THE HONG KONG POLYTECHNIC UNIVERSITY

Department of Logistics

MARITIME SAFETY POLICY

AND RISK MANAGEMENT

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CERTIFICATE OF ORIGINALITY

I hereby declare that this thesis is my own work and that, to the best of my knowledge and belief, it reproduces no material previously published or written, nor material that has been accepted for the award of any other degree of diploma, except where due acknowledgement has been made in the text.

____(Signed)

ZHENG HAISHA ____________________(Name of student)

TO MY DEAR FATHER, MOTHER AND BROTHER

ABSTRACT

The Port State Control (PSC) programme has been established to implement international maritime safety and security conventions since 1982. The port States which are members of the PSC programme conduct on-board inspections on foreign ships calling at their ports in order to prevent shipping accidents from occurring in their water. However, one of the difficulties of conducting on-board inspections is that a large number of ships call at a port at any one time, and under this situation port State cannot inspect every ship calling at its port due to the limitation of resource. Further on-board inspections could delay fast turnover rate that characterizes a good logistics system.

This study helps port States make use of vessels' historical safety records to identify potential substandard ships before conducting inspections and determine appropriate port inspection rates. Thus this research contributes to the existing maritime safety policy and risk management in four aspects.

First, this study addresses the effectiveness of the PSC programme and assesses

the methods of selecting ships for inspection. Data on ship total loss (annually, from 1973-2006) and on the PSC inspection records (annually, from 1994-2005) were collected and analysed. The results reveal that the programmes are effective to improve the safety level of maritime transport and the methods are effective but the efficiency and stability of these methods should be improved.

Secondly, two propositions are proposed to construct a risk indicator system, based on the theory of managerial function and the theory of predictive index in organizational behavior, which are (i) strengthening responsibilities of the actors within the maritime safety net; and (ii) abstracting characteristics form shipping accidents investigation. The new risk indicator system guided by the two propositions provides a basis for constructing a unified information collection database.

Thirdly, a new method of determining risk level of a ship is proposed based on the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) model. By comparing with the weighted-sum model used by the Tokyo MOU, it is proven that the TOPSIS model can improve the efficiency of identifying substandard ships under the existing Tokyo MOU information collection database.

Finally, for the first time, a tool, based on Stackelberg game, is proposed to decide an optimal port inspection rate. It is proven that by the proposed tool, at the equilibrium of the game, there are an optimal port inspection rate and an optimal shipowner's effort level. The result indicates that port States may not benefit from over-frequent inspection.

In summary, the whole research provides the basis for forming an integrated selecting-ships-for-inspection system. The effectiveness of the PSC programme provides the basis for its further development. Two propositions are the basis for constructing a risk indicator system. The TOPSIS model is to improve the efficiency of targeting substandard ships and a tool, based on Stackelberg game, is to determine the optimal port inspection rate.

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LIST OF ABBREVIATIONS

ABS	American Bureau of Shipping Ship Classification Society
BV	Bureau Veritas
CCS	China Classification Society
DNV	Det Norske Veritas
ELCTRE	Elimination et Choice Translation Reality
FOC	flags of convenience
FSA	Formal Safety Approach
GL	Germanischer Lloyd
ILLC	International Convention on Load Lines
ILO Convention	Merchant Ship Convention
IMO	the International Maritime Organization
ISM Code	International Safety Management Code
KR	Korea Register of Shipping
LR	Lloyd’s Register
MARPOL	International Convention for the Prevention of Pollution from

	ships
MRM	Maritime Risk Management
NK	Nippon Kaiji Kyokai
Paris MOU	The Paris Memorandum of Understanding on port state control 1982
PSC	Port State Control
RS	Russian Maritime Register of Shipping
RINA	Registro Italiano Navale
SOLAS	International Convention for the Safety of Life at Sea
STCW	International Convention on Standards of Training, Certification and Watchkeeping for Seafarer
Tokyo MOU	The Memorandum of Understanding on port state control in the Asia-Pacific Region 1993
TOPSIS	Technique for Order Preference by Similarity to Ideal Solution
UNCLOS 1982	United Nations Convention on Law of the Sea 1982
USCG	United State Coast Guard
USCG MSM	United States Coast Guard Marine Safety Manual
WPM	weighted-product model
WSM	weighted-sum model

1 Introduction

Maritime transport is about moving goods or passengers by sea. International trade is a factor to promote its development [17, p. 3]. On the other hand, shipping accidents [56] with serious danger to the environment and human beings is a factor to threaten its development. Port states benefit form its development and also inflict the damage. Therefore the port States conduct on-board inspections on calling ships to find balance between its development and its damage.

This chapter will first review the context where on-board inspections are conducted by port States. Then the research problem and the aim of the research study are stated. It concludes with the outline of the structure of the research study.

1.1 Background

Detrimental environmental and social impacts inflicted by shipping accidents threaten the interest of port States. In 1989, for example, the *Exxon Valdez* hit rocks in Prince William Sound spilling some 240,000 barrels of crude oil onto Alaskan shores in the United States of America. The disastrous ecological after-effects were the deaths of 250,000 seabirds, 2,800 sea otters, 300 harbour seals, 250 bald eagles, up to 22 killer whales, and billions of salmon and herring eggs [27]. About US$3 billion has been spent on the cleanup effort. On May 23, 2007, the Ninth United States Circuit Court of Appeals stood its ruling that Exxon owes US$2.5 billion in punitive damages [10, 28]. This incident evoked the attention of the world on shipping accidents.

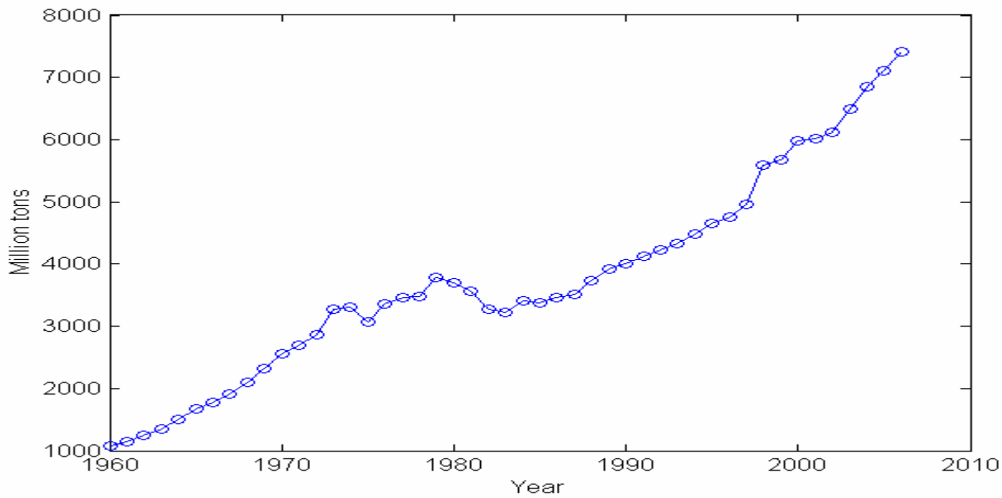
In terms of investigating shipping accidents, it is revealed that oil spillages, such as those caused by the *Exxon Valdez,* 1989; *Aegean Sea*, 1992; *Erika*, 1999; *Laura D'Amato*, 1999 and more recently the *Prestige*, 2002, show the importance of the inspection of such vessels [97]. Therefore inspection of ship safety is an administrative measure to decrease the likelihood of occurring shipping accidents [97]. Port States conduct on-board inspections on visiting foreign ships to prevent shipping accidents from occurring in their water.

The Port State Control (PSC) programme was introduced by the International Maritime Organization (IMO) in 1982 to implement international maritime safety and security conventions. Members of the PSC programme reach agreement on the requirements when conducing on-board inspections. After the PSC programme was introduced, safety inspections on visiting foreign ships are spread among port States [40].

Three trends have pressed port States to pay great attention on conducting inspections on visiting foreign ships.

