPA to inland ships (Cao, 2001).

Wang recommended a telescopic conveyor belt to reduce the extension of conveyor belt, improving maneuverability and visual range, (Wang & Zheng & Chen, 2013). Inland self-unload carriers have a conveyor belt extended out of the bow for unloading of cargo. The extension increases the maximum length of the carrier, weakening maneuverability like turning and visual range. Telescopic conveyor which has been widely used on new inland self-unload carriers after 2015, can take the conveyor belt back to a certain extent after unloading.

Kuang identified three common hazards which influence stability of inland self-unload carrier: free liquid surface, overload and improper loading (Kuang & Huang & Xie, 2010). Improper loading including unbalanced loading and over-high loading, decreases both stability and visual range. Many inland seafarers do not pay enough attention to the harm of improper loading. Unbalanced loading contributes to initial heel or excessive trim. Over-high loading raises the gravity center of cargo, leading to poor stability as well as excessive blind area.

Li advised designers to consider changing the shape of transverse section from V-shape to W-shape, lowering the gravity center of cargo, increasing the capacity of cargo hold (Li, 2011). Li made both qualitative analysis and quantitative analysis on the advantages of W-shape cargo hold.

Zhou demonstrated the sensitivity of stability to the amount of overload through a case study (Zhou, 2011). The stability of the chosen self-unload carrier decreased sharply as the draft went beyond the load line due to the V-shape cargo hold.

However, all these researchers just focused on certain problems of inland self-unload carriers rather than the overall risk. So there is a gap in researching the overall risk of inland self-unload carriers and the cost-effectiveness of risk control measures. A comprehensive analysis on the risk of inland self-unload carriers under the framework of FSA is meaningful in filling the gap.

1.3 Scope

This study limits to inland self-unload carriers of and above 300 GT in the PRD.
Nearly 90% researches including all studies in literature review are about inland self-unload carriers in the PRD since inland self-unload carriers in the PRD is more common than other areas. Besides, it is more easy for the author to collect data since the author works in Guangdong MSA governing the PRD.
Most of inland self-unload carriers below 300 GT in the PRD are very old ships about to be scrapped. Considering that such small inland self-unload carriers have gradually lost their market under the tendency of large dimension, considering that most of them stopped operation in the last ten years, inland self-unload carriers below 300 GT are excluded from the research scope.

1.4 Data sources

The lack of national database of marine industry increases the difficulty of applying FSA to domestic ships in China. Data about historical casualties is arranged from accidents reports one by one by the author. Though the author collects and arranges investigation reports as complete as possible in these three months, still there may be omission for lack of database in China. Cost-effectiveness of a RCO tends to be conservative in this study since adding omitted accidents into the calculation just makes it more cost-effective.

1.5 Assumptions

This study assumes that risk acquired from historical accidents data is equal to the risk at the present stage. The modification of historical data is omitted in this study. All hazards occurred in the past are assumed to be the whole risk of research object.

Number of inland self-unload carriers registered in Guangdong Province is easier to get than all inland self-unload carriers operated in the PRD. Actually, nearly all inland self-unload carriers of and above 1000 GT registered in Guangdong Province are operated in the PRD. As to inland self-unload carriers from 300 to 1000 GT, some of them may be operated in the east of Guangdong. Anyway, this study assumes that all of them sail in the PRD to get a higher NCAF in CEA. Correspondingly, the author excludes accidents of self-unload carriers registered outside Guangdong Province in statistics.

1.6 Announcement

The author identified one hazard – self-unload carriers' colliding small boats and put forwarded one RCO for inland self-unload carriers of and above 1000 gross tonnage (GT) in an unpublished assignment (Author, 2018). RCO 1 in this paper is just the same idea except that this research paper makes the scenario affected by the RCO more reasonable. The threshold of small boats is 30 GT in this study while it is 120 GT in the assignment. Two accidents involving multiple accidents are excluded because of the modification of the scenario. Besides, several newly collected accidents are added into analysis.

The cost of the RCO is higher in this study for using a more expensive product with larger visual range in CEA. The average risk reduction estimated by experts is less than the value assumed in the assignment. So NCAF of the RCO is higher than the value in the assignment.

The value of acceptable NCAF in this study is also more reasonable after comprehensive consideration of vacation, education and retirement in China.

1.7 Structure of Dissertation

This dissertation consists of six chapters. Chapter 1 introduces the research background, scope, assumptions and significance of this research. Chapter 2 presents the development, framework and techniques of FSA and choice of techniques in this research paper. Chapter 3 discloses information about the network of waterway in the PRD, characteristics of inland self-unload carriers in the PRD, recently introduced risk control measures and the calculation of acceptable NCAF in China. Chapter 4 is data analysis of historical accidents. Chapter 5 applies FSA to research object. Finally, Chapter 6 obtains summaries and conclusions.

2. METHODOLOGY OF FSA

This chapter demonstrates the development, framework and techniques of FSA. Five steps of FSA are presented. Brief principles on choosing models are illustrated.

2.1 Development of FSA

Methodology similar to FSA has been applied in the industry of off-shore platform for a longer time. As long ago as 1970s, UK and Norway started to develop Quantitative Risk Assessment (QRA) for off-shore industry in the North Sea (Brandsæter, 2002). In 1988, 167 fatalities died in the casualty of Piper Alpha and then experts introduced various models for risk analysis from other industries, summarizing a regulation about safety assessment which is very similar to FSA methodology. In 1993, IMO accepted the concept of FSA in a proposal submitted by UK. In 1997, IMO enacted Interim Guidelines for the application of Formal Safety Assessment. In 2001, IMO passed the formal guidelines, providing a systematic method for decision-making. The latest Guidelines for FSA was enacted in 2013 (IMO, 2013).

Member states and classification societies from IACS submitted many standard reports about applications of FSA to IMO in recent years, providing guidance for IMO's making rules, proving the effectiveness of FSA in marine industry. There were so many successful applications of FSA that China Classification Society (CCS), the only recognized organization of the administration in China, started to pay more attention to the usage of FSA in making and modifying rules of ocean-going ships as well as domestic ships including inland self-unload carriers. In 2015, CCS published Guidelines of Applications of FSA to Ships, which was an interpretation to the latest Guidelines for FSA enacted by IMO, facilitating the understanding of FSA (CCS, 2015).

2.2 Framework of FSA

Figure 2.1 shows the framework of FSA. For a complete application of formal safety assessment, there are five steps: Step 1 - Identifying as many hazards with related accident scenarios as possible and ranking them according to frequency and severity; Step 2 - Analyzing factors and event sequences of casualties as well as assessing the level of risk; Step 3 - Proposing RCOs to reduce risks; Step 4 - Calculating cost, benefit, GCAF, NCAF and other values of RCOs; Step 5 – Giving recommendations for decision-making.

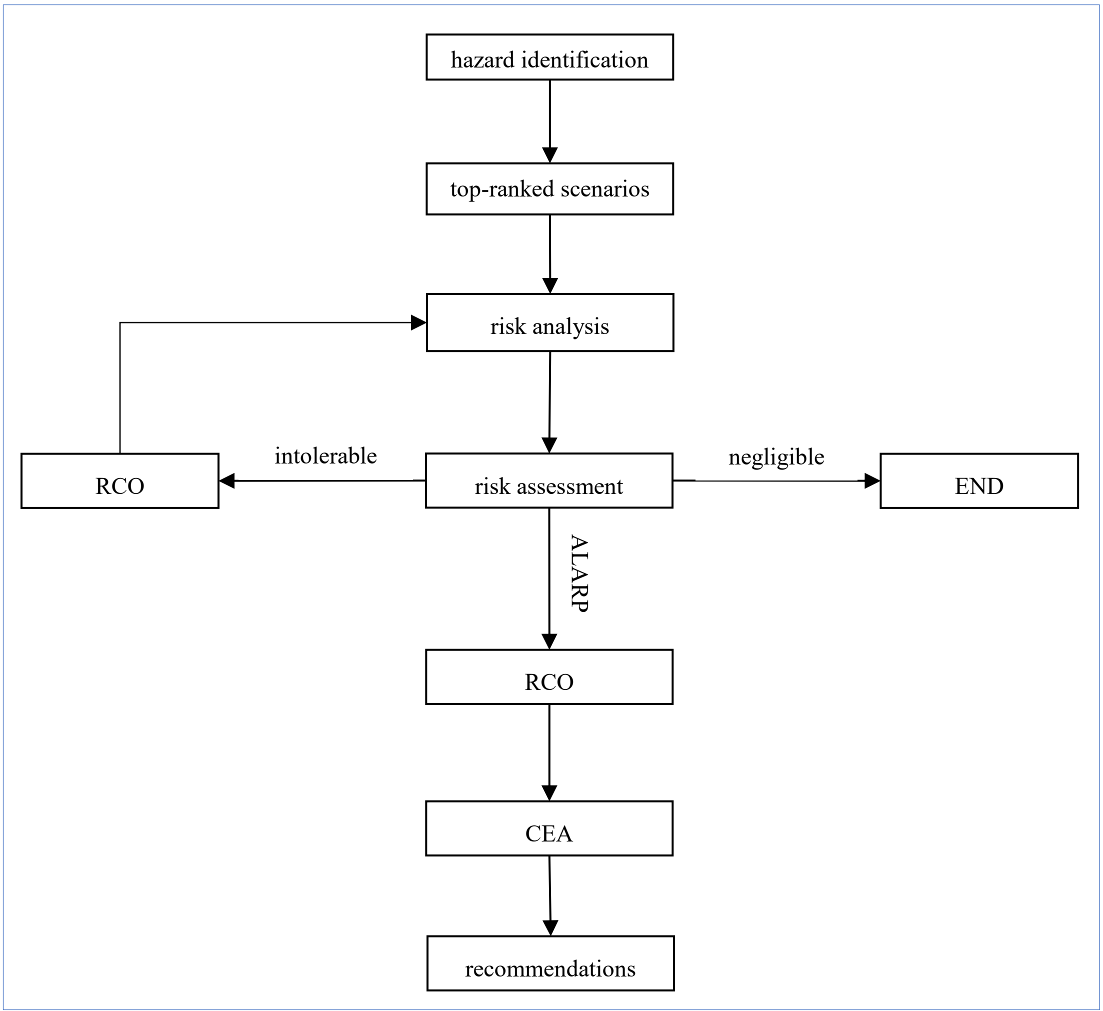

Figure 2.1 – Methodology of FSA
Sources: Author.

