



Vessel traffic safety in busy waterways: A case study of accidents in western shenzhen port



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ABSTRACT

Throughout the world, busy waterways near large ports witness heavy vessel traffic in recent decades. The waterways are characterized by high risk in terms of loss of life, property, and pollution to environment. To facilitate maritime safety management with satisfactory efficiency and efficacy, the authors propose a framework of safety indexes to evaluate the risk level in busy waterways according to the accident severity, fatality rate and special indicators of maritime transportation. The safety indexes consist of Safety Evaluation Index (SEI) and Safety Warning Index (SWI), and are derived from the proposed risk criteria of Chinese vessel traffic. As a case study, data on vessel traffic accidents reported in the Western Shenzhen Port, South China from 1995 to 2015 are analyzed. The actual risk level of this area during the period is calculated under the framework. The implementation of the safety indexes indicate that the risk criteria and safety indexes are practicable and effective for the vessel traffic management. The methodology based on long-term accident data can significantly support the risk analysis in the macroscopic perspective for busy ports and waterways, such that SWI can act as threshold to trigger actions, while SEI can act as an indicator to measure safety status.

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1. Introduction

Maritime transport is the backbone of the international trade and global economy. Around 80% of global trade by volume are carried by sea and are handled by ports worldwide (United Nations Conference on Trade and Development, UNCTAD, 2014). Chinese shipping and port industry have witnessed a drastic development during the last decades. The total freight volume of shipping industry and throughput of ports in China reached 5.98 and 12.45 billion tons respectively, which are 6.9% and 5.8% higher than that in 2013 (Ministry of Transport of the People's Republic of China, 2014). Among top 20 container terminals, 10 terminals come from China. For example, Shenzhen port, which is adjacent to Hong Kong in South China, ranks the third largest one in the world. Furthermore, the country is ambitious to launch the project of “The Belt and Road Initiatives” to open a new chapter in the shipping and port indus-

try. However, the continuous growth of vessel traffic in the busy waterways and the rapid expansion of some hub ports have posed great risk to the private and public sectors. In case of accidents, devastating consequence, such as loss of life, property and damage to environment, will hit the ports (Yip, 2008; Yin et al., 2010; Mou et al., 2010).

In 2014, 260 maritime accidents occurred in China, causing 247 lives loss and CNY 259 million loss (Ministry of Transport of the People's Republic of China, 2014). Studies based on accident statistics, especially long-term accident data, can clearly profile the safety level in maritime transportation, and demonstrate the overall picture of the current situation. Generally, safety means that people understand the risks and are prepared for them (Haapasari et al., 2015). It is the condition of being safe or free from dangers. The concepts of risk and safety are associated and overlap with each other. Kaplan (Kaplan, 1997) defined risk as a complete set of triplets which consist of “scenario, likelihood and consequence”. All of these triplets represent the three questions about risk: “What can go wrong? How likely it is? and What is the consequence?”. Aven (2012) classified the definitions of risk into nine categories. Goerlandt and Montewka (2014, 2015) reviewed the concepts of

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maritime risk and proposed that, in the application area, risk is strongly tied to probability and expected values.

In order to evaluate of safety, many efforts have been made in different engineering fields. Fault tree and event tree analysis were widely applied in the field of accident investigation. Liu (Liu et al., 2015) combined fault tree and quantitative analysis methods to obtain a more comprehensive view of accident and its possibilities to occur. In process industry, event tree method was applied to identify the accident propagation paths and the most dangerous equipment in order to analyze the domino scenarios which have severe consequences of accident. The safety level of land-use planning can then be improved (Alileche et al., 2016). Probabilistic Risk Assessment (PRA) methods are also extensively used in the field of safety management and risk analysis (Wu and Chen, 2016; Uralinis et al., 2015; Špačková et al., 2013). With the rapid development of information and computer technology, big data theory and advanced techniques were also introduced to study the mechanism of safety and accident. Martín (Martín et al., 2014) applied data mining technique to study the relationships between road conditions and crash accidents to improve road safety. Verma (Verma et al., 2014) utilized association rule mining to identify safety patterns in steel plant.

The authors appreciate the aforementioned methods and novelty in the academic fields. However, as a complex-social-technological system (Qureshi, 2007; Pence et al., 2014), maritime transportation is involved with couples of sub-system parts. Modelling all the parts and the coupled uncertainty of safety are challenging. Thus for maritime transportation system, safety can be defined as an acceptable state of risk by society (Eliopoulou et al., 2016). The International Maritime Organization (IMO, 2002, 2007) promoted Formal Safety Assessment (FSA) as a framework for risk assessment and management. Moreover, all risk is advised to be controlled under ALARP (As Low as Reasonably Practicable) principle (Jones-Lee and Aven, 2011). Basically, there are five steps when applying FSA method: the first step is “Hazard Identification”, then “Risk assessment”. In the third step, risk control options should be developed. Cost-benefit analysis about the risk control options is performed in the fourth step, and at last recommendations based on the aforementioned steps are proposed to decision-makers. Under the guideline of FSA, various risk assessments have been carried out in the field of maritime safety management (Görçün and Burak, 2015; Sutton, 2014; Zhang et al., 2013). However, Merrick and Van Dorp (2006) and Goerlandt (2015) criticized the imprecise risk measurement caused by subjective judgments and the uncertainty of risk during the procedure of performing FSA.