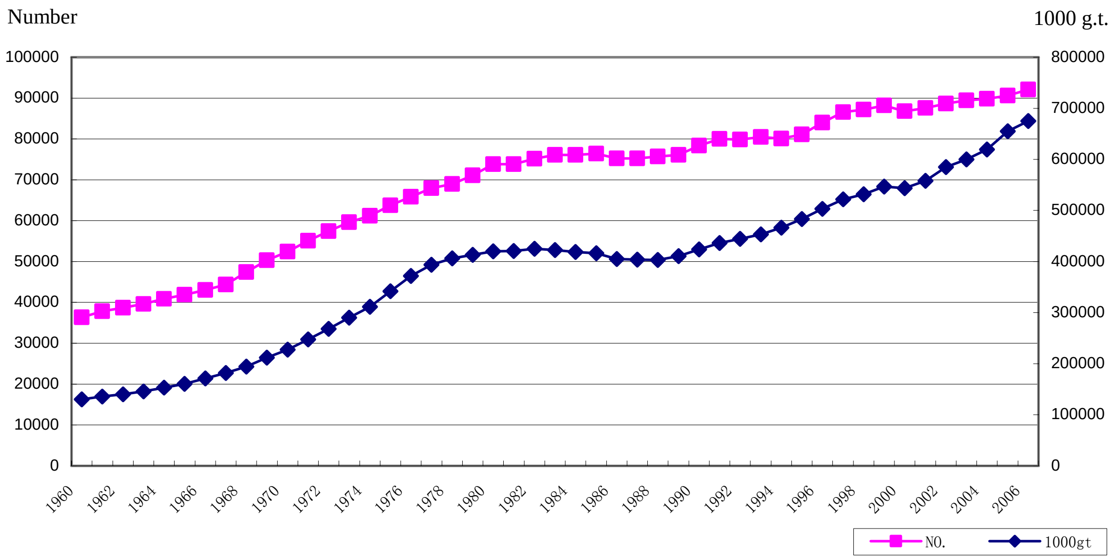
The first trend is that the growth of seaborne trade promotes the growth of maritime transport. The volume of international seaborne trade is kept in continued increase trend given the ongoing trend towards globalization (cf. Figure 1-1). The growth rate went up by 580% over the time period from 1960 until 2006. Accordingly, the expansion of the world trading fleet has been the evidence of the prosperity of maritime transport (cf. Figure 1-2). The growth rate in vessel number went up by 154% and the growth rate in carrying capacity went up by 420 % over the time period from 1960 until 2006. The facts indicate that more ships may call at a port State and hence more efforts of conducting ship inspections are required.

Figure 1-1: International Seaborne Trade over the Time Period from 1960-2006



Source: Review of Maritime Transport [73], 1960-2006.

Figure 1-2: World Trading Fleet Development over the Time Period from 1960-2006



Source: Shipping Statistics Yearbook [82], 1960-2006.

The second trend is that the chances of shipping accidents increase under the trend of the growth of maritime transport. China, for example, as the world's economic growth centre, may be increasingly confronted with the consequences of shipping accidents under the policy of openness and the trend for globalization. Based on the statistics from the Mariner Group, which has collected oil-pollution-related casualties over the time period from 1967 to 2004, the six worst casualties in the Chinese water were recorded from 1994 (cf. Table 1-1). The evidence shows that China faces more shipping accident risk after 2000; five of the six pollution-related casualties happened after 2000, accounting for about 80%. The fact indicates that shipping accidents threaten interest of port States accompany the growth of maritime transport.

Table 1-1: Oil Pollution-related Casualties in Chinese Water

No.	Time	Site	Event	Result
1	Oct. 17th, 1994	Hebei, China	An oil spill blamed on the Huahai No.2 tanker, owned by the Huahai Company of Beijing	1,000 meters of beaches and reefs at Dongshan, a resort area at Qinhuangdao, were polluted
2	Nov. 14th, 2000	Hong Kong, China	A small Chinese oil freighter collided with a Norwegian vessel and sank	Some 230 cubic metres of heavy oil leaked into the sea north of Hong Kong's Lantau Island, 10,000 square metres of the oil slick reached the 12-sq-km Sha Chau Marine Park, a dolphin sanctuary
3	Jan. 14th, 2001	Taiwan, China	An oil spill caused by a Greece-registered ship aground	Some 1,150 tonnes of fuel oil gushed out and marine mammals in the area, such as dolphins, were highly endangered by the spill
4	May 30th, 2001	near Shanghai, China	A collision between a South Korean vessel (Dayong) and a Hong Kong's vessel (Dawang) in dense fog at the mouth of the Yangtze River, near Jigujiao	About 700 tonnes of the chemical, which is poisonous to humans, seeped into the waters and and fishermen along the eastern coast fear their livelihoods could be threatened for years to come
5	Nov. 23rd, 2002	China	A Chinese ship has collided with a Maltese-registered oil tanker	Spreaded an oil slick of 2.5 miles by 1.4 miles across the Bohai sea
6	Dec. 7th 2004	China	A collision between two container ships near the mouth of South China's Pearl River, the region's biggest oil spill in five years.	Nearly 450 tonnes spilled. Oil was mainly leaking from the fuel tanks of the MSC llona, that caused a slick of about 17 kilometres long and up to several hundred meters wide.

Source: Oil Spill History [64].

The third trend is that it is widely accepted that the development of maritime transport is of great benefit to economic development [32, 53] and the environmental protection [45]. Maritime transport can be a major economic factor influencing international trade operation [32]. Without it the import and export of goods on the economic scale would not be possible. Over 90% of the international cargo is transported by sea [53]. On the other hand, after comparing cargo transport by sea with by road on environmental factors measured in terms of technology and economics, maritime transport is less environmentally damaging than road transport under the condition of safety transport [45]. This trend pushes port States to develop maritime transport.

In summary, the world economy has become increasingly reliant on global logistics, on maritime logistics in particular. Simultaneously, the fact, shipping has always been a risk industry, arouses public concerns of shipping risks. The standards of controlling risks shipping faces have consequently become higher and higher. Further, with the implementation of IMO Port State Control (PSC), it provides a 'safety net' to catch substandard ships and is regarded as measures complementary to Flag State Control (FSC) system in order to achieve the aim of 'cleaner oceans and safer ships'. PSC system and procedures, in many ways, can be improved upon. Among all, recognition and classification of substandard ships before accidents are vital for the success of PSC and maritime safety. They have also been considered as the weak links in the PSC programme. All these have triggered a great need for an integrated warning system for sub-standard ships that is not only interactive (dynamic) but also agile (quick response).

My research is kept on the line of conducting on-board inspection and put my focuses on selecting ships for inspection and determining port inspection rate. The following part is the research problem in this study.

1.2 Research Problem

Research problem is produced from the difficulties of conducting on-board inspections by port States. The following are the two difficulties.

First, limited resource restricts the amount of ship inspections [21]. There are a large number of foreign ship callings at a port each year. For example, there were 36,000 callings at Hong Kong ports by ocean-going vessels. Nearly average 100 ships per day called at Hong Kong ports. There are four officers in Hong Kong taking charge of on-board inspections. It is not realistic to check every ship.

Secondly, on-board inspections may do harm to economic development of a port. On-board inspections delay the fast turnover rate that characterizes a good logistics system. When a ship is to be inspected, more time need to be spent on waiting for the arrival of port State inspection officer and the on-board inspection. During the process, delay is caused and the ship's schedule may be changed.

Therefore loss is produced. For example, inventory cost is one of identified losses. Any loss caused by ship inspections is transferred ultimately to customers [35].

The difficulties, in summary, for port States to conduct ship inspections are that a large number of ships calling at a port at any one time, the port authority can not inspect every visiting foreign ship due to resource limitation, and further on-board inspections may do harm to economic development of a port in terms of fast turnover rate that characterizes a good logistics system. To address the two difficulties, the research problem is defined as the following:

(1) Are the PSC programmes and existing used methods to identify ships with high shipping accident risk level for inspection (hereafter, this kind of methods is abbreviated to ‘selection methods’) effective?

Assessment of effectiveness of the PSC programme and the existing used selection methods are to verify the performance of the PSC programme, i.e. improving maritime safety level, and to find weakness in the practice of the existing used selection methods. The first question is to provide the base for the further development of the PSC programme and the improvement of the selection methods.

(2) How should the vessels’ historical information be used to identify ships with high shipping accident risk level (hereafter, this kind of ships is abbreviated

to ‘ships with high risk level’)?

The second question includes two parts: (1) what information should be collected; and (2) how the information is used to identify the ships with high risk level. A vessel’s historical information includes ship age, ship type, flag State, classification society, shipowner, inspection records, and other information relative with the ship. The purpose of the second research question is to help port States identify ships with high risk level before conducting an on-board inspection, and thereby reduce ship delays due to unnecessary inspections.

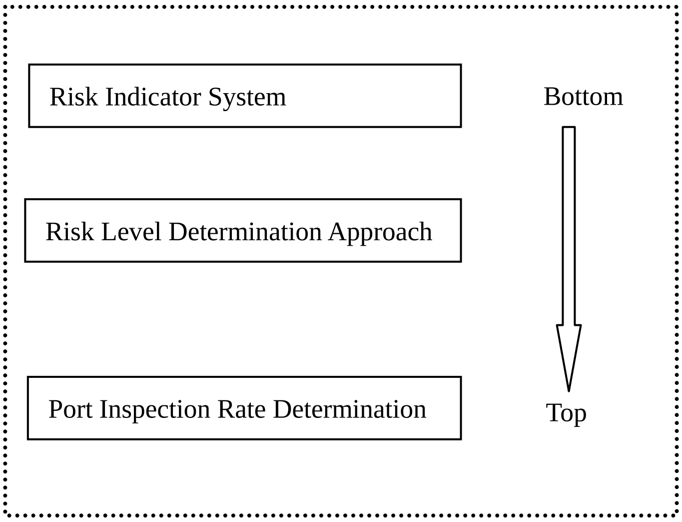
(3) How is an optimal port inspection rate determined?