2.3 Techniques Used in FSA

For hazard identification and risk analysis, IMO recommends 9 techniques in the latest guidelines in 2013: Fault Tree Analysis (FTA), Event Tree Analysis (ETA), Failure Mode and Effect Analysis (FMEA), Hazard and Operability Studies (HAZOP), What If Analysis Technique (WIAT), Risk Contribution Tree (RCT), Influence Diagram and Bayesian Network (IMO, 2013). Besides, there are various models widely used in hazard identification and risk analysis as long as they are effective. Statistical method is also a good tool for hazard identification and analysis.

Risk matrix model is critical in determining the priorities of hazards in Step 1. Finding the most risky hazards is important since it is unnecessary to analyze all hazards. All identified hazards are ranked based on their frequency and severity, and then researchers choose several main hazards with high risk to analyze in detail.

It is obvious that there is no absolute safety. All industries cannot mitigate all risks. So IMO recommended acceptable criteria on both individual risk and social risk in the latest guidelines. Social risk typically expressed as FN-diagrams or Potential Loss of Life (PLL), is more important than individual risk. Intolerable risk shall be reduced regardless of cost while negligible risk can be ignored. Most risk are located in the ALARP area where a RCO shall not be implemented unless the RCO is cost-effective. Also, Delphi method, Heinrich method, NSC-Simonds method, Symonds method, Ratio coefficient method are widely used. This research paper chooses Delphi method for determining the risk reduction and ratio coefficient method in calculating indirect property loss.

There are many recommended options, but it is unnecessary to use all of them in one report. Table 2.1 shows the applicability of methods for hazard identification, risk assessment and risk analysis (CCS, 2015). CCS just listed techniques used in Step 1 and Step 2. Actually some techniques in the table can also be applied in Step 4.

Table 2.1 - Applicability of techniques

Techniques	Hazard Identification	Risk Analysis			Risk Assessment
		Consequence	Possibility	Risk Ranking	
Brain Storm	A	B	B	B	B
Delphi	A	B	B	B	B
Checklist	A	N	N	N	N
PHA	A	N	N	N	N
FEMA	A	N	N	N	N
HAZOP	A	A	N	N	A
What If	A	A	A	A	A
Risk Matrix	A	A	A	A	B
HRA	A	A	A	A	B
FTA	N	B	B	B	B
ETA	N	A	A	B	N
FN-diagram	B	A	A	B	A
Bayesian	N	N	N	N	A

Note: A – very applicable; B – applicable; N – not applicable.

Sources: China Classification Society, (2015). *Guidelines for the Application of Formal Safety Assessment in Ships.* Peking: Author.

2.4 Techniques Chosen in this Research

Table 2.2 presents the techniques chosen in this research. Organizing a meeting of experts is inoperable for a student studying in university. Delphi is easier to operate since the author can consult the experts one by one by email or other electronic means. Most of experts consulted are investigators and surveyors from Guangdong MSA and 3 experienced navigators on the inland self-unload carriers in the PRD. Besides, their opinions are essential in identifying hazards and deciding risk reduction of RCOs. Preliminary Hazard Analysis (PHA) is much easier to operate for a student. PHA is suitable for brief analysis. Though the paper identifies as many hazards as possible, only several main hazards with high risk are further analyzed. Nearly all experts in Guangdong MSA advise me to focus on the top-ranked hazards rather than comprehensiveness of hazard identification. So PHA is enough for hazard identification in this research.

Table 2.2 – Techniques used in this paper

Step 1 - Hazards Identification		Step 2 - Risk Analysis		Step 4 - CEA
Identification	**Ranking**	**Analysis**	**Assessment**	**Risk Reduction**
Historical data	Historical data	FTA	FN-Diagram	Delphi
PHA	Risk Matrix	ETA		
Delphi				

Sources: Author.

3. BACKGROUND CONCERNING RESEARCH OBJECT

3.1 Waterway in the PRD

The PRD, mainly converged by the West River, the North River and the East River, is located in the middle south of Guangdong Province. So many rivers crisscross, forming a network of waterway with more than 6000 kilometers of inland navigation mileage, producing one of the three biggest economical circles in China. Throughput of ports in the PRD accounts for 80% of the whole throughput in Guangdong Province in the last decade, making one of the three busiest networks of waterway (Wang, 2013). As shown in Figure 3.1, the PRD is mainly made up by nine cities: Guangzhou, Zhaoqing, Foshan, Dongguan, Huizhou, Jiangmen, Zhongshan, Zhuhai and Shenzhen. Shenzhen is excluded from the research since it is a typical seaport with little inland navigation mileage.

Figure 3.1 – Network of waterway in the PRD
Sources: Retrived from world wide web, editted by the author.

Besides massive merchant ships, there are more than 10,000 small fishing boats in the PRD. Figure 3.2 is a typical fishing boat in the Pearl River. Normally, these ships are around 10 meters and less than 30 GT. Fishmen on the boats are local villagers with little safety awareness.

Figure 3.2 – A typical fishing boat in the Pearl River
Sources: Author

With the development of economy, considerable bridges have been built in recent years in the PRD. There is a bridge on the main waterway every 6 kilometers averagely in the PRD. Insufficient clearance of some bridges on the main waterway restricts the development inland navigation, raising the risk of bridges' being collided by ships with high maximum height like self-unload carriers.

3.2 Characteristics of Inland Self-unload Carriers in the PRD

Figure 3.3 is a picture of a typical inland self-unload carrier operated in the PRD. Normally, self-unload carriers have bigger sheer at stem, resulting in greater blind area than general bulk carriers. Besides, there is a conveyer belt extending out of the bow for conveying sand or gravels from carriers to the wharf, making the visibility of navigators even worse. Excessive blind area makes seafarers inconvenient to observe the small ships which are easy to enter into the blind area. According to Regulations of Statutory Survey for Chinese Inland Ships, the blind area shown in Figure 3.4, should not be longer than 1.5 times of overall length (L_{oa}), or the carrier shall install a video monitoring device with the function of night vision on the bow to eliminate the blind area (CCS, 2015). Most ships choose operational methods like ballast handling to meet the requirement. However, shipowners and operators always violate operational requirements since some operation need a lot of time, leading to excessive blind area in unloaded voyage. Even in fully loaded voyage, the cargo is higher than general bulk carrier because of V-shape cargo hold as seen in Figure 3.5. Huge blind area exists if stowage is unreasonable. If the density of bulk cargo is very small, some operators may violate the limitation of the cargo height, leading to excessive blind area as well as poor stability (Author, 2018).

Inland self-unload carrier's loading sand is operated in the river rather than wharf. Sand dredges transfer wetted sand with about 20% water to self-unload carriers directly. Normally an inland self-unload carrier is always overloaded when it just finishes the loading process, which is allowed tacitly for the high efficiency of the loading method, as long as the carrier does not sail before pumping out water, resulting in risk of overloaded navigation when moving away from the dredge to mooring place. Seafarers' sailing before water's being pumped out completely enough results in overloaded voyage. Sometimes, an inland self-unload carrier may be overloaded even after the water is totally pumped out because seafarers cannot accurately estimate how much wetted sand shall be loaded. What's worse, stability of self-unload carrier is quite sensitive to the quantity of excess cargo because of the V-shape cargo hold.

Normally, for the sake of reducing bending stress of the hull gird, cargo hold is loaded from stern to bow. Some operators transfer too much sand to the stern of the cargo hold, contributing to excessive trim by stern which leads to water's flooding into hull from the entrance of engine room on the stern. Besides, some operators on the dredge may transfer more sand to one side of the cargo hold, leading to excessive heel.

Figure 3.6 shows the loading process of inland self-unload carriers in the PRD. Normally there are more or less 6 heaps of sand in the cargo hold. The loading sequence is from NO.1 to NO.6, resulting in excessive trim by stern to the carrier in loading NO.1 to NO.4, which is risky for small carriers with limited stability margin.

Figure 3.3 – A Typical inland self-unload carrier in the PRD
Sources: Author

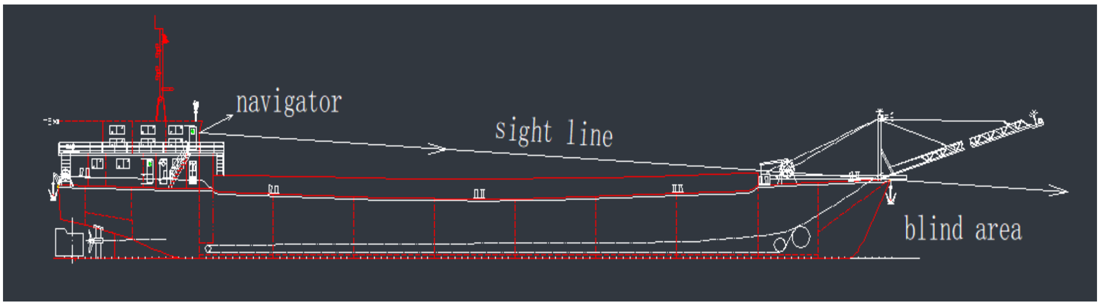

Figure 3.4 – Pictorial view of blind area
Sources: Author

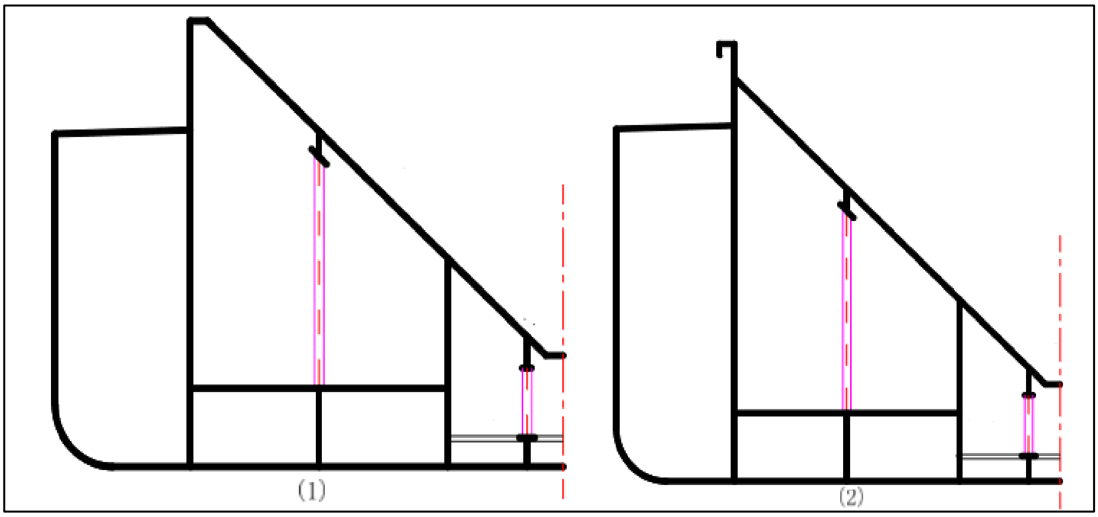

Figure 3.5 – Transverse section of inland self-unload carriers
Sources: China Classification Society, (2016). Standards for Steel Inland Ships. Peking: Author.