Risk awareness is the most significant element in the safety management and accident prevention. It usually refers to the acknowledgement of risks and the active process of risk reduction or elimination. For safer shipping, IMO has developed and maintained comprehensive regulatory frameworks such as the international convention for the Safety of Life at Sea (SOLAS) and Standards of Training, Certification and Watch keeping for Seafarers (STCW), and guided the regulatory development within its member states. By thoroughly enforcing these laws and regulations, maritime safety can be expected (Eliopoulou et al., 2016). Maritime Safety Administration (MSA) in China, the same agency as the coast-guard in other countries, is the competent authority to enforce the laws and regulations of navigation safety. An effective approach to enhance the risk awareness of shipping stakeholders, is launching campaign for law enforcement, e.g. more detailed Port State Control (PSC) inspections and on-scene safety patrols, especially when the safety status of vessel traffic is getting worse or the risk is emerging. These actions are of great importance to reduce the accident rate within their governing waters. The same is true for the airport security inspections. For instance, some security incidents will

automatically raise security/risk level, and consequently the airport authority will apply more extensive inspections for passengers.

In order to determine the conditions, which can effectively trigger the actions to maintain the safety of vessel traffic, the authors designed, updated and validated two kinds of safety indexes, Safety Evaluation Index (SEI) and Safety Warning Index (SWI), based on the 20-year accidents data of the western ports and waterways of Shenzhen (Mou et al., 2007).

2. Safety index and risk criteria

2.1. Philosophies

Safety index is a number designed to quantify the situation of safety. Since accidents and incidents are the dominant indicators of safety, safety index can be designed using data of accidents. Li et al. (2014) designed the safety index for targeting high-risk vessels. The index was derived from the probability of accidents based on Logistic Regression with a set of variables such as ship age, size and nationality, etc. In road safety management, Chen et al. (2016) developed safety index by combining the indicators of safety performance, policy and culture. The proposed index was used to benchmark road safety performance in European Union. However, there are rare safe indexes, which are explicit and effective to evaluate the safety status of vessel traffic from macroscopic perspective.

The authors believe that well designed safety indexes are beneficial for the vessel traffic management. It can embody a reachable goal for safety management in the future, work as a tool to benchmark the safety status in the previous days, and act as safety threshold. These indexes can be decomposed into Safety Evaluation Index (SEI) and Safety Warning Index (SWI). The former one are based on historical accident data, e.g., the accident rate, the accident severity, the fatality and multi-fatalities, hull loss, etc. These actual risk levels can be compared with the risk criteria which are also derived from historical accident data. If the risk level is lower than risk criteria, the safety status is good (acceptable), otherwise is bad (unacceptable). The latter ones, SWI, are produced on the basis of the risk criteria. It is reasonable that the products of the criteria and exposures (vessels or lives) are unacceptable values of accident number, hull loss and fatalities, which means that the unacceptable values can be treated as the thresholds for risk control.

The acceptable risk level is diverse among different regions and fields, while few risk criteria exist in the maritime community. To deal with it, the authors reviewed the criteria internationally accepted or adopted in the fields of aviation, civil engineering, offshore engineering, etc., put the risk criteria in the context of regional work safety status and policy performance, combined with a couple of specific indicators in maritime industry, and finally treat it as ALARP. It can be concluded that the established risk criteria are practicable. Further, these vessel traffic risk criteria can be adopted for design the Safety Indexes of SEI and SWI. The indexes will facilitate the MSA of China evaluate the traffic situation. Fig. 1 illustrates the framework to design and apply safety indexes for vessel traffic. If the safety status is good and the risk level is below the SWI, it indicates that current safety management measures are effective and should be maintained. Otherwise campaign for law enforcement, safety patrol and other safety policy should be carried out to improve the safety status.

2.2. Practicable vessel traffic risk criteria in China

To design practicable risk criteria of vessel traffic, the following questions should be properly answered.