The optimal port inspection rate is determined through taking into account positive and negative economic effects of ship inspections on a port and shipowners calling at the port. So the third research question is to help port States achieve the goal of preventing the occurrence of shipping accidents in their water without hampering their ports’ economic progress, and motivate shipowners to implement required safety maintenance policies.

1.3 Objectives of this Research Study

An integrated selecting-ship-for-inspection system is proposed in this study, which includes three subsystems mainly a risk indicator subsystem, a risk level determination approach subsystem and a port inspection rate determination subsystem (cf. Figure 1-3).

Figure 1-3: An Integrated Selecting-Ships-for-Inspection System



An Integrated Slecting-Ships-for-Inspection System

The three subsystems construct the integrated selecting-ships-for-inspection system. A risk indicator subsystem is a primary subsystem. The subsystem is to guide port States to collect information about a ship's risk level of the occurrence of shipping. A risk level determination approach subsystem is a risk assessment system based on the risk indictor subsystem. The purpose of the approach is, by means of a scoring mechanism, to determine a ship's risk level of the occurrence of shipping accidents from the information contained in the risk indicators. The determination of port inspection rate subsystem is to decide which percentage of visiting foreign ships should be inspected without hampering the port's economy development.

The relations among these subsystems are that the risk level determination approach is based on a risk indicator system, and the optimal port inspection rate is determined in the port inspection context.

This study is to address the most critical issue in formulation of an integrated selecting-ships-for-inspection system for port States. The relationship between this system and the research problem can be described as the following:

(1) The first research question, the assessment of effectiveness of the PSC programmes and the existing used selection methods, focuses on basis for constructing the integrated system. Reasons to further develop the PSC programmes and ways to improve the selection methods are explained in this question.

(2) The first sub-question of the second research question, what information should be collected, focuses on the risk indicator system. It is proposed in this question that the guidelines for collecting vessels' information and the ways to investigate whether certain pieces of new information should be abstracted as a risk indicator.

(3) The second sub-question of the second research problem, how the collected information is used, puts focuses on risk level determination approach. It is proposed in this question that a new tool to improve the efficiency of identifying substandard ships.

(4) The third research question, how is port inspection rate to be determined, puts focuses on the port inspection rate determination. It is proposed in this question that a decision-making tool to consider the relationship behind the two parties, port authorities and shipsowners, during the process of deciding port inspection rates.

1.4 Structure of this Thesis

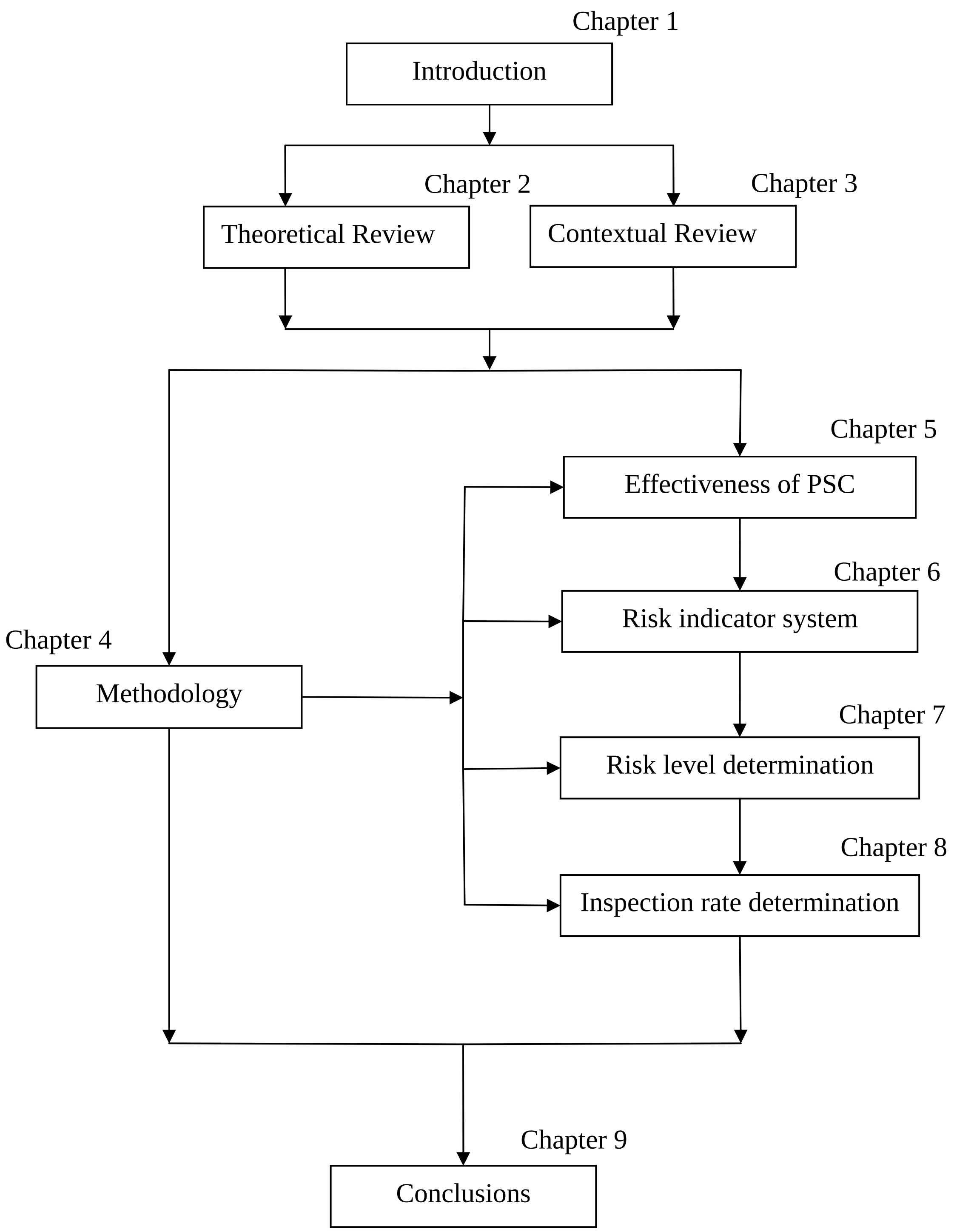
The organization of this thesis is summarized as the following (cf. Figure 1-4):

Chapter 1 is provides the context where on-board inspections are conducted by port States and then introduces the research problem from the context. Chapter 2 critically reviews relevant literature on theories in risk assessment. Chapter 3 reviews maritime safety management and selection methods aopted by the PSC programme to provide the research contextual background. Chapter 4 provides a brief theoretical framework for the discussions conducted on the remaining chapters.

Chapter 5 assesses the effectiveness of the PSC programmes and the existing selection methods. Chapter 6 proposes two guiding principles to construct risk indicator system. Chapter 7 discusses the risk level determination approach, and the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) is introduced to improve the efficiency of selecting ships for inspection. Chapter 8 discusses the process of optimal port inspection rate determination based on a Stackelberg game.

The last chapter, Chapter 9 summarizes the whole research, concludes the thesis and points out the directions for further research.