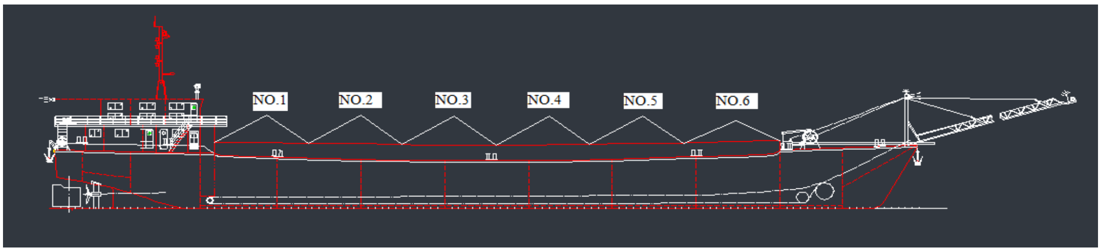

Figure 3.6 – Pictorial view of loading process
Sources: Author

3.3 Recently Introduced RCMs

Both the administration and CCS introduced several risk control measures in recent years: 1) limitation to the length of stem extension of the conveyer belt; 2) limitation to the length of blind area; 3) installation of video monitoring device with the function of night vision if the blind area is beyond the stipulated length (introduced in 2015); 4) establish standard manual to guide the loading and erect rulers in the cargo hold to measure the height of cargo; 5) establish requirements on watching in fishing areas and wharf areas.

Video monitoring device with night vision can totally eliminate the blind area, but it is voluntary. Shipowners prefer to choose operational methods like ballasting instead of installing video device to save cost. The operational procedures are not as practical as the installation of video monitoring device with the function of night vision since manning on inland self-unload carrier is limited and it is not easy to cope with so many small ships. From the perspective of the administration, it is not easy to supervise seafarers' implementation.

The standard loading manual relies on the implementation of seafarers. Worse still, potential excessive trim may be caused by the standard loading process.

All in all, the recently introduced measures are relatively reasonable but too reliable on good safety awareness of seafarers. Measures which facilitate seafarers' fulfilling duties shall be paid more attention.

3.4 Acceptance Criteria of GCAF and NCAF

Acceptable criteria varies in different countries. Once IMO recommended 3 million ($) as threshold value of GCAF and NCAF. The value has become outdated and new criteria is still in discussion (Skjong, 2018). Rolf Skjong recommended the following formula to calculate optimum acceptable NCAF (Skjong, 2002): $NCAF_A = ge(1\text{-}w)/4w$. In the formula: g is gross domestic product (GDP) per capita; e is expected lifetime of a person assessed at birth; w is the proportion of time we invest in economic activity. Considering vacation, education and retirement, w is around 1/7 for China. As seen in Table 3.1, the optimum acceptable $NCAF_A$ for China in 2017 is 1,000,000 ($).

Table 3.1 – Calculation of acceptable NCAF

g ($)	w	e (year)	$NCAF_A$
9300	1/7	75	1,000,000

Sources: national bureau of statistics of China.

4. DATA ANALYSIS OF HISTORICAL ACCIDENTS

Considering that accidents reports from 2016 to 2017 is still not completely available, resulting in obstacles in collecting investigation reports, considering that voluntary installation of video device with night vision (RCO 1) was introduced in 2015 (CCS, 2015), leading to difficulty of figuring out the number of carriers which voluntarily installed video device, this study uses data from 2006 to 2015 for analysis.

4.1 Classification of Accidents

Regulation on Investigation of Inland River Traffic Accidents divides accidents into six main categories: a) collision, contact or damage by waves; b) touching rocks or grounding; c) fire or explosion; d) sinking; e) damage of important components which affect seaworthiness obviously; f) others (China Transport Ministry, 2012).

Inland self-carriers' touching rocks is not common because riverbed of inland waterways in the PRD are covered by silt. It is unnecessary to set Category b in this research. The draft of most inland self-unload carriers is about 4 meters and heavy groundings also rarely happen. As to category e, there is enough time for seafarers to take measures to prevent further risk as long as the rudder is still working. The only reported case about failure of important component is the failure of rudder which resulted in a collision in the end and the case can be classified into collision. Damage by waves never happened to inland ships of 300 GT and above in the past in the PRD. For the convenience of researching, the author classifies accidents into five specific types: collision, sinking, contact, fire, explosion, others. Collision means collision between ships. Contact means ships' contacting objects which are not ships, including bridges, rocks, reverbed and other unidentified objects. Fire and explosion are easy to understand as their names suggest. Sinking means a self-unload carrier's sinking without collision, contact, fire and explosion. Accidents do not belong to any type above are classified into others. 98 accidents involving 101 inland self-unload carriers of and above 300 GT happened from 2006 to 2015.

Figure 4.1 shows the distribution of accidents in each year. There is neither obvious increasing nor decreasing tendency in these ten years. More accidents happened when estate industry was booming like 2007, 2011 and 2015, for the sake of more voyages of inland self-unload carriers in a prosperous market of estate industry. Figure 4.2 shows the distribution of accidents in each type. From the perspective of number of accidents, collision is the main accident type. Sinking which is mainly self-sinking for the sake of classing sinking accident caused by collision, contact, fire or explosion into the primordial accident, is the second most, followed by contact.

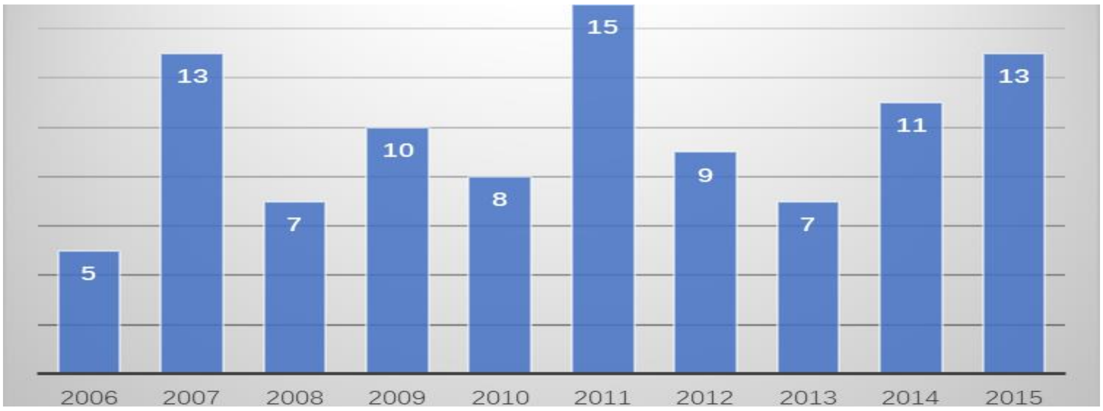

Figure 4.1 – Distribution of accidents in each year
Sources: Author.

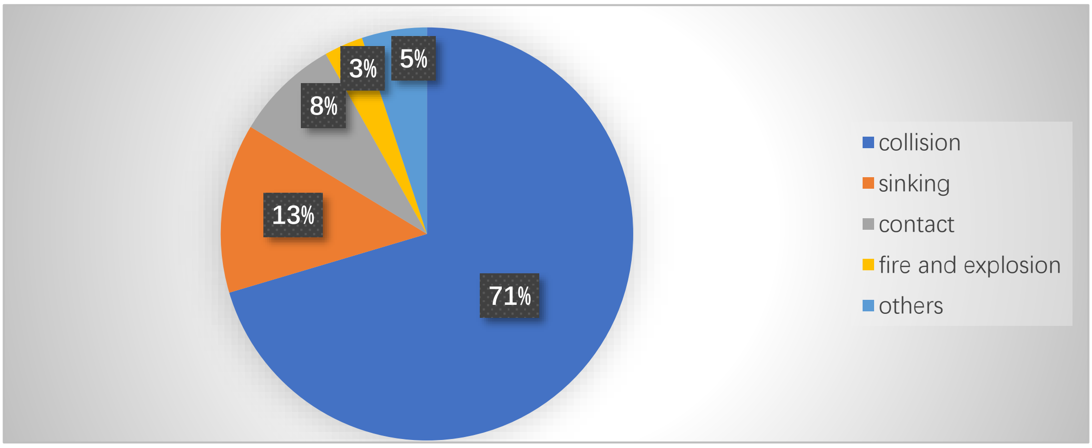

Figure 4.2 – Distribution of accidents in each type
Sources: Author.

4.2 Definition of Human Errors

Normally investigators define a major cause and several minor causes in a report. Most of these causes are human errors. It is difficult to classify human errors since they are interrelated. In this paper, omission means the navigator does not observe or observe potential risks too late to avoid the accident because of fatigue, distraction and excessive blind area. Carelessness means the navigator has observed the potential hazard early enough but pays limited attention, like haste misjudgment, omission of signal and dangerous operations (deviating customary route, dangerous overtaking, overspeed, keeping small distance, ignoring VHF, etc.). Poor skill means the navigator pays enough attention but still fails to operate correctly due to unfamiliarity with ship maneuverability and navigable environment. For instance, a navigator berths carefully but still collides other ships or shoreside structures.

4.3 Data Analysis Concerning Collision

Figure 4.3 shows the distribution of all 69 collisions in six time zone. There are more collisions which happened from midnight to 8:00 in the next morning. Fatigue and bad visibility at this period may be two factors.