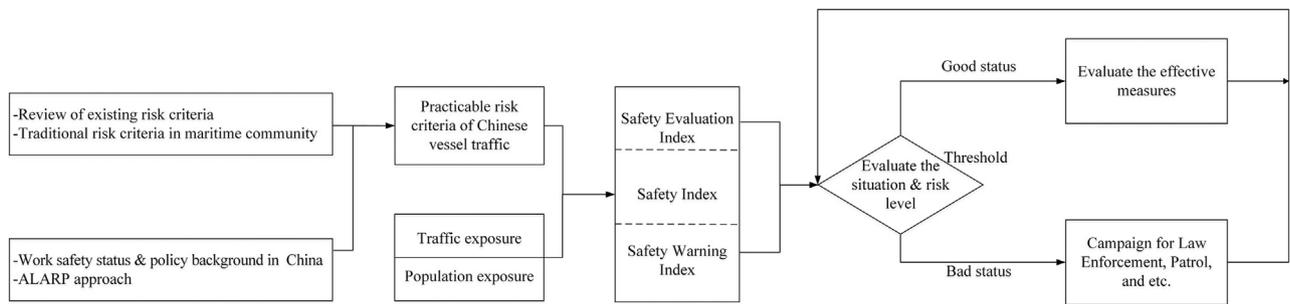


Fig. 1. Framework to design and apply safety indexes for vessel traffic.

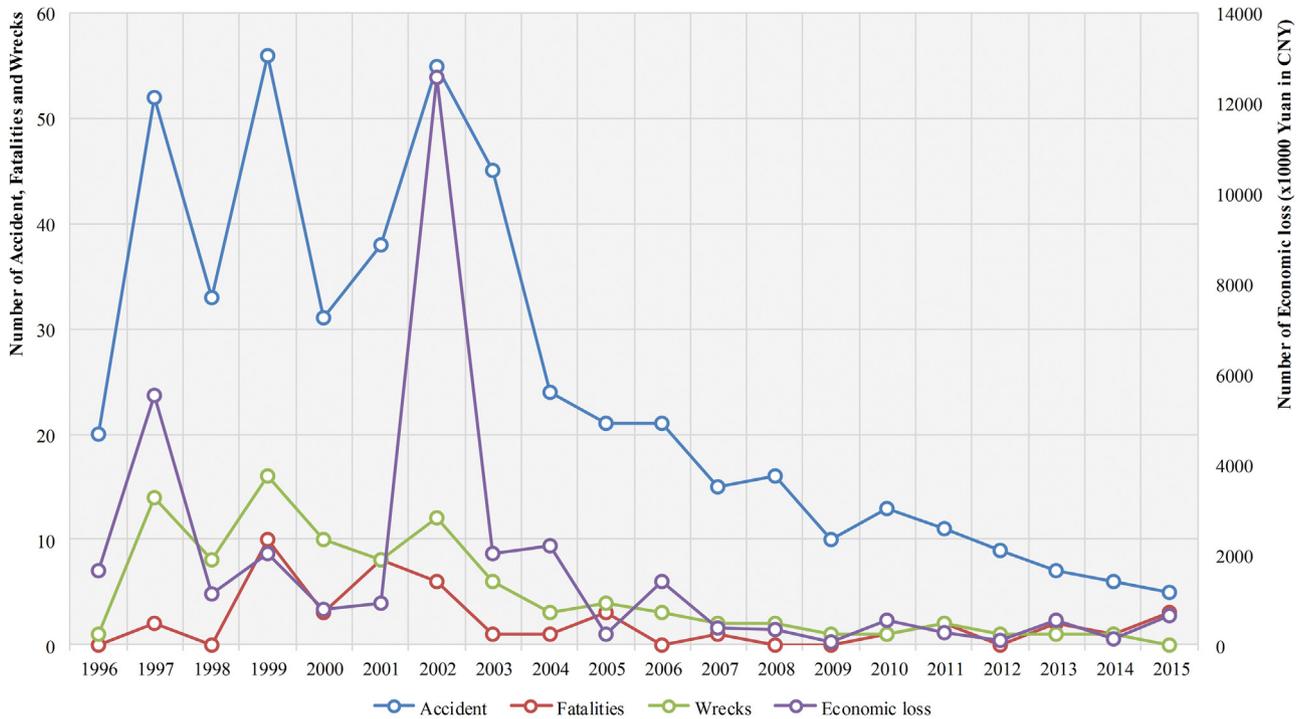


Fig. 2. Ship accident data.

- Can the criteria be examined at international level within modern industries?
- How to take account of the traditional indicators of maritime transportation?
- What is the work safety and policy context of the questioned region?

As being inherent to an undesired event, the severity of accident and the exposure to death are two key subjects deserving the attention in risk assessment for modern societies. From this point, the framework of risk criteria commonly can be established on the frequencies of accident severity and fatality [Blaydes and Leigh \(2006\)](#). Severity can be divided into catastrophic, hazardous, major, minor and negligible. In China, multi-fatality with more than 10 death toll in maritime transportation is defined as catastrophic accident. Their likelihoods of occurrence are described and perceived respectively in the following linguistic description: extremely improbable, improbable, remote, occasional and frequent, which correspondingly relate to certain probability values or intervals ([Table 1](#)). In China, maritime transportation shares the same rule to categorize accidents according to the severity ([Ministry of Transport of People's Republic of China, 2015](#)). Concerning the risk of fatality, both individual and societal risk should

Table 1
Practicable risk criteria for vessel traffic in China.