Figure 1-4: Organization Chart of the Thesis



2 Risk Assessment in Maritime Transport - Theoretical Review

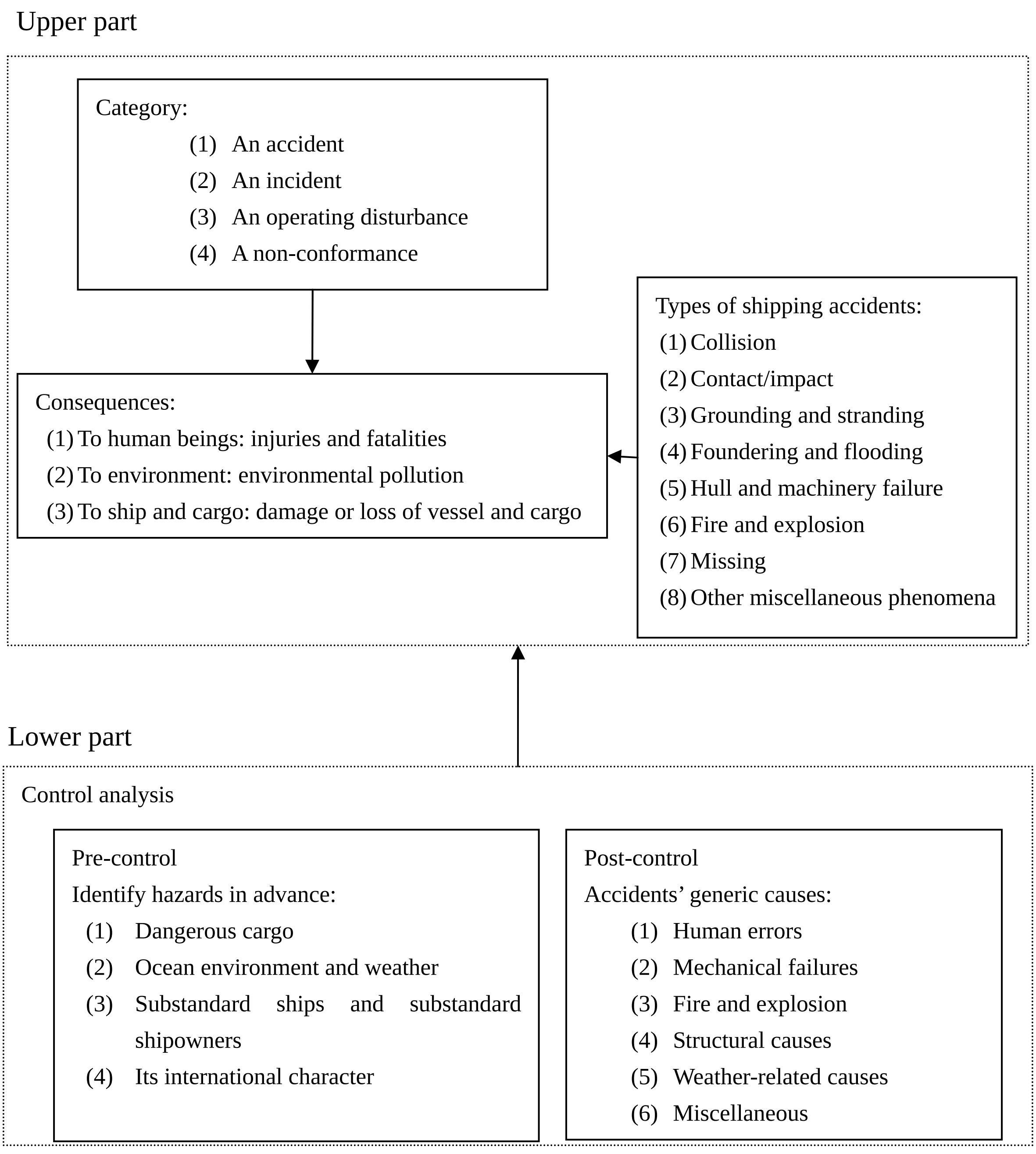
This chapter critically reviews relevant literature on theories in risk assessment..

2.1 Understanding Shipping Accidents

A theoretical framework for a systematic understanding of shipping accidents was summarized based on the research of Kristiansen [50]. Shipping accidents category, consequence of shipping accidents, types of shipping accidents and identified shipping accident causes (cf. Figure 2-1) are included in this summary.

The upper part in Figure 2-1 shows the category of shipping accidents based on different degrees of seriousness. The category includes accident, incident, operating disturbance, and nonconformance. An accident is defined as an undesired event that results in damage to human beings, ship and cargo and/or the environment [33, 36, 50]. An incident is defined as an undesired event that is detected, brought under control or neutralized before it results in accidental outcomes [50]. An operating disturbance is defined as a situation where the operating criteria for a system or component are violated [50]. A non-conformance is defined as a situation in which the operation is outside certain criteria that have been determined as acceptable [50].

Figure 2-1: Understanding Shipping Accidents



Source: Adaptation from Kristiansen [50].

An accident, as defined by Kristiansen, will cause the most serious outcomes. The consequence of an accident can be grouped into the following three effect aspects: (1) to human beings, i.e. injuries or fatalities; (2) to environment, i.e. environmental pollution; and (3) to ship and cargo, i.e. damage or loss of vessels and cargos [33, 36, 50].

Types of shipping accidents include (1) collision, i.e. striking between ships; (2) contact/impact, i.e. striking with other surface external objects, not a ship; (3) grounding and stranding, i.e. hitting the seabed or shore; (4) foundering and flooding, i.e. opening and flooding of hull; (5) hull and machinery failure, i.e. directly responsible for the accident; (6) fire and explosion, i.e. fire, explosion or dangerous goods release; (7) missing; and (8) other miscellaneous phenomena.

The term shipping accidents used in this study refers to the first category of shipping accidents, i.e. accident, and does not involve with incident, operating disturbance, and nonconformance. Although information on incident, operating disturbance, and nonconformance is useful for maritime safety management, shipowners do not report the information publicly. Therefore port States as external managers collect information on accidents of a vessel, the characteristics of which information are of clear phenomena, consequences and reported publicly. Casualty Return [14] and World Casualty Statistics [102] are data resources of this kind of information.

The lower part in Figure 2-1 shows shipping accident causes, which have been identified to prevent shipping accidents from happening and can be used in helping risk control. Based on the guideline of pre-control and post-control, these causes are grouped into two categories.

Pre-control includes identifying hazards in advance. Hazards means possible events or conditions that may result in severity, i.e. cause significant harm. The hazards, identified in advance, include (1) dangerous cargo, which can cause fire easily, explosion, poisoning, or other environmental damage; (2) ocean environment and weather; (3) substandard ships and substandard shipowners; and (4) a ship's international character.

Post-control comes from the investigation of accidental causes. An accident can be due to the following generic causes: (1) human errors; (2) mechanical failures; (3) fire and explosion; (4) structural causes; (5) weather-related causes; and (6) miscellaneous. More generally, an accident can be attributed to technical causes and human causes. As a rule of thumb, 20% of shipping accidents are often attributed to technical causes, and 80% to human causes, which have been proven by Gaader, Rognstad, and Olofsson [33], Kristiansen, Koster, Schmidt, Olofsson, Soares, and Caridis [51] and Soares, Teiceira, and Antao [85].

Attempts to realize pre-control and post-control of the occurrence of shipping accidents have been conducted and are reviewed in following sections.

2.2 Research Directions of Risk Assessment in Maritime Transport

Although maritime transport has been existing for a long time, the use of formalized approaches to quantify risks in probabilistic terms has lagged somewhat behind other industries, such as the nuclear, aviation and chemical industries [25, 84]. However, risk assessment research, to reduce shipping accident risk, has been conducted.

There are three research directions in the field of risk assessment in maritime transport: elimination of technical causes, elimination of human causes and overall risk level analysis. The following are to review research studies in the three directions.

2.2.1 Elimination of Technical Failure

2.2.1.1 Stability Theory and Reliability Theory

Researchers initially applied risk assessment to the fields of ship design and shipbuilding. These attempts are to improve quality of ship structure. Stability theory and reliability theory have been developed and are under continued development.

Stability theory has been used in the field of probabilistic resistance.

Attempts standing for intact ship stability and ship with damage stability started in the 1940s. To prevent ships from capsizing when they meet beam seas and winds, the research methods were adopted as follows: phase plan analysis [7]; forced stochastic rolling looses motion stability [71]; model experiments [101]; and the probabilistic models developed from full-scale data [22]. Surf riding was studied by Umeda [94]. Pure loss of stability was investigated by Umeda and Yamakoshi [95].

Watertight compartment was one of the early examples in which probabilistic assessments of risk of failure were made. The accident of the *Titanic* in 1914 is a case in point. Water intake can only be controlled by subdividing the ships in watertight compartments so there are always enough intact ones to provide the necessary buoyancy. Wendel [99] initially discussed this problem. Tagg [89] investigated the probability of survival for different types of ships. Abicht [1] extended the concept to assess the effect of subdivision on the expected oil outflow from damaged tankers. A recent research direction is to design configurations on probability of oil outflow if collision or grounding happens.

Reliability theory has been used to quantify the probability of structural failures and the contribution of different components to it. Attempts to simplify design problems by application of reliability based methods have started in the 1970s [61]. For example, fatigue cracks may often threaten watertight integrity, and reliability approaches have been used to quantify the risk of crack growth and to plan maintenance. Soares [83] reviewed these previous studies.

2.2.1.2 Formal Safety Assessment

Pure engineering and technological solutions have reached a point of diminishing returns, and this calls for methods where human element is considered. Soares and Teiceira [84] point out that many of the contributors for the major part of shipping accidents are human errors in all phases of the process, i.e., ship design, shipbuilding and operation not the residual risk inherent in the pure design decisions. The concerns about human element have motivated to unify human element and technology in the general operational aspects of shipping.

The Formal Safety Approach (FSA) was adopted to realize this kind of unification. It uses formalised analysis and quantification of risk as a basis for rational decision making. In essence, the analysis consists of: the identification of hazards; the assessment of risks associated with the hazards; ways of managing the risks identified; cost benefit assessment of the options identified; and decision on which options to select. According to this process, the FSA approach would allow safety goals to be set by identifying specific risks and hazards and then dealing with them through rational risk management methods. Rosqvist and Tuominen [75] described steps of the FSA in detail. The FSA is a research framework during the process of analysing issues to introduce the concept of risk.

The concept of FSA was first presented in 1993 (MSC/62/24/3) and was adopted by the IMO in 1995. It reached a consensus on what kinds of analysis should be applied in assessing the safety of a ship's hull and machinery, its environment, its performance or related factors as an aid for improving ship safety [25]. As stated by Wang [98], it is considered that "marine safety may be significantly improved by introducing a formal 'goal-setting' safety assessment approach so that the challenge of new technologies and their application to ship design and operation may be dealt with properly".