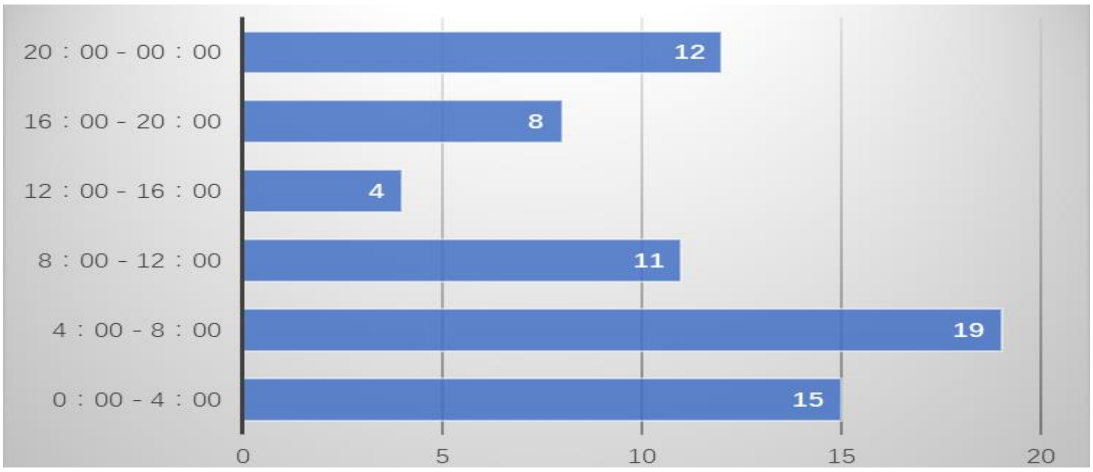

Figure 4.3 – Distribution of collisions in time zones
Sources: Author.

Table 4.1 shows the major causes of the 69 collisions. Almost every accident involves human error. However, for some collisions like self-unload carriers' colliding small boats due to omission of watch, owing all responsibilities to seafarers is unfair. According to the communication with seafarers on self-unload carries, operational procedures are not as practical as the installation of video monitoring device to eliminate blind area since manning on inland self-unload carrier is limited and it is not easy to cope with so many widely distributed small boats. China MSA has organized training courses about watching in fishing areas and wharf areas, the effectiveness is not good. From the perspective of the administration, it is not easy to monitor seafarers' obeying operational procedures (Author, 2018).

Recognizing that most of collisions can be avoided if one side takes measures reasonably, so the faults of self-unload carriers in accidents mainly caused by the other ships are also helpful in hazard identification and analysis. Considering that three collisions happened between inland self-unload carriers, actually there are 13 inland self-unload carriers encountered collisions mainly caused by the other ship. In these 13 cases, only one carrier was totally without fault. The most common cause is carelessness.

Table 4.1 – Major causes of collisions

The other ship's fault	10
Ommision (did not observe or observed the other ship too late to avoid collision)	30
Carelessness (observed the other ship early but paid no attention or dangerous operations)	22
Poor skill (observed the other ship and paid enough attention but failed)	2
Climate (Heavy fog)	2
Uncertifacted navigator	2
Failure of rudder	1

Sources: Author.

Table 4.2 illustrates that 70% of collisions are self-unload carriers' colliding other ships. 58% of ships collided by self-unload carriers are small boats (less than 30 GT), as seen in Table 4.3. Table 4.4 provides a horizontal comparison on the number of collisions with small boats by ship type operated in the PRD. Inland self-unload carriers account for 80% collisions with small boats while its proportion in ships in the PRD is far less than 80%, demonstrating self-unload carriers' higher frequency of colliding small boats. Larger blind area may be one of the causes. Table 4.5 shows the GT of the 28 inland self-unload carriers which collided small boats. 22 of them are carriers of 1000 GT and above. Considering that the number of inland self-unload carriers less than 1000 GT are almost the same with the number of carriers of and above 1000 GT, inland self-unload carriers of 1000 GT and above have higher frequency in colliding small boats. Normally, the larger the inland self-unload carrier is, the wider its blind area is, partly proving the influence of blind area. Table 4.6 shows the conditions of loading for self-unload carriers which collided small ships. Most of self-unload carriers which collided small boats are unloaded. Normally, unloaded inland self-unload carriers own larger blind area, further proving the positive correlation between blind area and self-unload carriers' colliding small boats.

Table 4.2 – Forms of collisions

Colliding	Being collided	Head-on	Total
48	16	5	69

Sources: Author.

Table 4.3 – GT of ships collided by inland self-unload carriers

less than 30	30 - 150	150 and above	total
28	2	18	48

Sources: Author.

Table 4.4 – Types of ships which collided small boats

self-unload carrier	oil tanker	high-speed ship	general carrier	container
28	1	1	1	1

Sources: Author.

Table 4.5 – GT of inland self-unload carriers which collided small boats

300 to 1000 GT	Of 1000 GT and above	total
6	22	28

Sources: Author.

Table 4.6 – Loading conditions of inland self-unload carriers

Without load	Full load	Total
23	5	28

Sources: Author.

Table 4.7 shows the materials of small boats collided by inland self-unload carriers. Over 90% of them are wooden boats which are more difficult to be detected by radar than steel ships (Lv, 2016).

Table 4.7 – Materials of small boats collided by inland self-unload carriers

wooden	steel	Total
25	3	28

Sources: Author.

As seen in Table 4.8, most of small boats collided by self-unload carriers are fishing boats. About one fourth of the 24 fishing boats are uncertificated, which means they are made by local villagers without certification, resulting in difficulty of raising safety level by improving regulations of small boats. The solution to uncertificated small boats is strengthened supervision rather than improved regulations of them.

Table 4.8 – Usage of small boats collided by inland self-unload carriers

Fishing boat	Traffic boat	Cargo boat	Ferry
24	1	2	1

Sources: Author.

As seen in Table 4.9, there are less collisions with small ships from April to June because fishing in the Pearl River is forbidden in this period (Kong, 2017), confirming the important role of fishing boats in these small boats.

Table 4.9 – Small boats collided by inland self-unload carriers in each month

Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
3	3	3	0	1	0	2	2	7	3	0	4

Sources: Author.

As seen in Table 4.10, mostly, visibility was good when collisions between inland self-unload carriers and small boats happened since navigation in heavy fog is forbidden. Fog did not play an essential role in self-unload carriers' colliding small boats while device with additional function of passing through heavy fog is far more expensive than the common type. So the function of passing through heavy fog is unnecessary.

Table 4.10 – Visibility when inland self-unload carriers collided small boats

Good	Light fog	Heavy fog	total
24	3	1	28

Sources: Author.

4.4 Data analysis concerning sinking

There are 13 sinking casualties from 2006 to 2015. All 13 sinking accidents are capsizing because bulk slip and free liquid surface make the unseaworthy carrier easy to capsize in the final stage of accidents.

As seen in Table 4.11, none of sunken inland self-unload carriers is unloaded since unloaded self-unload carriers have enough freeboard to ensure stability margin. Sunken self-unload carriers are either loaded or in the process of loading and unloading. As seen in Table 4.12, most of sunken inland self-unload carriers are less than 1000 GT because smaller carriers have less stability margin. Their stability is easy to become unqualified for overload.

Table 4.11 – Loading conditions of sunken inland self-unload carriers

Loaded	Loading	Unloading	Unloaded
5	6	2	0

Sources: Author.

Table 4.12 – GT of sunken inland self-unload carriers

Less than 1000 GT	Of and above 1000 GT
9	3

Sources: Author.

Figure 4.4 shows the distribution of sinking in six time zones. More accidents happened from 20:00 to 8:00 in the next morning. Seafarers' fatigue results in omission and carelessness. Poor vision in night is obstacle to communication between seafarers on carriers and operators on dredgers as well as detection of dangers.

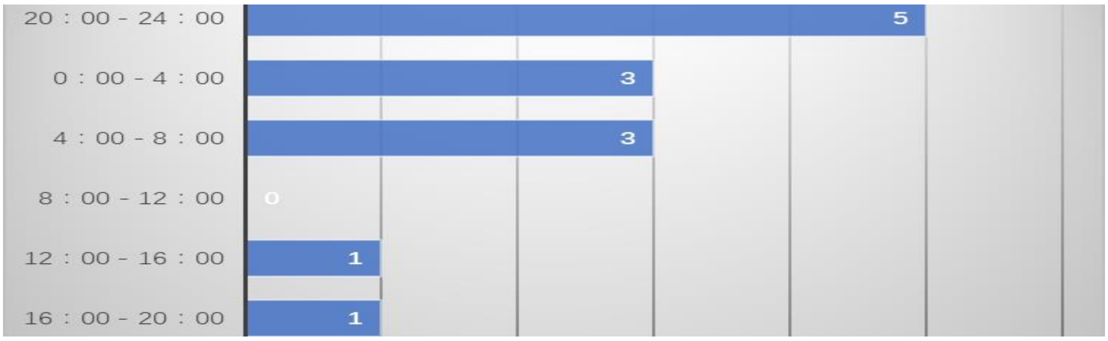

Figure 4.4 – Distribution of sinking accidents in time zones

Sources: Author.

Figure 4.5 shows the major causes of the 13 sinking accidents. Obviously, improper loading is the main cause. Mainly, there are three kinds of improper loading: unbalanced transverse loading, unbalanced longitudinal loading and over-high loading. Unbalanced transverse loading contributes to heel, reducing freeboard and inlet angel. Unbalanced longitudinal loading results in unacceptable trim, reducing inlet angel. Over-high loading raises the gravity center of cargo, leading to poor stability as well as excessive blind area. Overload is the second major cause. Seafarers always let the inland self-unload carriers overload first, and then pump out water. Seafarers may sail before water is pumped out completely enough or fail in estimation of the amount of wetted sand should be loaded. They do not want to trouble themselves to unload excessive sand. Also, shipowners may encourage seafarers to ignore small amount of overload which means additional money for them.