Indicator	Qualitative definition	Probability Criteria	
		Occurrences/Year	
Catastrophic	Extremely improbable	$<10^{-9}$	10^{-9}
Hazardous	Improbable	$10^{-7}-10^{-9}$	10^{-8}
Major	Remote	$10^{-5}-10^{-7}$	10^{-6}
Minor	Occasional	$10^{-3}-10^{-5}$	10^{-4}
Negligible	Frequent	$>10^{-3}$	10^{-3}
Individual fatality		$10^{-6}-10^{-8}$	10^{-7}
Multiple fatalities		10^{-9}	10^{-9}
Hull loss		$10^{-3}-10^{-4}$	10^{-4}

be assessed. Engineering practice has witnessed many similar standards of individual risk. Society in general has a strong aversion to multiple casualty accidents. Thus, societal risk is a weighting factor to risk and can be narrowed down to the probabilities of multiple fatalities. Health & Safety Executive ([HSE, 2001](#)) investigated the actual fatality rate for workers in even the most hazardous industries. The statistics show this rate normally to be well below the risk of death to any individual of 1 in 1000 per annum for workers and of 1 in 10,000 per annum for the public who have a risk imposed on them 'in the wider interest of society'. [HSE \(2001\)](#) concluded that

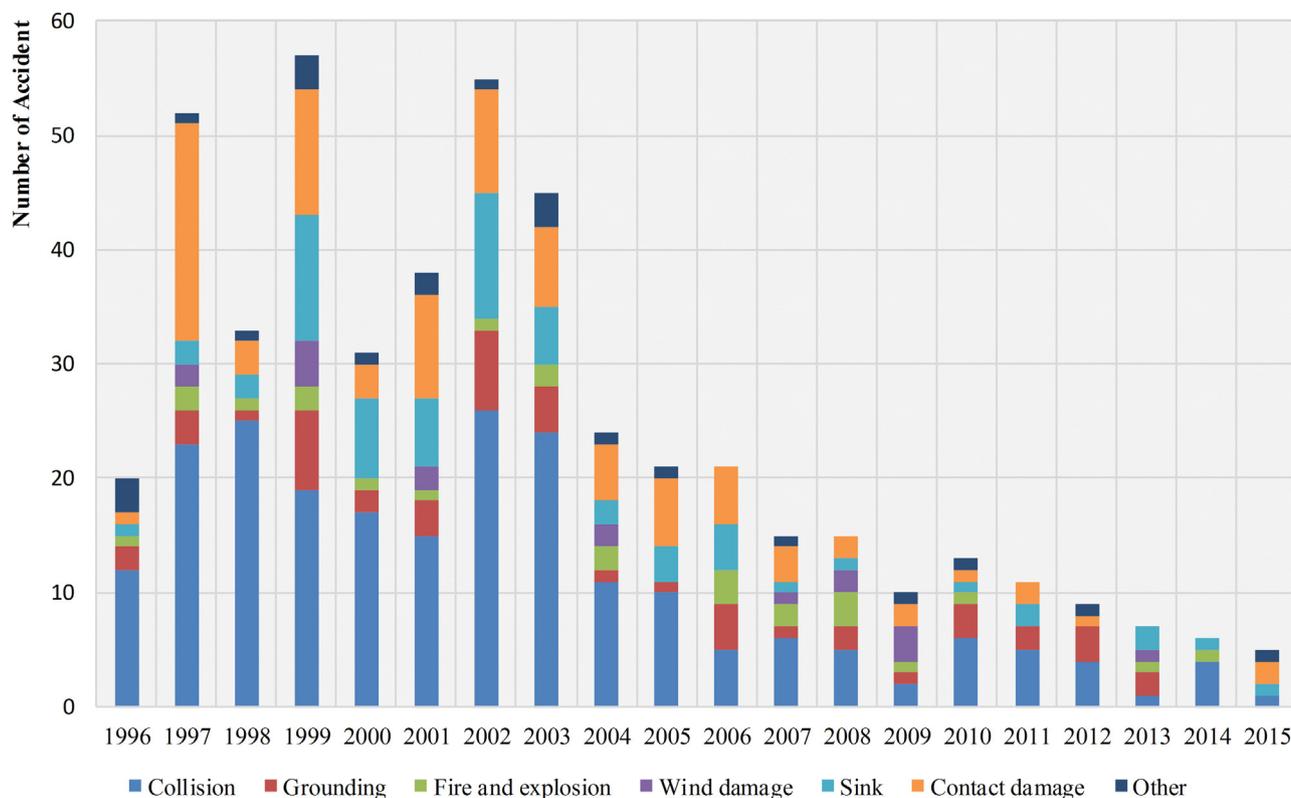


Fig. 3. Categories of accidents.

an individual risk of death of one in a million per annum for both workers and the public corresponds to a very low level of risk and should be used as a guideline for the boundary between the broadly acceptable and tolerable regions. HSE (2001) also proposed that the risk of an accident causing the death of 50 people or more in a single event should be regarded as intolerable if the frequency was estimated to be more than one in five thousand per annum.