The FSA includes the techniques such as Fault Tree Analysis and Failure Mode and Effect Analysis. Their research topics include propulsion systems of steering gears and engine room fire [25].

One of the characteristics of FSA is selected focus [50, p.11]. FSA assessment (i.e. a risk analysis and assessment methodology) is in general seen as a promise for more efficient control of risk. However, such methods may be criticized in a number of ways: they oversimplify the systems studied, a number of failure combinations are overlooked due to the sheer magnitude of the problem, and operator omissions (e.g. forgetting or overlooking something) are not addressed in these models.

2.2.2 Elimination of Human Failure

Human causes are directly related to personnel and crews competence. So the International Safety Management (ISM) code was introduced.

The ISM code concerns about the poor management standards and the contribution of the human error and management shortcoming from marine casualty investigations. When a common understanding is established for the main causes to the accidents, the clauses that form the ISM code can be linked to these causes as potential preventive measures. It is planned that an expert panel shall make an estimation of the various preventive measures.

So the scope of the ISM code is directly related to personnel and crew competence and general operational aspects of shipping. An operator is required to demonstrate that he has an effective safety management system that addresses all identified risks and provides proper controls for dealing with these risks.

2.2.3 Overall Risk Level

The overall risk level means the possibility of the occurrence of shipping accidents and is the main concern of the maritime safety management after dealing with the individual identified technical or human risk. The calculation of overall maritime risk of a vessel has the following development:

Firstly, risk in the context of engineering is normally presented as the product of the consequences and the probability of occurrence. Li and Cullinane [56] follow this concept and construct a maritime risk, which is that the relationship between a risk and a hazard can be described by the elements of probability and severity of the hazard as shown in the following formula:

$$R = SP$$

where R represents the risk associated with a particular hazard as measured in monetary terms, S represents the likely severity associated with succumbing to the hazard and P is the probability of occurrence of such a maritime hazard at a given time period.

Secondly, based on the concept of particular risk, the concept of total risk picture for a given activity or system is developed [56], which can be complex and involve a number of types of shipping accidents that may lead to a particular consequence, demonstrated as follows:

$$R = \sum_{i=1}^{n} s_i p_i, \qquad i = 1,2,\cdots,n$$

Where $R =$ total risk; $i =$ a type of shipping accidents that may lead to a particular consequence; $s_i =$ consequence measure for the i type of shipping accidents and $p_i =$ probability of the relevant consequence s_i for the i type of shipping accidents.

Finally, a framework to construct the total risk picture for a given activity or system is further developed [50, p.32], which can be more complex and involves many different phases relating to relevant scenarios. The framework is to break the total risk picture down into different phases of relevant risk scenarios, as demonstrated below:

$$R = \sum_i \sum_j s_{ij} \cdot p_{ij}$$

where: R, i have the same meanings as the above defined; $j =$ number of phases within each accidental type; $s_{ij} =$ consequence measure for the i type of shipping accidents at the j phase and $p_{ij} =$ probability of the relevant consequence s_{ij} for the i type of accident at the j phase. This equation computes the total risk for a given activity/system as the sum of the risks for each shipping accident type and each phase of the accidental process.

The standard approach to total risk analysis of a vessel is easy to state but extremely difficult to implement. In theory, it would entail the estimation of probability and consequence. In practice, however, such a method would present nontrivial and perhaps insurmountable difficulties, since probability and consequence are difficult to estimate in quantitative terms. One main reason is that the calculation of the probabilities of shipping accidents is very difficult, since shipping accidents are typically very rare events [33].

Shipping accident statistics analysis is one way to overcome these difficulties in calculating total risk of a vessel [33, 84]. Studies based on shipping accident statistics provide an overall view about the levels of safety involved in the shipping activity through the frequency of casualties, which imply the hypothesis that risk levels existing in maritime transportation can be estimated through analysis of shipping accident statistics. Soares and Teiceira [84] claim that shipping accident statistics analysis is the first type of studies that addresses safety levels and updates based on data that are more recent and being regularly published, such as Shipping Statistics Yearbook [82] and World Casualty Statistics [102].

On the basis of the primary accident statistics, specific research, reflecting the distinction of safety records in the different types of ships, ship sizes, ages etc, has been developed. Faragher, Pizzo and Rausch [29] studied the effect of age on the casualty. Pronce [72] analysed the relationship between marine vessel total losses and selected vessel population characteristics such as ship age and registration flag. Thyregod and Nielsen [91] studied the age effect on the total yearly casualty rate. Li and Wonham [58] studied the relationship between accident total loss and flags through examination of twenty-year of data on 36 world principal fleets and on world fleets in general, analysing their safety records in terms of accidental total loss. This kind of research provides theoretical base for forming a method used to identify substandard ships.

2.3 Summary

In the area of risk assessment in maritime transportation the use of formalised approaches to the quantification of risks in probabilistic terms has lagged somewhat behind other industries, such as nuclear and process. At present, there are three directions in this area to quantify risk and to support decisions, which are studies based on elimination of technical causes, elimination of human causes and overall risk level analysis. Each of these directions has the different research focus. Elimination technical and human failures are grouped into post-control and can propose concrete measures no matter technology or ordinary safety management, to improve the safety of maritime transport. Overall risk level analysis provide basis for pre-control to find substandard ships since the statistic characteristics of substandard ships are investigated through statistic analysis. However, although substandard ships are potential vehicle for risks, these researches do not put their focus on the relationship behind ships and risks, so an integrated warning system for sub-standard ships will fill this gap to develop a maritime risk criterion number for a specific type of ships.

3 Ctronlling Substandard Ships - Contextual Review

3.1 Understanding Substandard Ships

Maritime administrative authorities and IMO divide ships into substandard ships and standard ships. The definition of substandard ship used in the United States Coast Guard Marine Safety Manual (USCG MSM) [96] is that in general a vessel is regarded as substandard if the hull, machinery, or equipment, such as lifesaving, fire fighting and pollution prevention, is substantially below the standards required by the United States laws or international conventions, due to: (1) the absence of required principal equipment or arrangement; (2) gross non-compliance of equipment or arrangement with required specifications; (3) substantial deterioration of the vessel structure or its essential equipment; (4) non-compliance with applicable operational and/or manning standards; or (5) clear lack of appropriate certification, or demonstrated lack of competence on the part of the crew.

Under the PSC programmes, substandard ships are judged based on the international conventions which are required by the programmes. In this study, the concept of substandard ship defined under the PSC programmes is adopted, since most port States have been members of the programmes.

Substandard ships are seen as a set of ships with high shipping accident risk [42]. Based on substandard ship's definition, a substandard ship is a ship which is substantially below the standards required by the international conventions designed to remove shipping accident risks [4]. So substandard ships are to be regarded as ships with high risks.

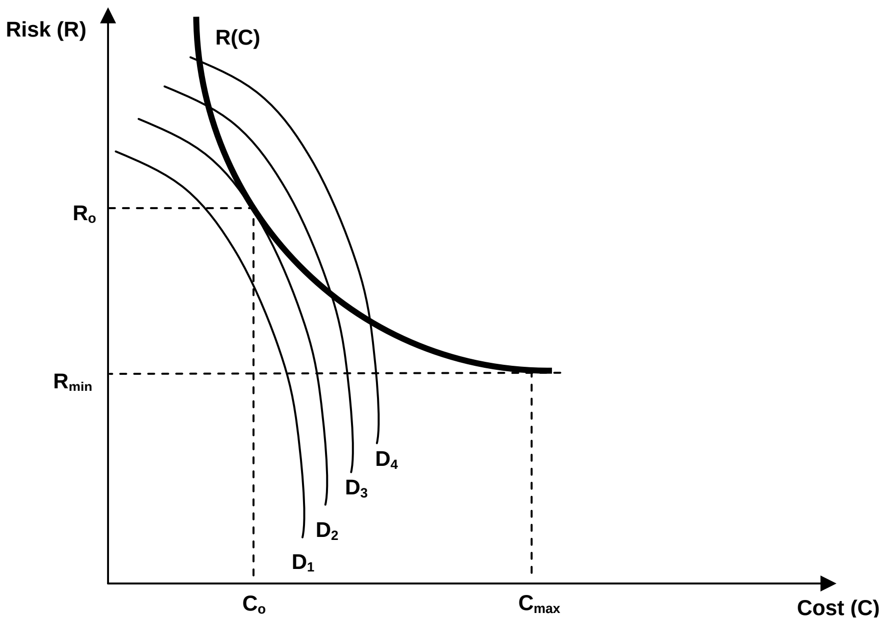
The following are the main characteristics of sub-standard ships based on the research of Li [59]: (1) an ageing fleet; (2) few restrictions on competence as to crew; (3) inadequate training; (4) too heavy crew workload; (5) poor maintenance; (6) communication difficulties; (7) poor management; and (8) crew's adverse living circumstances.

Economic interest and lacking a safety culture explain the occurrence of substandard ships [33, 56].