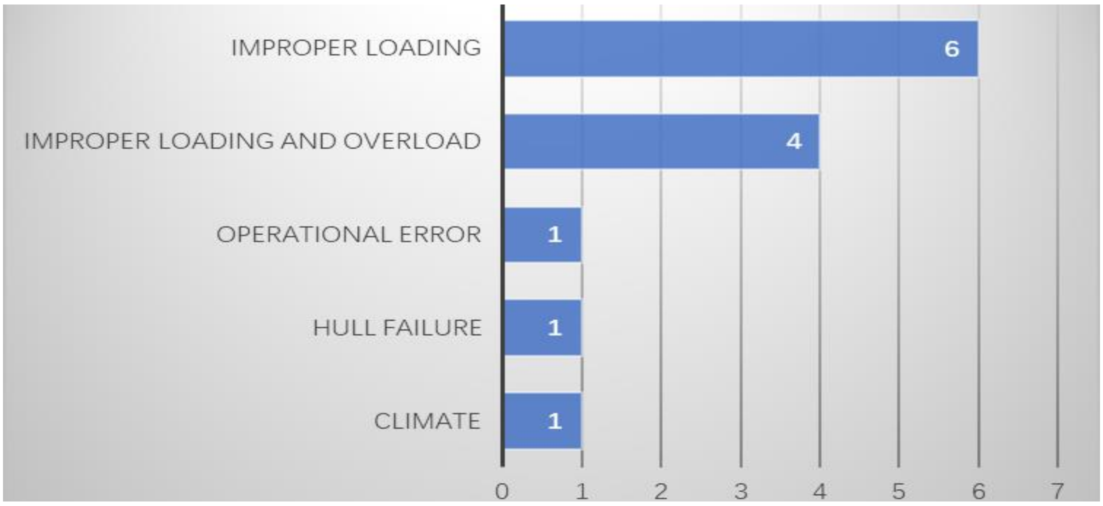

Figure 4.5 – Major causes of sinking accidents
Sources: Author.

4.5 Data analysis concerning contact

Table 4.13 shows the objects contacted by inland self-unload carriers in the PRD. Six of objects contacted by inland self-unload carriers are bridges because of the high density of bridges in the PRD.

As seen in Table 4.14, carelessness is the most common major cause of contact. However, the severest contact which led to collapse of the bridge contacted, is caused by heavy fog.

As seen in Table 4.15, all of the eight inland self-unload carriers which contacted bridge or other objects are of and above 1000GT since bigger carriers have both higher height and deeper draft.

As seen in Table 4.16, inland self-unload carriers account for 37.5% of ships contacting bridges in the PRD. The frequency of colliding bridges is higher than other ships but not so obvious as colliding small boats.

Table 4.13 – Objects contacted by inland self-unload carriers

Bridge	Rock	Wharf
6	1	1

Sources: Author

Table 4.14 – Major causes of contacts

Carelessness	Poor navigation skill	Climate (Heavy fog)
5	2	1

Sources: Author

Table 4.15 – GT of inland self-unload carriers in contacts

Less than 1000 GT	Of and above 1000 GT
0	8

Sources: Author

Table 4.16 – Ships which contacted bridges in the PRD by ship type

Inland self-unload carrier	General cargo ship	Working ship
6	7	3

4.6 Data analysis concerning fire and explosion

Fire and explosion is not common for inland self-unload carriers. Two fire casualties were caused by welding. One explosion was caused by short circuit and fuel of flash point less than 60 Celsius degree which has been forbidden to use on inland self-unload carriers. For lack of historical data, statistical analysis for fire and explosion is meaningless.

4.7 Summary of data from 2006 to 2015

As seen in Table 4.17 and 4.18, more than half of fatalities are third parties. Most of them are fishmen collided by inland self-unload carriers. Table 4.19 shows the frequency and PLL of two scenarios which shall be further discussed in Chapter 5.

Table 4.17 – Number of accidents and fatalities

Initial event	Number of accidents				Number of fatalities	
	total	With fatality		Without fatality	Crew	Third party
		To crew	To 3rd party			
Collision	69	5	33	31	18	50
Sinking	13	6	0	7	18	0
Contact	8	0	1	7	0	8
Fire	2	1	0	1	1	0
Explosion	1	1	0	0	3	0
others	5	4	0	1	4	0
Total	98	17	34	47	44	58

Sources: Author.

Table 4.18 – Frequency of accidents (Fleet = 12899 ship*years)

	Frequency			
Initial event	total	With fatality		Without fatality
		To crew	To 3rd party	
Collision	5.35E-03	3.88E-04	2.56E-03	2.40E-03
Sinking	1.01E-03	4.65E-04		5.43E-04
Contact	6.20E-04		7.75E-05	5.43E-04
Fire	1.55E-04	7.75E-05		7.75E-05
Explosion	7.75E-05	7.75E-05		
others	3.88E-04	3.10E-04		7.75E-05
Total	7.60E-03	1.32E-03	2.64E-03	3.64E-03

Sources: Author.

Table 4.19 – Two scenarios of inland self-unload carriers of and above 1000 GT

Scenarios	Number of accidents	Fatalities	Frequency	PLL
Collide small boats due to omission	16	19	2.46E-3	2.92E-3
Collide small boats due to carelessness	5	6	7.68E-4	9.21E-4

Note: Fleet = 6512 ship*years; all fatalities in the table are to third party like fishmen.

Sources: Author.

5. THE APPLICATION OF FSA TO RESEARCH OBJECT

5.1 STEP 1 – Hazard Identification

5.1.1 List of Identified Hazards

The HAZID was first conducted by the author who is a nominated surveyor, and then supplemented and perfected by experts familiar with research object (i.e. shipowners, navigators, ship designers, surveyors and investigators from the PRD). As seen in Table 5.1 to 5.3, 30 hazards were identified by checking operations in three working conditions: sailing; loading and unloading; berthing and mooring.

Table 5.1 – Potential hazards under condition of sailing

NO.	Hazard
1	Colliding small boats due to omission
2	Collision with ships more than 30 GT due to omission
3	Collision or contact due to intentional carelessness (like dangerous operations)
4	Collision or contact due to unintentional carelessness (like haste misjudgment)
5	Sinking due to over-high load
6	Sinking due to overload
7	Sinking due to rapid rotation with initial heel caused by improper load
8	Collision or contact due to poor skill
9	Collision or contact due to uncertificated navigator
10	Collision or contact due to failure of important components such as rudder
11	Sinking due to free liquid surface in the cargo hold
12	Collision or contact due to climate (heavy fog)
13	Sinking due to climate (rapids)
14	Sinking due to hull failure

Sources: Author.

Table 5.2 – Potential hazards under condition of loading and unloading

NO.	Hazard
1	Capsizing caused by excessive heel due to unreasonable distribution of cargo
2	Capsizing caused by excessive trim due to unreasonable distribution of cargo
3	Capsizing caused by poor stability due to intentional overload
4	Capsizing caused by free liquid surface due to failure of pump
5	Capsizing caused by free liquid surface due to failure of alarm system and forgetting start-up
6	Capsizing caused by free liquid surface due to failure of high-level-water alarm system

Sources: Author.

Table 5.3 – Potential hazards under condition of berthing and mooring

NO.	Hazard
1	Contact or collision when berthing due to poor skill
2	Contact or collision when berthing due to omission
3	Personal injury due to wrong operation of machine
4	Personal injury due to failure of structure (like conveyor arm, cable and anchor chain)
5	Drowning as consequence of sinking in water due to omission of seafarers
6	Fire or explosion caused by short circuit and accumulated gas
7	Fire or explosion caused by welding and accumulated gas in repairing
8	Being collided due to turning off anchor light in mooring
9	Being collided due to mooring in customary route
10	Being collided in traffic boat (normally every carrier in the PRD equips a small traffic boat)

Sources: author.

5.1.2 Top-ranked Hazards

Table 5.4, 5.5 and 5.6 define the frequency index, severity index and risk matrix. The frequency index of a hazard is decided by the magnitude of its frequency. Severity index is decided by effects on human and property loss.

Table 5.4 – Definition of Frequency Index

FI	**Severity**	**Definition**	**F**
7	Frequent	Likely to occur once per month on one ship	10
6		Likely to occur once per year on one ship	1
5	Probable	Likely to occur once per year in a fleet of 10 ships	10^{-1}
4		Likely to occur once per year in a fleet of 100 ships	10^{-2}
3	Remote	Likely to occur once per year in a fleet of 1,000 ships	10^{-3}
2		Likely to occur once per year in a fleet of 10,000 ships	10^{-4}
1	Extremely remote	Likely to occur once per year in a fleet of 100,000 ships	10^{-5}

Sources: IMO, (2013). *Revised Guidelines for Formal Safety Assessment (FSA) for Use in the IMO Rule-Making Process*. London: Author.

Table 5.5 – Definition of Severity Index

SI	**Severity**	**Effects on human**	**Property loss ($)**	**S**
1	Minor	Minor injuries or very small property loss	< E5	0.01
2	Significant	Single severe injurie or small property loss	E5 – E6	0.1
3	Severe	Single fatality or multiple severe injuries or medium property loss.	E6 – 2.0E6	1
4	Catastrophic	Multiple fatalities or huge property loss	> 2.0E6	10

Sources: author.

Table 5.6 – Definition of Risk matrix

Risk Index (RI)					
FI	Frequency	SEVERITY			
		1	2	3	4
		Minor	significant	severe	catastrophic
7	Frequent	8	9	10	11
6		7	8	9	10
5	Reasonably probable	6	7	8	9
4		5	6	7	8
3	remote	4	5	6	7
2		3	4	5	6
1	Extremely remote	2	3	4	5

Sources: IMO, (2013). *Revised Guidelines for Formal Safety Assessment (FSA) for Use in the IMO Rule-Making Process*. London: Author.

Table 5.7 shows the two top-ranked hazards with respect to human life. Big inland self-unload carriers' colliding small boats results in third-party fatalities while small carriers' sinking leads to fatalities of crew.

Table 5.8 shows the two top-ranked hazards with respect to property loss. Big inland self-unload carriers' contacting bridges normally results in considerable property loss for high cost of repairing bridges.

Table 5.7 – Top-ranked hazards with respect to human life

Main Hazards	FI	SI	RI
Fatalities as consequence of colliding small boats by big carriers (of and above 1000 GT) with blind area due to omission	3	3	6
Fatalities as consequence of sinking due to overload or improper loading of small carriers (less than 1000 GT).	3	3	6

Sources: author

Table 5.8 – Top-ranked hazards with respect to property loss

Main Hazards	FI	SI	RI
Medium property loss as consequence of collision due to omission or carelessness	3	3	6
Medium property loss caused by contact of carriers of and above 1000 GT	3	3	6

Sources: author

5.2 STEP 2 – Risk Analysis

5.2.1 ETA and FTA on Accidents

Figure 5.1 shows the ETA on collision. The event sequence of colliding small boats, colliding bigger ships and being collided are different. Normally, colliding small boats brings about limited damage to inland self-unload carriers but catastrophic damage small boats. In contrast, collisions with large ships, especially with huge sea-going vessels, result in high risk of fatalities on inland self-unload carriers. After collision, seafarers have more chance to survive if inland self-unload carriers sink slowly.