In the shipping industry, hull loss rate is an indicator traditionally used and well accepted (Kristiansen, 2004). Since 1966, the annual hull loss rate has decreased from the worst rate of 6.7 per thousand vessels to 1.7 per thousand ships (IMO Library Services, 2006, 2012). The order of 10^{-4} can be employed for the acceptable risk criteria of annual hull loss rate. In addition, per vehicle transport distance (vessel-km) is another special unit used to link risk in the transportation industry, e.g. 10 deaths per vessel-km. In China, the risk control goal involved with this indicator is in the order of 10^{-8} . The multiple fatalities (for example 10 deaths) per vessel-km at a magnitude of 10^{-9} per vessel-km is fairly high in Dutch dangerous cargo transportation (Roeleven et al., 1995).

Risk criteria are strongly region oriented. Besides the international level, it should be integrated in the light of the average work safety status and policy background in a certain region. While the ultimate goal, zero risk, may not be realistic, it seems to be logical to set the allowable risk as low as reasonably practicable (ALARP). The main idea of ALARP approach is to find the region of tolerable risk based on the typical probabilities of occurrence and reduce the risk to a level 'as low as reasonably practicable'.

In general, the risk criteria of vessel traffic can firstly be derived from the definition of risk and criteria internationally accepted or adopted in the field of aviation (Brooker, 2006; European Organisation for the safety of air Navigation (EOSAN), 2000), civil engineering (Purdy, 1993), offshore engineering (Toffoli et al., 2005; Frederking et al., 2004), public health (Stirling and Gee, 2002), etc., and then be examined with the probabilities of different sever-

ity of accidents and fatality (individual and multiple) with the international level in different engineering areas. Meanwhile, the risk criteria should take account of the traditional indicators in maritime transportation, current work safety status and policy background in a certain region. Finally, the allowable risk is monitored according to the principle of ALARP. Thus the authors propose practicable risk criteria for vessel traffic in China as shown the right column of Table 1. These values are determined from the lower limit of the probability of the occurrences or the center of the probability interval. Meanwhile, as the discussed above, these values are in conformity with knowledge and experience from engineering fields including maritime industry, and Chinese situations.

2.3. Safety indexes

Practicable risk criteria make it possible to design the reasonable SEI and SWI. By analyzing statistics on the long-term data of accidents and exposures (ships and lives), the actual frequencies of occurrence can be determined. The order of the frequency value is treated as actual risk level. The safety status of vessel transiting in the waterway is determined based on the comparison of accident frequency value and the risk criteria (Table 1) by the corresponding orders, if there is no violation to the risk criteria, the safety status of vessel transiting in the waterway is good, otherwise is bad. As for SWI, it can act as safety thresholds and provide early warnings to favor safety regime's timely response. The SWI can be derived from the products of exposures and the risk criteria. Because the risk criteria are measured by years, under some circumstances, annual assessment will lag behind the requirement of warning. It is better to shorten the action period of some SWI to one month. Therefore, long term statistics on maximum of monthly occurrences can be a part of SWI.



Fig. 4. Spatial patterns of ship accidents (red dots stand for accident). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Table 2
Statistics of Ship accident.

Year	Total	Negligible	Minor	Major	Hazardous	Catastrophic
1996	20	15	3	1	1	0
1997	52	37	4	5	6	0
1998	33	26	1	3	3	0
1999	56	38	7	7	4	0
2000	31	21	4	6	0	0
2001	38	30	1	4	3	0
2002	55	49	1	2	3	0
2003	45	39	4	1	1	0
2004	24	20	2	1	1	0
2005	21	18	1	2	0	0
2006	21	8	6	5	2	0
2007	14	9	2	2	1	0
2008	16	12	4	0	0	0
2009	10	8	2	0	0	0
2010	13	8	2	3	0	0
2011	11	6	2	3	0	0
2012	9	8	1	0	0	0
2013	7	4	1	2	0	0
2014	6	4	1	1	0	0
2015	5	2	3	0	0	0

3. Data source

To design the safety indexes, it is necessary to obtain accident data with different severity and pattern, which can be used to calculate the actual risk, and also the traffic patterns which is the basis of exposures estimation.

3.1. Accident data

Shenzhen is located on the east bank of the estuary of the Pearl River and is adjacent to Hong Kong. The western waterways form the single access for most ships from upstream river to Hong Kong, and it also provides a shortcut for those to cross the water from Hong Kong going to east coast of China. With the development of new ports and waterways, the traffic risk is increasing rapidly in the congested ports and waterways.