It is analysed that the difference between the risk level required by a maritime administer and the risk level accepted by individual shipowner (cf. Figure 2-2) [56]. The result reveals that the maritime administrator wants to minimize the risk level ($R_{\min}$) with the requirement of the maximum cost ($C_{\max}$) provided by individual shipowner, on the other hand, individual shipowner, based on his utility function (D), determines the acceptable risk level (R_0) with the cost (C_0) at the cross of Risk-Cost curve $R(C)$ and disutility indifference curve (D). In theory, the interest of $C_{\max} - C_0$ is the motivation of the operation of substandard ships. Additionally, in practice, low freight rates and fierce competition further weaken the demand for standard ships.

The lack of a safety culture might be another reason of the occurrence of substandard ships. The concept of safety culture is that in order to operate a ship safely, it is not enough to have a technically safe system, and for safe operation it is also equally important that the operating personnel should have a proper attitude to safety and management, and the workers must be committed to safety and must realize that safety has the highest priority above all.

Figure 2-2: Risk Preference Patterns Between Shipowners and a Maritime Administer



Resource: [56]

Three prevailing groups of cultures exist in maritime industry [33]: (1) evasion, for example "cutting corners", which does not comply with rules and regulations; (2) compliance culture, which comply with rules and regulations, but only fulfilling the minimum requirements, and (3) safety culture, which continues to improve safety and quality. In the environment of the culture of evasion, there is great potential for the occurrence of substandard ships.

Maritime authorities who lack effective control on safety management to ships provide the conditions for the development of substandard ships. For example, concerning crew qualification, a common phenomenon is fraudulent certificates of competency. Some states do not implement or follow the proper procedure and control in the process of conducting examinations and the subsequent issuing of certificates.

Substandard ships are not only caused by economic interest and lack of safety culture pursued by shipowners, but also pushed by maritime authorities who ignore their safety control responsibility. All these factors provide a hotbed for producing substandard ships.

The following part, Section 2.3.2, is to review maritime safety management system. This system is to manage shipping safety and reduce substandard ships. The entire system is complex since shipping has the nature of internationalization.

3.2 System for Controlling Substandard Ships

3.2.1 The International Maritime Organization

The International Maritime Organization (IMO) is the principal regulatory body in respect of matters related to safety at sea and the prevention of marine pollution at the international level. This organization, a specialized agency of the United Nations (UN), was established in 1948. To help prevent shipping accidents and oil pollution, this organization issued more than 40 international maritime conventions relating to maritime safety and security.

The main criticism is that the IMO is too slow to react to significant issues. Since the IMO is largely a world political organization, the enforcement of major decisions requires consensus among member states. However, usually consensus is difficult to achieve since every state protects its own interest. Although under current conventions there is little in the way of direct enforcement action that may be taken by the IMO, the IMO still tries to improve the safety level at sea by impelling each member state to achieve consensus.

3.2.2 International Safety Shipping Conventions and Regulations

The IMO issued more than 40 international maritime conventions relating to maritime safety and security. The main conventions are listed as follows:

1. International Convention for the Safety of Life at Sea, 1974 with 1978, 1988 protocol and amendments (SOLAS).

The sinking of the *Titanic* on its maiden voyage in April 1912, in which more than 1500 passengers and crew lost their lives, led to the SOLAS convention. The main objective of the SOLAS convention is to specify minimum standards for the construction, equipment and operation of ships [86]. The Original version of the SOLAS convention was adopted in 1974 and was amended a number of times in order to adopt the development of new technology and new safety knowledge.

2. International Convention on Load Lines, 1966 and its Protocol of 1988 (ILLC).

To indicate a ship’s safe carrying capacity, lines at the ship’s side are required by the ILLC, since it has long been recognized that limitations on the draught to which a ship may be loaded make a significant contribution to its safety. The added concern of this convention is that the potential hazards present in different geographical zones and different yearly seasons are taken into account. This convention applies to all ships of 24 metres in length or more, built after May 1970, and ships of 150 gross tonnages or more, built before that date.

3. International Convention for the Prevention of Pollution from ships,

1973 as modified by the Protocol of 1978 relating thereto (MARPOL 73/78).

The pollution damage caused by the *Torrey Canon* in 1967 led to the MARPOL 73 convention. MARPOL 73/78 has a direct effect on preventing pollution from ships. The focus of this convention is on pollution from routine tanker operations and from discharge of oily wastes from machinery spaces. The convention applies to all seagoing ships, except tankers of less than 150 gross tons and other ships of less than 500 gross tons.

4. International Convention on Standards of Training, Certification and Watchkeeping for Seafarer, 1978 and 1995 (STCW, 1978) and (Revised STCW 95)

The STCW convention seeks to establish basic requirements on training, certification and watchkeeping for seafarers at an international level. The origin of adoption of the SCTW convention is the realization that human failure plays a prime role in marine casualties.

5. Merchant Ship (Minimum Standards) Convention, 1976 (ILO Convention No. 147).

The Merchant Ship Convention seeks to strengthen substantially the international will to eliminate the operation of substandard ships. The convention focuses on improving the efficiency and safety of navigation, enhancing measures to protect the marine environment and advancing seafarers' interests in the fields of health and safety. The convention applies to every seagoing ship employed for any commercial purposes.

The ILO Convention No. 147 prescribes a set of minimum standards relating to safety, social security, shipboard conditions of employment and living arrangements to be observed in merchant shipping.

6. International Safety Management Code (ISM)

The International Safety Management Code seeks to induce shipping companies to create a safety management system. The Code, a fairly short document of about 9 pages, borrows an idea of a quality management system and states basic principles and controls which should be obeyed.

These conventions and regulations construct the guidelines for maritime safety control of maritime safety management.

3.2.3 Flag State Control

The IMO is principally a body for the formulation of policies and international ship safety conventions. The flag States have the primary responsibility for implementing and enforcing these policies and conventions. The following is to review the concept of flag State, the responsibility of flag State control and the main issue in the enforcement of flag State control.

3.2.3.1 The Concept of Flag State

Flag State generally denotes the state whose nationality a ship bears and a ship flies the flag which is the symbol of the ship's nationality. After a ship finishes registration, a state assumes authority over the ship and undertakes the national and international responsibilities of a flag State in relation to that ship.

A state has the exclusive right to exercise legislation and enforce jurisdiction over ships flying its flag on the high sea (UNCLOS 1982, Art. 90). In addition to these rights conferred on flag States, there are also considerable obligations. Article 94 of the UNCLOS 1982 Art. 94 states the fundamental principles.

"Duties of the Flag State

1. Every State shall effectively exercise its jurisdiction and control in administrative, technical and social matters over ships flying its flag.

2. In particular every State shall:

(a) maintain a register of ships containing the names and particulars of ship flying its flag, except those which are excluded from generally accepted international regulations on account of their small size; and

(b) assume jurisdiction under its internal law over each ship flying its flag and its master, officers and crew in respect of administrative, technical and social matters concerning the ship.

3. Every State shall take such measures for ships flying its flag as are necessary to ensure safety at sea with regard, inter alia, to:

(a) the construction, equipment and seaworthiness of ships;

(b) the manning of ships, labour conditions and the training of crews, taking into account the applicable international instruments;

(c) the use of signals, the maintenance of communications and the prevention of collisions.

4. Such measures shall include those necessary to ensure:

(a) that each ship, before registration and thereafter at appropriate intervals is surveyed by a qualified surveyor of ships, and has on board such charts, nautical publications and navigational equipment and instruments as are appropriate for safe navigation of the ship;

(b) that each ship is in charge of a master and officers who possess appropriate qualifications, in particular in seamanship, navigation, communications and marine engineering, and that the crew is appropriate in qualification and numbers for the type, size, machinery and equipment of the ship;

(c) that the master, officers and, to the extent appropriate, the crew are fully conversant with and required to observe the applicable international regulations concerning safety of life at sea, the prevention of collision, the prevention, reduction and control of marine pollution, and the maintenance of communications radios.

5. In taking the measures called for in paragraphs 3 and 4, each State is required to conform with generally accepted international regulations, procedures and practices and to take any steps which may be necessary to secure their observance.

6. A State which has clear grounds to believe that proper jurisdiction and control with respect to a ship have not been exercised may report the facts to the Flag State. Upon receiving such a report, the Flag State shall investigate the matter and, if appropriate, take any necessary action necessary to remedy the situation.

7. Each State shall cause an inquiry to be held by or before a suitably qualified person ore persons into every marine casualty or incident of navigation on the high seas involving a ship flying its flag and causing loss of life of serious injury to nationals of another State shall co-operate in the conduct of any inquiry held by that other State into any such marine casualty or incident of navigation."

Within international law it is explicitly stated that flag State is primarily responsible for ensuring compliance with international minimum standards. In other words, the flag State is required to take necessary measures for ships flying its flag to ensure safety at sea with regard to construction; maintenance and seaworthiness; manning, labour conditions and crew training; and prevention of collisions.

However, some of flag States either by intent, ignorance or incompetence are failing to detect and eradicate substandard ships.

3.2.3.2 Flag of Convenience

The origin and development of Flag of Convenience (FOC) is reviewed based on the investigation of Cooper [16].