Figure 5.2 shows the FTA on collision. Human factors account for considerable proportion of major causes. The most common major cause varies from scenarios. Omission is more common in colliding small boats while carelessness is more common in collision with ships more than 30 GT.

Figure 5.3 shows the FTA on sinking accidents. About 80% of sinking accidents resulted from poor stability. Improper load and overload are causes of poor stability. Overload and improper load are easy to observe but seafarers just ignore the hazards for various factors such as poor safety awareness. The key to controlling overload and improper load is effective supervision.

The event sequence of sinking is quite simple. Most of inland self-unload carriers capsized suddenly and rapidly without time for escaping. So ETA on sinking accident is omitted here.

Figure 5.4 shows the ETA on contact. The most severe scenario is that a self-unload carrier contacts a bridge with people on it and makes the bridge collapse. For contacts with underwater objects, inland self-unload carriers capsize rapidly when excessive heel or trim appears, or seafarers normally have enough time to deal with damage or evacuate.

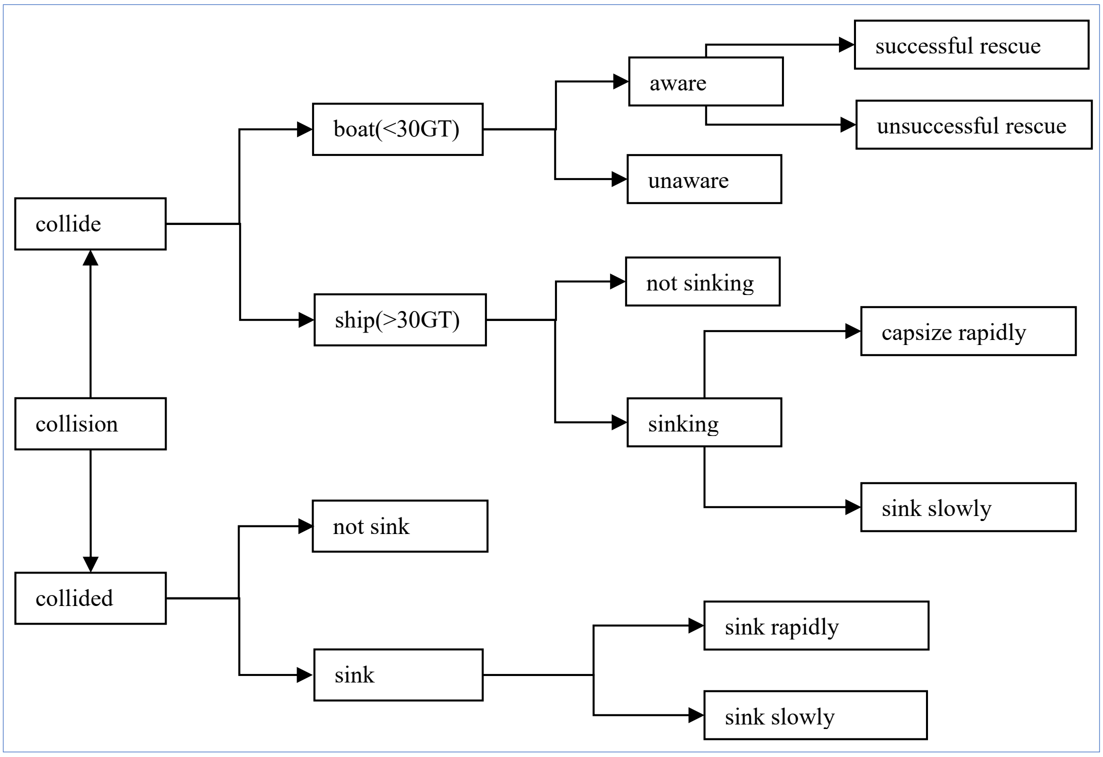

Figure 5.1 – ETA on collision
Sources: author.

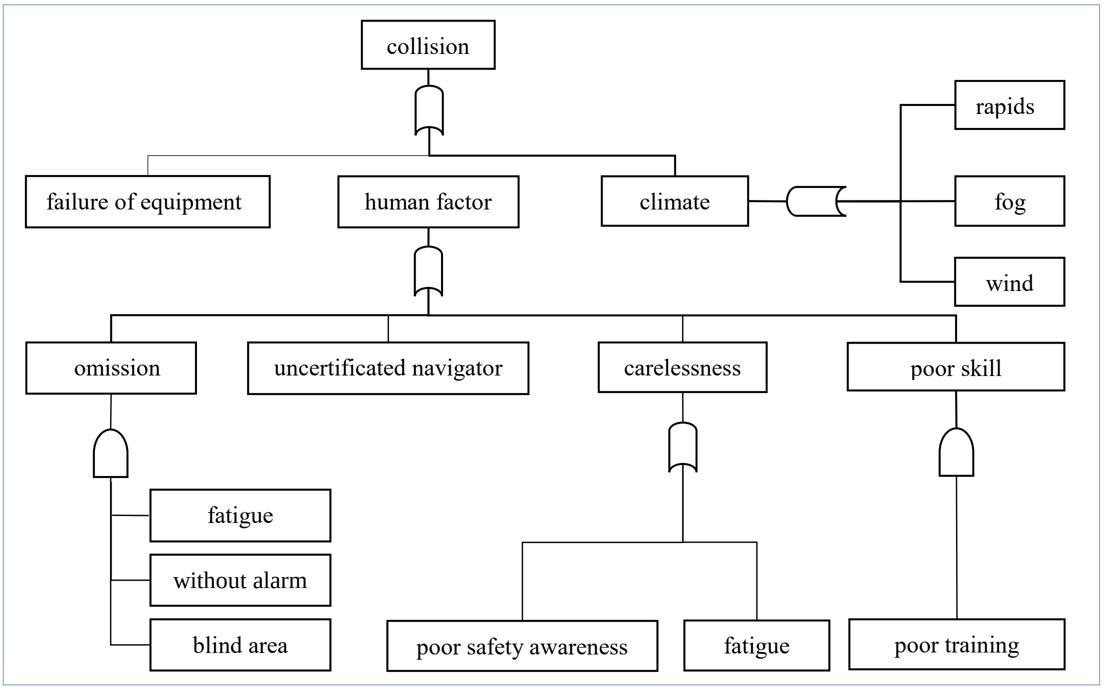

Figure 5.2 – FTA on collision
Sources: author.

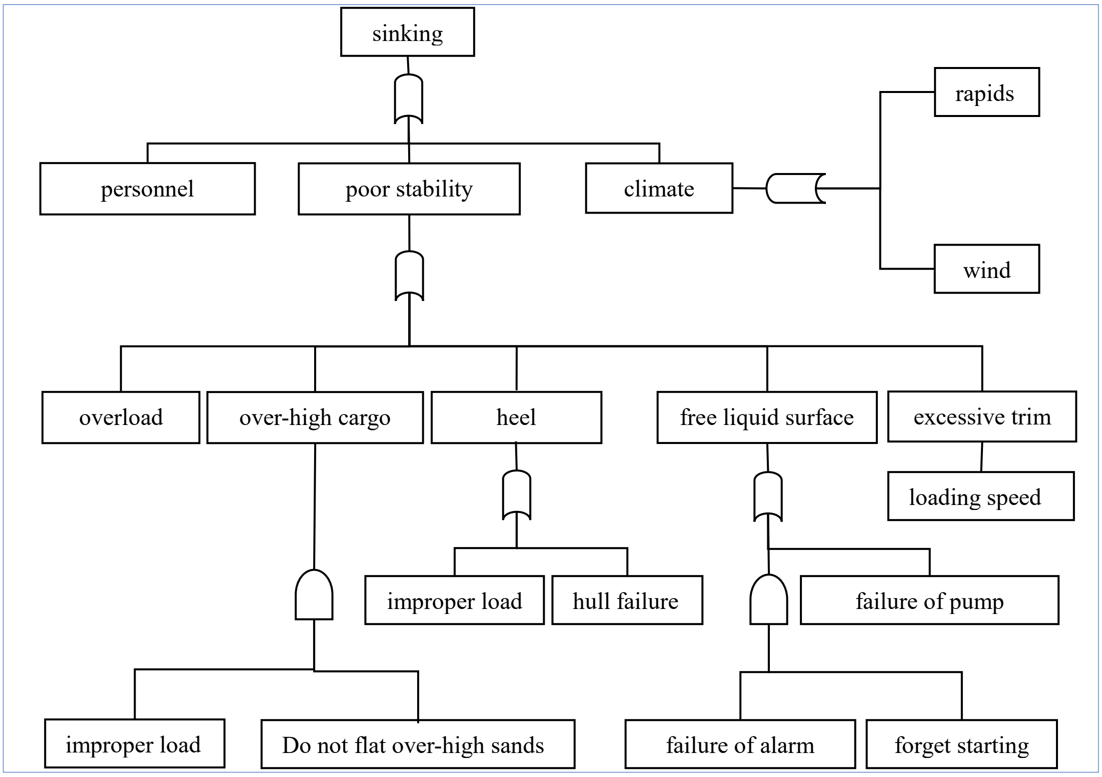

Figure 5.3 – FTA on sinking accident
Sources: author.