The accident data was collected from the database of Shenzhen MSA from 1996 to 2015 (Table 2, Figs. 2 and 3). Collision, contact damage, sink and grounding accident take major part of the ship accident records (45.56%, 18.65%, 12.9% and 10.1% respectively). Monthly occurrences were fluctuating with maximum 5 cases. Fig. 4 demonstrates the spatial patterns of accidents that happened in the waters from 2003 to 2015.

3.2. Vessel patterns

Vessel patterns can be extracted from the traffic data which was collected from Shenzhen MSA and Ministry of Transport of the People's Republic of China. On the basis of the traffic data, the characteristics of traffic such as distribution of ship length and ship types can be obtained (Figs. 5–7). This paper only presents the latest traffic data from 2003 to 2015. In this period, the traffic volume of Shenzhen has witnessed a continuous growth from 230,000 to 535,000 transits. Among the traffic more, than 83.8% of them are in the western area. The MSA of Shenzhen performed a field observation on vessel traffic in 2013. Container ships and cargo ships are dominant types in the vessel traffic, and ferry and fishing ships are with similar percentage of more than 10%. Fig. 7 demonstrates that

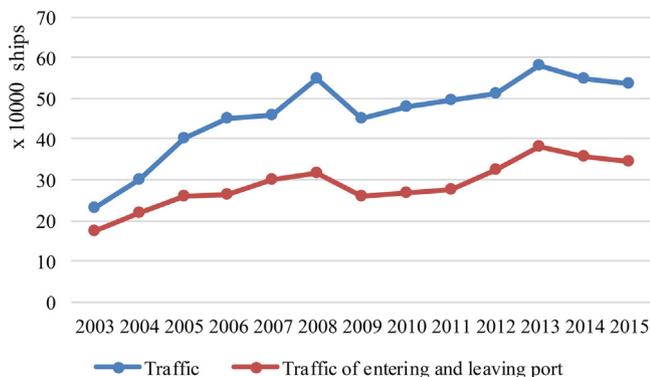


Fig. 5. Ship traffic in Shenzhen Port.

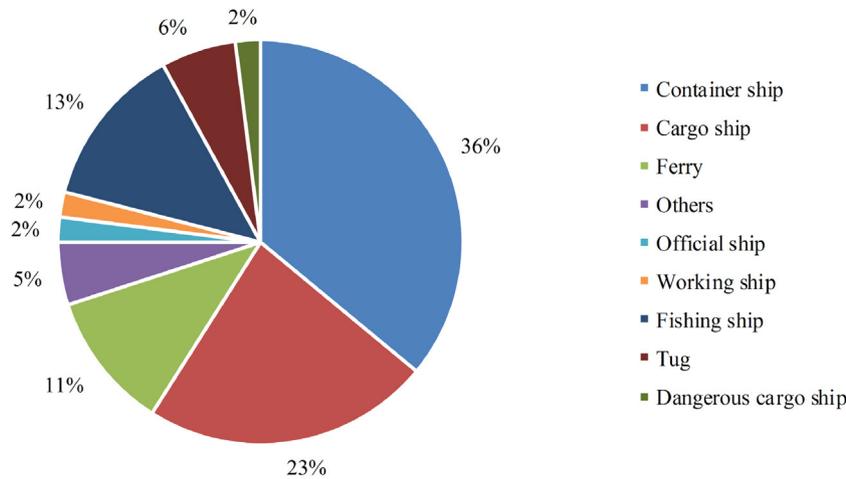


Fig. 6. Ship category distribution of vessel traffic.

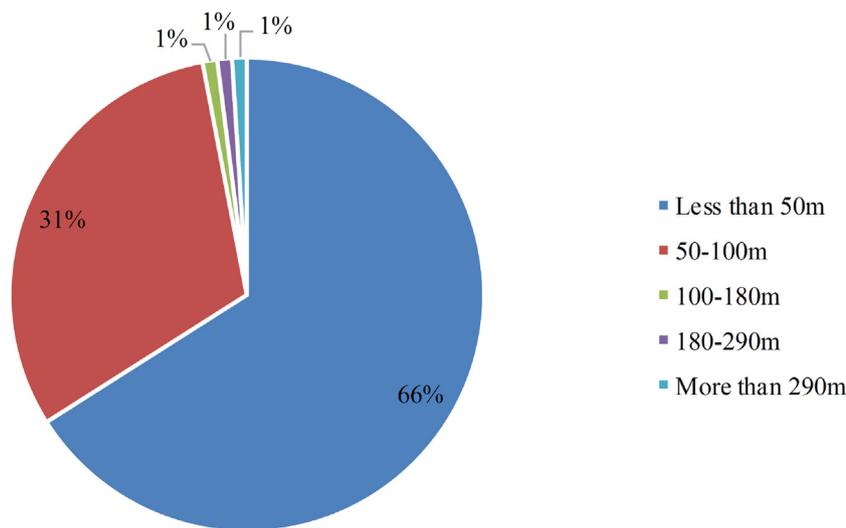


Fig. 7. Ship length distribution of vessel traffic.

small vessels, for example length over all (LOA) below 50m, shares more than half of the vessel traffic. Compared with the traffic composition in 2004, the share of container ship remained stable at 36% meanwhile ferry's dropped into 11%, which indicates the upward trend of cargo transportation. The trend of ship's maximization is also proved by the comparison of ship length distribution between 2004 and 2013 that the share of ship with length less than 50 m dropped from 90% to 66%. In addition, several years of data from MSA and Vessel Traffic Services (VTS) shows that the amount of passing traffic has increased from 24.28% to 35.5%. In 2015, the traffic of ship entering or leaving the ports of Shenzhen is 345,000 transits, and the passing vessels are up to 190,000 transits.