The origin of FOC was traced back to the 16^{th} century. Spain was the first FOC and English merchant operators were the first users of such FOC, who intended to circumvent restrictions limiting non-Spanish vessels from West Indies trade [16]. Since then the development of FOC can be divided into three stages.

The first stage is from the 16th century to the 1920’s. At this stage, traditional maritime nations controlled ships and registry flags, and the political factor, mainly to avoid being blocked and captured, was the motivation for re-flagging. In 1812, for example, United States' shipowners in Massachusetts changed to the Portuguese flag to avoid being captured by the British.

The second stage is from the 1920's to the 1970's and the purpose of re-flagging was mainly for the advantage of low cost taxation and registration. Panama and Liberia are the main FOC states.

The third stage is from 1970s. FOC has become a widespread phenomenon and becomes a business for many countries. The motivation for switching flags during this period was to reduce operating costs by employing cheaper maritime labour, which is the main reason for flagging out. Another important reason for a modern day re-flagging is to avoid the strict regulations and safety controls of home countries.

The development of FOC shows that FOC provides opportunities for the occurrence of substandard ships. FOC states have few restrictions as to crew and, in some cases, no programmes of the enforcement of required standards of competence. Shipowners acquire a greater freedom to recruit masters, officers and crew from any country to supply their ships and the freedom provides for substandard shipowners the chance to recruit persons without regard to their compatibility, competence or the training undergone.

3.2.4 Classification Society

Classification societies are the bodies which issue class certificates to ships based on drawings, engineering documentation, and inspections during building and tests. And after a ship is classed, it will be surveyed on a regular basis and given recommendations for necessary maintenance and repair to keep its class. In this sense, the class is a kind of quality check.

Classification societies are independent bodies. It means that the classification societies have no official role relative to international and national regulations. They set standards for design, maintenance and repair of ships covering: hull strength and design; materials; main and auxiliary machinery; electrical installations; control systems; and safety equipment.

Classification societies are commercial institutions. The class is the basis for negotiating insurance of a ship. A shipowner is, in principle, free to select a class among about 40 class institutions in all. Shipowners jumping between institutions can avoid costly maintenance and delay an outstanding survey for 3 months. Classification societies face matters related to trade-off between safety and profit to keep a shipowner to pay for a class and associated services.

Different classification societies vary in standards, control regimes and tariffs and some of them may not seriously enforce control and maintenance. For a long time, some classification societies, however, are accepted as quality classification institutions, which are organized in the International Association of Classification Societies (IACS). The IACS consists of 10 member societies: American Bureau of Shipping Ship Classification Society (ABS); Bureau Veritas (BV); China Classification Society (CCS); Det Norske Veritas (DNV); Germanischer Lloyd (GL); Korea Register of Shipping (KR); Lloyd's Register (LR); Nippon Kaiji Kyokai (NK); Russian Maritime Register of Shipping (RS); and Registro Italiano Navale (RINA).

The new trend is that some flag States give classification societies the right to survey ships for registration.

3.2.5 Port State Control (PSC)

3.2.5.1 The Concept of PSC

The main idea underpinning the PSC programmes is that the port States conduct inspections on foreign ships in their ports to verify that the condition of each ship and its equipment complies with the requirements of international regulations and that each ship is manned and operated in compliance with these rules. The port States are entitled the right to require defects to be put right and detain ships for this purpose if necessary (UNCLOS, 1982).

Port States assume the role of the policeman. While it remains the primary obligations of flag States to ensure that vessels registered in their jurisdictions meet appropriate standards, it is clear that some flag States tend to ignore their responsibility, such as the appearance of FOC. The focus has shifted to those with the most lose if shipping accidents happen, namely port States. It is these states which are, by default, being forced to become the first line of defence against substandard ships.

Shipping is a global industry so it needs collaboration between nations. The PSC programmes are initiated by developed maritime nations to prevent substandard ships from trading in their water [100]. The programmes have covered most of the ports worldwide.

The task of the PSC is that many of IMO’s most important technical conventions contain provisions for ships to be inspected when ships arrive at foreign ports to ensure that these ships meet the requirements. These conventions include (cf. Asia-Pacific Port State Control Manual [4]): (1) ILLO 1966/1988; (2) SOLAS 1974/1978/1988; (3) MARPOL 1973/1978; (4) STCW 1978; (5) ILO Convention No. 147.

As a general guide, ships from non-convention states are expected to have been surveyed in a similar manner to those from convention states and should meet all the requirements of these conventions. Therefore, the port States would usually require a full survey to be carried out to ensure that a ship from a non-convention state meets the requirements of the convention, unless the non-convention state has some reciprocal agreement with the particular flag State.

The PSC weaves the safety net for the maintenance of marine safety, security and prevention of pollution in compliance with the international Standards. It is a means of enforcing compliance where shipowners and flag States have failed in their responsibility to implement or ensure compliance.

3.2.5.2 Application of the PSC Inspection

The process of conducting the PSC inspection is similar in all port States joining in the PSC programmes. Hong Kong is a member of the Tokyo MOU (the Memorandum of Understanding on port State control in the Asian-Pacific region 1993) and the application of the PSC inspection at Hong Kong port is taken as an example.

In 1995 the PSC programme was introduced in the Hong Kong by its Marine Department, as an important safety measure for the safety management of the Hong Kong port. The purpose of this inspection system is to ensure that non-Hong Kong registered ships, when they are calling at Hong Kong ports, comply with the requirements of the international maritime conventions regulated by Asia-Pacific PSC Manual [4].

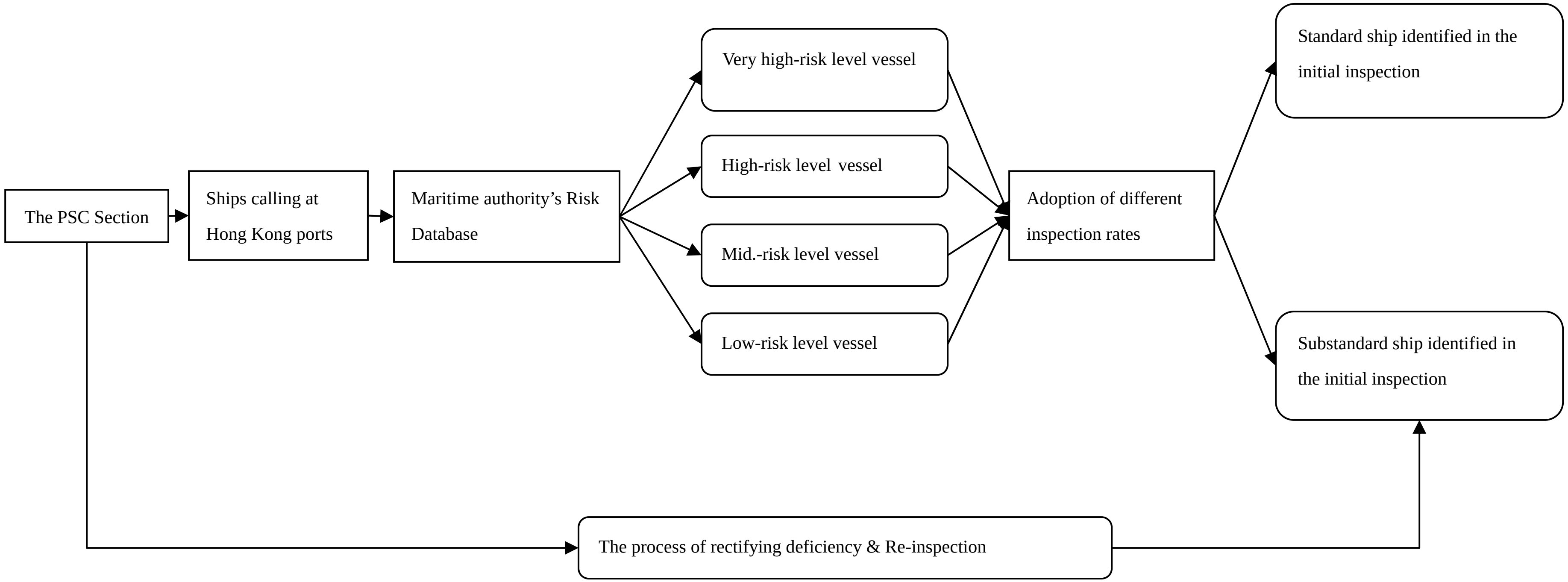
In 2003, more than 20,000 vessels were examined. The inspection rate in Hong Kong Marine Department is about 17% [3]. The whole inspection procedure is illustrated in Figure 2-3.

There are four officers taking charge of spot-checking about 4,000 vessels per year. On average, every inspector can check one ship per day. So the four officers select, based on the values of risk levels of ships within Hong Kong ports, ships with bigger value to conduct on-board inspections.