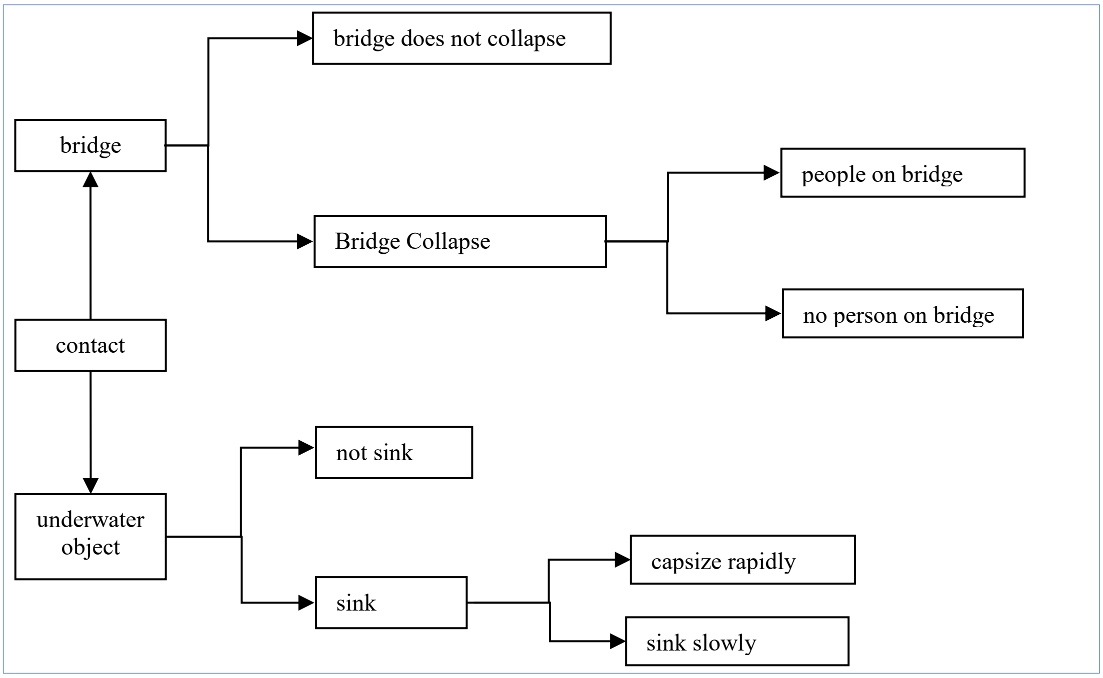

Figure 5.4 – ETA on contact
Sources: author.

5.2.2 Risk Assessment

5.2.2.1 Individual risk assessment

Intuitively, individual risk of third parties or passengers is not in the scope of this study. Only the individual risk of crew on inland self-unload carriers in the PRD is researched. Assuming a crew size of 8 on a typical inland self-unload carrier according to the average gross tonnage of the fleet and manning principals, the individual risk of crew is estimated to be 4.3E-04 per ship year. Table 5.9 shows the individual risk criteria recommended by the IMO (IMO, 2000). Besides, Li recommended 1.4E-4 as the datum value of individual risk of staff in transportation industry in China (Li, 2010). If we adjust one order of magnitude to make the ALARP area, it is 1.4E-5 to 1.4E-3. According to the individual risk acceptance criteria, the individual risk of crew on inland self-unload carriers falls within the ALARP area.

Table 5.9 – Individual risk criteria

	Lower limit of ALARP	Upper limit of ALARP
Crew	10-6	10-3
Passenger	10-6	10-4
Third parties, public ashore	10-6	10-4
For new ship	10-6	Reduce an order of magnitude

Sources: IMO. (2000). Decision parameters including risk acceptance criteria: submitted by Norway (MSC 72/16/X). London: Author.

5.2.2.2 Social risk assessment

The societal risk to crew is expressed through FN-diagram presented in Figure 5.5 established by the method recommended by the IMO. Societal risk of crew on inland self-unload carriers in the PRD falls within the ALARP area. IMO gave several FN-diagrams for ocean-going ships including bulk carriers based on data from LMIS from 1978 to 1998. Compared with the FN-diagram of ocean-going bulk carriers in Figure 5.6, inland self-unload carriers' frequency of multiple fatalities is lower because of fewer seafarers and higher survival rate than ocean-going carriers.

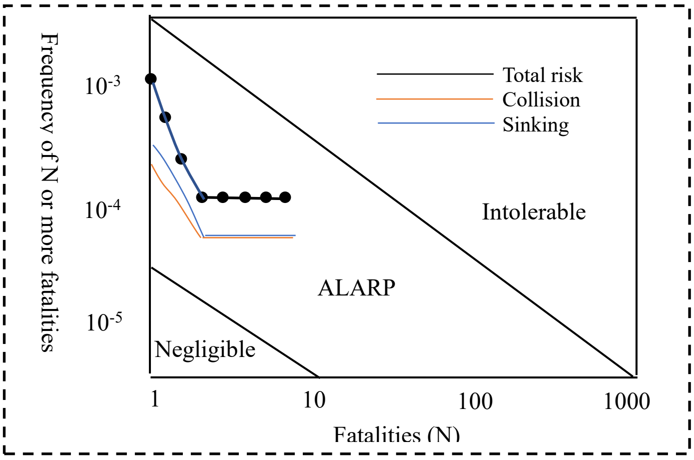

Figure 5.5 – FN-diagram for risk of research object to crew (2006-2015)

Sources: author

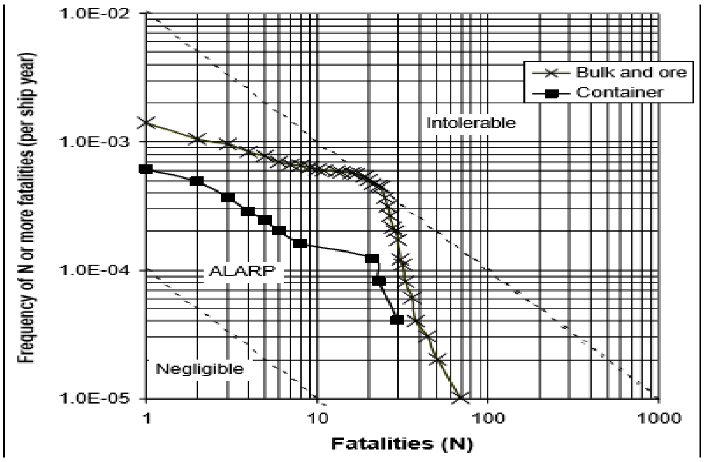

Figure 5.6 – FN-diagram for risk of ocean-going ships to crew (1978-1998)

Sources: IMO. (2000). Decision parameters including risk acceptance criteria: submitted by Norway (MSC 72/16/X). London: Author.

Though inland self-unload carriers caused considerable fatalities to third parties like fishmen, it is difficult to establish acceptable criteria because it is not easy to determine the Economic Value (EV) for involving two parties in one accident. This study established a FN-diagram for inland self-unload carriers' risk to third parties by halving the third-party fatalities as well as using the same EV of inland self-unload carriers in the PRD. As seen in Figure 5.7, the risk is also in the ALARP area.

Table 5.10 supplements the process of calculating PLL_A and FN-diagram. For an inland self-unload carrier in the PRD, an average PLL_A is based on the EV of the activity. It is not possible for the author to get the accurate EV for self-unload carriers in each year from 2006 to 2015. By consulting shipowners, based on the average gross tonnage of the fleet, the average annual EV (which is equal to the annual turnover) for each carrier is estimated to be approximately $400,000.

For decreasing trend of occupational fatalities and increasing trend of GNP in the last decade, PLL_A calculated by data of 2017 is more reasonable.

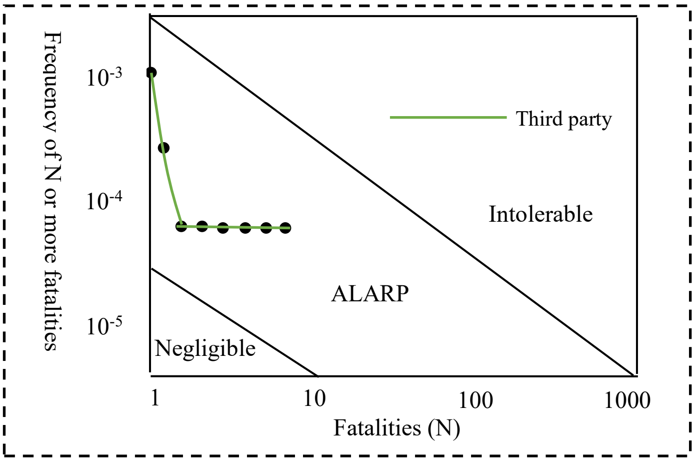

Figure 5.7 – FN-diagram for risk of research object to third parties (2006-2015)

Sources: author

Table 5.10 – Data about calculation of PLL_A

Year	Occupational fatalities	GNP ($) trillion
2006	112822	3.4
2007	101480	4.1
2008	91172	4.9
2009	83196	5.3
2010	79552	6.2
2011	75572	7.4
2012	71983	8.1
2013	69434	8.8
2014	68061	9.8
2015	66182	10.5
2016	43062	11.2
2017	37852	12.4
EV of one ship ($)	400,000	
PLL_A = number of fatalities · EV / GNP = 1.22E-3 (data of 2017)		
$F_1 = PLL_A/(1+1/2+1/3+1/4+1/5+1/6+1/7+1/8)$ = 4.5E-4		

Sources: National Bureau of Statistics of China.

5.3 STEP 3 – Identification of Risk Control Options

Table 5.11 – Risk Control Options

RCO 1	Video monitoring device with night vision for carriers of and above1000 GT
RCO 2	TCPA and DCPA alarm of Radar with training for carriers of and above1000 GT
RCO 3	Improved design of loading and unloading procedure
RCO 4	Electrical overload and over-high load supervising system
RCO 5	Improved safety education of seafarers
RCO 6	Set standard for noise of navigation room and rest rooms (< 65 DB)
RCO 7	W-Shape cargo hold

Sources: Author.

Table 5.11 presents 7 alterative RCOs put forward by experts and the author.

RCO 1 can eliminate the excessive blind area to facilitate the watch of seafarers, reducing possibility of colliding small boats due to omission. Its effectiveness varies from visual range of video device. Normally, speed of inland self-load carrier ranges from 13 to 17 kilometer per hour. Most navigators consulted said they need at least 300 meters distance to ensure success rate of avoiding colliding small boats at that speed. Risk reduction of video device with visual range of 300 meters shall be discussed in Step 4.

RCO 2 mainly reduces hazards detected by radar but omitted. Alarm based on TCPA and DCPA can remind navigators of the potential hazards at an early stage. Besides, considerable navigators said they need training on radar, especially for imported radar with instruction of foreign languish. MSA can organize onboard training once a year. However, the cost benefit assessment is complex because some carriers have already installed radar with alarm voluntarily, resulting in huge work of calculating the number of carriers with or without alarm.

RCO 3 aims to reduce capsizing caused by improper loading. The administration shall establish criteria for stability in the process of loading. It can be lower than the normal criteria with certain limitations of operations like maximum steering angle, distance between anchorage and dredger, etc. Nonetheless, overload in the process of loading without any standard shall be forbidden. Its initial cost, namely the design fee, is cheap. The main cost is reduced shipment or reduced loading efficiency. Its effectiveness depends on the implementation.