Combined with the aforementioned traffic information, the total traffic can be estimated and the magnitude of traffic volume growth is precisely calculated, which is also the critical variable for the later risk level calculation.

3.3. Exposure population

The exposure to fatality risk is a key subject which can reflect the safety status of certain area. By combining the exposure population as denominator and accident casualty records, the risk of fatality can be obtained. Statistics indicate that the passenger capacity of Shenzhen has increased from 2.46 million in 2003–4.65 million in

2015. Based on this fact and taking an average of 10 crew members per vessel for other ship types, the total exposure of population is up to 10.15 million in 2015, which is twice as large as the number of exposure in 2004.

4. Implementation of safety indexes

4.1. Results of safety indexes

The safety indexes have been estimated since 2004, and was put into use in 2005. Every year the MSA updates the indexes to assess the risk of vessel traffic in the waters. Table 3 shows the actual risk level of the Western Shenzhen Port in the last 20 years. The order of the values of the risk level can be taken as the SEI which can be compared with the criteria in Table 1.

Generally, the SWI can be derived from the products of the risk criteria and the exposures. For example, according to Table 1. the criteria of the 'Major' accident rate will be 10^{-6} . Given the exposure of traffic is 535,000 in 2015, the annual threshold will be 5 cases. However, according to the criteria, the rate of the 'Hazardous' and 'Minor' accident are different from that of the 'Major' accident by 2 orders of the magnitude, which means the occurrence of the 'Hazardous' accident should be nearly zero, while the threshold of 'Minor' accident will be 100. The number for 'Minor' accident

Table 3
Actual risk level of the western ports and waterways in Shenzhen.

Items	1996	1997	1998	1999	2000	2001	2002
Negligible	8.00E-05	1.90E-04	1.30E-04	2.00E-04	1.10E-04	1.40E-04	2.10E-04
Minor	1.60E-05	2.00E-05	5.20E-06	3.70E-05	2.20E-05	4.70E-06	4.30E-06
Major	5.30E-06	<u>2.50E-05</u>	<u>1.60E-05</u>	<u>3.70E-05</u>	<u>3.30E-05</u>	<u>1.90E-05</u>	8.70E-06
Hazardous	<u>5.30E-06</u>	<u>3.00E-05</u>	<u>1.60E-05</u>	<u>2.10E-05</u>	0	<u>1.40E-05</u>	<u>1.30E-05</u>
Catastrophic	0	0	0	0	0	0	0
Hull loss	5.30E-06	7.10E-05	4.10E-05	8.50E-05	5.50E-05	3.80E-05	5.20E-05
Fatalities	–	–	–	<u>2.00E-06</u>	6.10E-07	–	–
Items	2003	2004	2005	2006	2007	2008	2009
Negligible	1.70E-04	6.67E-05	4.50E-05	1.78E-05	1.96E-05	2.18E-05	1.78E-05
Minor	1.74E-05	6.67E-06	2.50E-06	1.33E-05	4.35E-06	7.27E-06	4.44E-06
Major	4.35E-06	3.33E-06	5.00E-06	<u>1.11E-05</u>	4.35E-06	0	0
Hazardous	<u>4.35E-06</u>	<u>3.33E-06</u>	0	<u>4.44E-06</u>	<u>2.17E-06</u>	0	0
Catastrophic	0	0	0	0	0	0	0
Hull loss	2.61E-05	1.00E-05	1.00E-05	6.67E-06	4.35E-06	3.64E-06	2.22E-06
Fatalities	–	–	–	–	1.13E-07	0	0
Items	2010	2011	2012	2013	2014	2015	
Negligible	1.67E-05	1.21E-05	1.57E-05	6.90E-06	7.27E-06	3.74E-06	
Minor	4.17E-06	4.05E-06	1.96E-06	1.72E-06	1.82E-06	5.6E-06	
Major	6.25E-06	6.07E-06	0	3.45E-06	1.82E-06	0	
Hazardous	0	0	0	0	0	0	
Catastrophic	0	0	0	0	0	0	
Hull loss	2.08E-06	4.05E-06	1.96E-06	1.72E-06	1.82E-06	0	
Fatalities	–	2.28E-07	0	1.87E-07	8.94E-08	2.96E-07	

Table 4
SWI designed for the Shenzhen Maritime Safety Administration (MSA).

Indicator	Thresholds Occurrence/year
Hazardous	≤1–2 cases
Major	≤5 cases
Minor	≤10 cases
Negligible	≤20 cases or Sum of Minor and Negligible 30 cases
Total accident	≤37 cases/Year or ≤5 cases/Month

threshold is too large to meet the ALARP principle and also is not in consistent with the actual accident statistics, in this case the SWI should be reviewed from long term statistics and proposed in ALARP approach. In the real safe work status, MSA cannot totally eliminate the Hazardous accident (see Table 2), so it is better to take 1 or 2 cases as SWI. For the Western Shenzhen Port, the detailed SWI are presented in Table 4.

4.2. Implementation and discussion

From Table 3, the actual risk level of the Catastrophic, Hazardous, Major, Minor, Negligible, Hull Loss and Fatality are in the range or the order of 0, 10⁻⁵–10⁻⁶, 10⁻⁵–10⁻⁶, 10⁻⁵–10⁻⁶, 10⁻⁴–10⁻⁵, 10⁻⁵–10⁻⁶ and 10⁻⁶–10⁻⁷ respectively during 1996–2004. At the beginning of 2005, after the totally examination of the Safety Evaluation Index, the MSA realized the high risk level of hazardous and major accidents (underlined in Table 3). In 2005, MSA re-adjusted the routes of different vessel traffic, especially for the high-speed catamaran, and increased the patrols and PSC inspections. These campaigns worked well in the vessel traffic safety management in 2005. Unfortunately, a Liquefied Petroleum Gas (LPG) ship “Ya Ping” collided with a general cargo ship “Yi Shun” in 2006, resulting in a three-day-long closure of the fairway. It was a severe accident of the port and indicated an excess of the safety index. Thus, the MSA timely launched a two-year-long campaign for the dangerous cargo ships and old small ships. All the local sectors of the MSA were informed by the safety goal according to safety index designed: (1) strictly avoid fatality event and the up limit of fatality will be 3 deaths; (2) absolutely avoid the multiple fatalities; (3) eliminate the hazardous accident, and control it within 2 occur-

rences per year. With every efforts of colleagues in the MSA, as the result, the maritime accident and incident frequency in Shenzhen waterways has decreased to a very low level with a downwards trend since 2008.

The framework can also be introduced to other ports and waterways. The key is to collect sufficient historical data of accidents and traffic, and to establish regional risk criteria. The criteria presented in this paper have been examined at the international level in different engineering fields and conservatively treated for safe using or reference. For the SWI, the detailed indexes probably be different from what is presented in this paper. They depend on the policy of the authorities. The indexes will be robust and will also be based on risk criteria and statistics on accidents.

5. Conclusions

Vessel traffic in the vicinity of busy waterways and large ports pose high risk to both private and public sectors. Safety and risk management related to the vessel traffic has been becoming a very important issue in maritime industry. However, few safety indexes that can evaluate the safety status of vessel traffic from macroscopic perspective have been proposed. In order to facilitate the authority on maritime safety and risk management, the authors propose a framework of safety indexes based on the accident severity, fatality rate and special indicators of maritime transportation. The safety indexes consist of Safety Evaluation Index (SEI) and Safety Warning Index (SWI), and were derived from the proposed risk criteria of Chinese Vessel Traffic. As a case study, the vessel traffic and accidents in the Western Shenzhen Port has been presented.

After Analyzing the historical accident data with a span of 20 years, the following conclusion can be drawn:

1. The full examination of the Safety Evaluation Indexes indicates the general safety status of vessel traffic in Shenzhen waters is good. The indexes were fluctuating during the time span and in some years the high risk level originated in hazardous accidents.
2. SWI, which is produced by the products of risk criteria and exposures (vessels or lives) and long-term statistics on accidents, has been developed as the threshold to trigger risk control.

3. Since 2005, the indexes have been widely implemented in safety management for vessel traffic by the Shenzhen MSA as part of their safety policy. According to the historical accident data, the actual risk level of vessel accident witnessed a downward trend which indicates that the safety indexes are effective and practicable. The framework of safety indexes can also be applied for other ports and waterways to improve maritime safety management

To maintain the efficiency and efficacy of the safety indexes, the following suggestions are proposed:

1. To enhance the awareness of the important role of maritime safety to the economy, society and ecological benefits and the functions of the safety indexes in improving maritime safety, a comprehensive system of regulations and laws should be adopted.
2. Since long-term data of vessel traffic accident is required to estimate the regional risk criteria and safety indexes, the maritime safety administration or competent authorities should establish a complete database of vessel traffic accidents and accident record and investigation policy.
3. The maritime safety administration or competent authorities, as the agency which is responsible for the continuously improvement of maritime safety and risk management, and implementation of safety indexes, should prepare and adopt series of safety measures to mitigate the risk and improve safety of the vessel traffic in their governing waters.

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