RCO 4 is a good concept about preventing intentional overload and over-high load, but there is no mature product. Besides, wave and flow distribution are challenges for the accurate detection of freeboard. Both the cost and benefit are hard to estimate.

RCO 5 pays attention to the widely existed human errors in accidents. MSA can organize brief onboard training once a year by sending brochures about lessons learned from accidents. Its cost is limited since the training is conducted onboard. However, uncertainty of human errors makes the risk reduction extremely difficult.

RCO 6 aims to create a better rest environment for seafarers to mitigate fatigue. Strengthened structure and improved hull lines are the main cost while risk reduction is hard to determine.

RCO 7 lowers the barycenter of cargo to improve stability, but W-shape cargo hold needs two conveyors belts, further weakening visual range, leading to difficulty in estimating risk reduction.

5.4 STEP 4 – Cost-effectiveness Analysis

RCO 1 is analyzed in this step because its cost and benefit are relatively easier to assess than other RCOs. Cost benefit assessments of other RCOs need further study.

5.4.1 Cost estimation

Initial cost is based on information from suppliers. Lifetime of inland self-unload carriers is 33 years according to Regulation on Old Ship Management (China Transport Ministry, 2002). Table 5.12 presents the marginal cost of RCO 1 for new ship.

Table 5.12 – Marginal Cost of RCO 1 for new ship (Depreciation rate = 5%)

RCO	Replacement cycle	Marginal Initial cost ($)	Marginal Operation cost ($)	Total marginal cost ($ / ship*year)
RCO 1	5 years	2,000	200/cycle	265

Sources: Author.

5.4.2 Risk reduction of RCO 1

Risk reduction is based on considerations of scenarios affected. Experts opinions on risk reduction of big carriers' colliding small boats due to omission range from 20% to 70% and concentrate in the range of 40% to 70%, as seen in Table 5.13.

Some experts think RCO 1 can also reduce big carriers' colliding small boats due to carelessness. In some historical accidents, navigators observed small boats early but missed them after small boats' entering into blind area. In contrast, some experts deem carelessness means poor safety awareness. An incautious navigator would not use the device even if he had observed small boats. The consensus degree is low. This study ignores the risk reduction from this scenario to get a higher NCAF.

Table 5.13 – Risk reduction of big carriers' colliding small boats due to omission

< 10%	10%-20%	20%-30%	30%-40%	40%-50%	50%-60%	60%-70%	> 70%
0	0	2	2	6	6	6	0

Sources: Questionnaires from experts (single choice question).

Table 5.14 – Results of CEA of RCO 1 based on different risk reduction

PLL (1)	property loss (2)	Reduction Proportion (3)	Risk Reduction ΔR= (1)*(3)	Cost ΔC	Benefit ΔB=(2)*(3)	NCAF (ΔC-ΔB)/ΔR
2.92E-03	114	20%	5.84E-04	265	22.8	414,726
2.92E-03	114	30%	8.76E-04	265	34.2	263,470
2.92E-03	114	40%	1.17E-03	265	45.6	187,842
2.92E-03	114	50%	1.46E-03	265	57.0	142,466
2.92E-03	114	60%	1.75E-03	265	68.4	112,215
2.92E-03	114	70%	2.04E-03	265	79.8	90,607

Sources: Author

5.5 STEP 5 – Recommendations

An RCO is regarded to be cost-effective if the NCAF is less than USD 1 million, which has been explained in Chapter 3. Obviously, RCO 1 is cost-effective, as seen in Table 5.14. The actual NCAF of RCO 1 should be even lower. This study recommends the implementation of RCO 1 and further research of the other six RCOs.

6. SUMMARY, PROSPECT AND LIMITATION

The application of FSA methodology to inland self-unload carriers in the PRD is conducted according to the data from 2006 to 2015, filling the gap of overall risk assessment of inland self-unload carriers in the PRD. The overall risk of research object is located in the ALARP area, which means a RCO shall be implemented to reduce the risk when it is cost-effective.

Colliding small boats is a top-ranked hazard for inland self-unload carriers of and above 1000 GT. RCO 1 is a cost-effective solution to this hazard. This study advises the administration to make the installation of video monitoring device with night vision from voluntary to mandatory.

Capsizing due to improper load or overload is a top-ranked hazard for inland self-unload carriers less than 1000 GT. RCO 3 and RCO 4 are likely to be solutions. The cost is so high if RCO 4 just applies to self-unload carriers in the PRD that it need more inland self-unload carriers to split the soft developing fee. Further research on the application of FSA to inland self-unload carriers in the whole country is recommended.

Historical accidents show that almost every casualty is caused by human errors more or less. RCO 5 and RCO 6 are designed to reduce human errors.

With the tendency of large-size ship, RCO 7 may be a solution to over-high load for inland self-unload carriers wide enough.

This study is not a standard report for omission of most RCOs' CEA. IACS and ICFTU indicated that considerable applications of FSA need 1 year and some applications even need 2 or 3 years (Papanikolaou, 2009, P. 126). It is impossible to finish an application of FSA to a ship type in 3 months.

The absence of maritime database in China results in obstacle of applying FSA in the whole country. Fortunately, the national maritime database is in construction. Further research on applications of FSA shall be more convenient in the future.

REFERENCES

Author, (2018). Formal Safety Assessment of Inland Self-unload carriers in the PRD. Unpublished master's assignment. World Maritime University, Dalian, China.

Bai, Y. (2003). Formal Safety Assessment Applied to Shipping Industry. *Marine Structural Design*. Elsevier Ltd.

Brandsæter, A. (2002). Risk assessment in the offshore industry. *Safety Science, 40*(1–4), 231-269.

Cao, R. F. & Gao, Z. S. & Zhu, F. H.. (2001). The Application of ARPA to Inland Ship. *2001 China navigation committee inland ship navigation committee conference* (pp.29-30).

Chen, Z. Y. & Wang, Z. H. (2008). Considerations and Measures of self-unload carriers in Guangdong. *Pearl River Water Transportation* (5), PP. 34-36.

China Classification Society, (2015). *Guidelines for the Application of Formal Safety Assessment in Ships.* Peking: Author.

China Classification Society, (2011). *Regulations of Statutory Survey for Chinese Inland Ships.* Peking: Author.

China Classification Society, (2015). *2015 Amendment of Statutory Survey for Chinese Inland Ships.* Peking: Author.

China Classification Society, (2016). *Standards for Steel Inland Ships.* Peking: Author.

China Fisheries Inspection Bureau, (2009). *Regulations of Statutory Survey for Chinese Inland Fish Boats from 5 to 12 Meters.* Peking: Author.

China State Council, (2005). *Regulations on minimum manning of ships.* Peking: Author.

China State Council, (2017). *Regulations on Compensation of Employment Injury Insurance.* Peking: Author.

China Transport Ministry. (2002). Regulation of Old Ship Management. *Pearl River Water Transportation*(22), 60-64.

China Transport Ministry. (2007). Regulation on Investigation of Inland River Traffic Accident. *Pearl River Water Transportation*(22), 60-64.

China Transport Ministry. (2012). Amendment of Regulation on Investigation of Inland River Traffic Accident. *China State Council Bulletin*(22), 60-64.

China Transport Ministry. (2014). Statistical methods for water traffic accidents. *China State Council Bulletin* (1), 44-47.

Hu, L. (2008). Inland Navigators' Operational Skill of Radar. *China Water Transportation 8*(11), 17-18.

IMO. (2000). Decision parameters including risk acceptance criteria: submitted by Norway (MSC 72/16/X). London: Author.

IMO. (2001). Formal Safety Assessment Fore-end watertight integrity: submitted by IACS (MSC 74/5/X). London: Author.

IMO, (2013). *Revised Guidelines for Formal Safety Assessment (FSA) for Use in the IMO Rule-Making Process*. London: Author.

IMO. (2014). Formal Safety Assessment-Crude Oil Tankers: submitted by Denmark (MEPC 58/17/2). London: Author.

Kong, Y. Y. & Yue, H. Y. (2017). Banned fishing period increases two months. *Ocean and Fishing* (3), P. 17.

Kuang, Y. S. & Huang, W. Q. & Xie, Z. T. (2010). An Analysis on Inland Self-unload Carrier. *China Water Transportation* (4), 21-22.

Li, S. H. (2012). Method for Improving Stability of Self-Unloading Sand Ship. *Guangdong Shipbuilding, 31*(1), 78-79.

Lv, Z. Y. (2016). Causes of Collisions between Commercial Ship and Fishing Boats. *China Maritime Safety* (12), PP. 32-33.

Li, B. Y. (2010). Study on Criteria of Acceptable Risk. Unpublished master’s thesis. Jiangsu University, Zhenjiang, China.

Lois, P. & Wang, J. & Wall, A. & Ruxton, T. (2004). Formal safety assessment of cruise ships. *Tourism Management, 25*(1), 93-109.

Papanikolaou A. (Editor) (2009). ‘Risk-Based Ship Design, Methods Tools and Applications’ Springer, ISBN 978-3-540-89042-3. Chinese translation by Shanghai Jiao Tong University Press ISBN 978-7-313-07658-8.

Pu, B., & Xia, D. (2002). Problems of Inland Self-unload Carriers. *Guangdong Shipbuilding* (3), PP. 8-10.

Skjong, R. & Ronold, K. O. (2002). So much for safety. OMEA-2002-28451, Oslo, Norway.

Skjong, R. (2018). *Risk Based Maritime Safety Management.* Unpublished lecture handout, World Maritime University, Malmo, Sweden.

Wang, J. & Foinikis, P. (2001). Formal safety assessment of container ships. *Marine Policy, 25*(2), 143-157.

Wang, N. L. (2013). *Study on the structure and optimization of the Pearl River Delta inland navigation channel network*. Unpublished master’s thesis, South China University of Technology, Guangzhou, China.

Wang, P. S. & Zheng, Q. L. & Chen, X. H.. (2013). *Research on Telescopic Conveyor Belt of Inland Self-unload Carrier.* Paper presented at the Inland Maritime Committee of Nautical Association of China. Annual conference 2013. China.

Zhou, C. (2011). Analysis of Self-Discharging Sand Carrier Vessel' s Stability and Emergency Scheme after Capsizing. *China Navigation, 34*(3), 44-48.