If serious deficiencies are noticed, the ship will be detained under the request of the PSC programme until the deficiencies are rectified completely. According to the data published on the Hong Kong Marine Department official website (http://www.mardep.gov.hk/en/others/dlist.html), from January 1998 to September 2005, more than 1,000 ships or vessels have been detained in Hong Kong water. In 2003, the maximum of this amount reached 241 and the detention percentage is more than 26%.

Inspection costs spent on checking vessels at the first time are paid by Hong Kong government, and only substandard ships verified by Marine Department will pay for the re-inspection fees. For re-inspection, the hour payment for per vessel is HK$ 3,270 and document charge is HK$ 1,115.

Figure 2-3: Hong Kong the PSC Inspection Procedure



3.3 Selection Methods for Targeting Substandard Ships

There are three typical selection methods adopted by the United States Coast Guard (the USCG) [96], the Paris Memorandum of Understanding on port State control 1982 (the Paris MOU) [67] and the Memorandum of Understanding on port State control in the Asia-Pacific Region 1993 (the Tokyo MOU) [4]. Three regions are advanced in the implementation of the PSC programmes. According to the statement of Özcayir [66, p.35], starting from the 1970s the USCG increased its emphasis on the examination of foreign vessels. The Paris MOU has been in operation since July 1982. The successful experience of the Paris MOU encouraged the Tokyo MOU to work.

The occurrence of selection methods is the result of the development of conduction port States inspections. At the beginning there were no fixed selection methods. In most cases, foreign vessels were boarded only when a particular problem was perceived. On May 1st 1984 the USCG adopted risk-based methodologies as the model for the development and implementation of the security element into the PSC programme. A target matrix is used to identify those vessels at greatest risk of being substandard based on identified risk factors. Afterwards the Paris MOU committee agreed to adopt a risk-based inspection regime to scrap its 25% inspection regime. From March 2004, the Tokyo MOU implemented a computer based ship targeting system for providing a tool for the

PSC officers for selecting ships to inspect.

3.3.1 The Target Matrix Method Used by the USCG

The goal of the PSC programme enforced by the United States is to identify and eliminate substandard foreign merchant ships from their water and to encourage those committed to trading with the United States to adopt management philosophies that ensure compliance with accepted standards [96]. The USCG is the primary agency with responsibility for formulating policies for implementing and enforcing the PSC programme.

If evident factors as a whole or individually endanger the vessel, persons on board, or present an unreasonable risk to the marine environment, the vessel should be regarded as a substandard ship, and should be detained. Vessels which pose the very highest risk are boarded during every U. S. port call while vessels that pose the lowest risk are boarded no more than annually.

Prior to 1983, the USCG practised random monitoring of vessels. The USCG inspection teams, following their policy of inspecting only a fixed percentage of the vessels, frequently boarded the same vessels in port after port and voyage after voyage, without considering the previous records of the vessels or the potential hazards to the port.

In 1984, a multi-tier inspection program, the PSC Program, was ordered by Congress in the Department of Transportation Appropriation Bill [24]. Since this revision, the USCG has followed a two-tier policy emphasizing the monitoring and inspection of those vessels that pose the greatest threat to the port and environment.

A targeting matrix is used to identify those vessels at greatest risk of being substandard based on identified risk factors (cf. Table 2-1). The risks associated with each of these factors are determined based on the USCG boarding data. These determinations are used to assign points using the targeting matrix, which determines the boarding priority given to foreign vessels entering the United States water.

Ships entering a harbour are classed as either High or Low priority vessels (cf. Table 2-2). All ships are "inspected" or "examined" at least once a year. Tankers are "monitored" twice a year at least; more often in the case of High priority vessels. If a ship passes these inspections and is not caught spilling oil while being monitored or at any other time, it continues to be a Low priority vessel. If it does not pass the inspection or has been caught spilling oil, then it is required to bring the vessel up to standard. In addition, it will be placed on the High Priority list for its next visit to any United States ports and will again be inspected and monitored. If it passes the inspection and makes a successful transfer it is then placed on the Low priority list.

Table 3-1: Risk Factors of Foreign Vessel Targeting Matrix

Risk indicators	Indicator measurement	Points and targeting criteria
ship owner	A ship-owner/operator/charterer detention ratio	5 points – Targeted owners list (updated monthly); Targeting Criteria: A targeted owner includes any owner, operator, or managing operator whose vessels have been detained in the U. S. more than once within the previous 12 months under the provisions of an international convention. If a vessel owner or operator has at least 25 vessels that visit U. S. ports each year, the company will not be targeted unless it accumulates 3 or more detentions within a 12-month period. To reduce our administrative burden, we will give the company involved an opportunity to demonstrate their fleet size.
Flag State	A Flag State detention ratio $= \frac{\text{nummber of detentions under a flag State}}{\text{number of vessels under its registry, which entered U.S. waters}}$	7 points –Targeted Flag State List (updated monthly); Targeting Criteria: A flag State's detention ratio $\geq$ An average detention ratio with more than a single detention carried out under the authority of an international convention within the past 12 months ;Data: 3 years
classification society	A classification society detention ratio $= \frac{\text{number of class-related detentions}}{\text{number of distinct arrivals}}$	Priority 1: Targeting Criteria: ≥ 10 arrivals with a detention ratio more than 4 times the average OR < 10 arrivals and involved with at least one detention in the previous 3 years; 5 points: Targeting Criteria: ≥ 10 arrivals with a detention ratio between 3 and 4 times the average; 3 points: Targeting Criteria: ≥ 10 arrivals with a detention ratio between 2 and 3 times the average; 1 points: Targeting Criteria: ≥ 10 arrivals with a detention ratio between the average and 2 times the average; 0 points: Targeting Criteria: ≥ 10 arrivals with a detention ratio below the average OR < 10 arrivals with no detentions in the previous 3 years; Note: Targeted Classification Society List
boarding history	Detention number; Other operation control number (i.e. Customs hold); Casualty number; Violation number; Time since last initial inspection	5 Points Each: Targeting Criteria: Detention within the previous 12 months; 1 Point Each: Targeting Criteria: Other operational control (i.e. Customs hold) within the previous 12 months; 1 Point Each: Targeting Criteria: Casualty within the previous 12 months; 1 Point Each: Targeting Criteria: Violation within the previous 12 months; 1 Point Each: Targeting Criteria: Not boarded within the previous 6 months.
Vessel type and age	Vessel type and age	1 Point: Targeting Criteria: Oil or chemical Tanker; 1 Point: Targeting Criteria: Gas carrier; 2 Points: Targeting Criteria: Bulk Freighter over 10 years old; 1 Point: Targeting Criteria: Passenger Ship; 2 Points: Targeting Criteria: Carrying low value commodities in bulk.
Total		Total the points assigned from each row; Compare the total with the Foreign Vessel Targeting Criteria priority as determined through a review of the description of priority Ⅰ, Ⅱ, Ⅲ and Ⅳ boarding.

Resource: According to Figure D4-1 Foreign Vessel Targeting Matrix [96]

Table 3-2: Priority Matrix of Foreign Vessel Targeting Matrix

Priority Level	Criteria
Priority Ⅰ	(1) ≥ 17 on the targeting matrix; (2) Stateless vessels; (3) Vessels suspected of involvement in a marine casualty that may have affected seaworthiness; (4) Vessels suspected of hazarding the port or environment as a result of a hazardous materials release, or an ongoing discharge of oil; (5) Vessels specifically targeted for boarding as Priority I vessels by the Commandant as noted in MSIS (or by targeted class list); and (6) Vessels specifically targeted by the Officer in Charge Marine Inspection (OCMI)/ Captain of the Port (COTP) for boarding prior to entry based on specific information or other identifiable criteria indicating a high likelihood that a vessel is substandard.
Priority Ⅱ	(1) 7 – 16 points on the matrix. (2) Vessels that do not have, or are past due for, an annual Tank Vessel Examination, Biennial Certificate of Compliance Examination, or Annual Control Verification Examination; (3) Vessels with overdue outstanding requirements issued at previous examinations (4) Vessels that lack a record of previous Coast Guard examination; and (5) Vessels that have engaged in an international voyage and have not been examined since being released from a port state intervention carried out by the U.S. or any other party to the applicable convention.
Priority Ⅲ	(1) 4 to 6 points on the matrix; (2) Vessels that do not have, or are past due for, an annual Freight Vessel Examination, or quarterly Control Verification Examination; and (3) Vessels alleged to be substandard by a member or members of the ship's crew, a professional or other association, a trade union or any other interested person(s).
Priority Ⅳ	(1) 0 to 3 points on the matrix; and (2) Vessels possessing none of the critical criteria discussed under the higher priorities.

Resource: According to Figure D4-1 Foreign Vessel Targeting Matrix [96]

3.3.2 Ship Targeting System Used by the Tokyo MOU

From March 2004, the Tokyo MOU implemented a computer based ship targeting system to use as a tool by the PSC officers for selecting ships [4]. Table 2-3 and Table 2-4 list the risk factors, value and criteria, and inspection priority.

Table 3-3: Risk Factors of Ship Targeting System

Risk factors	Target Factor Value (TFV)
Ship Age	0 Point: 0-5 years; 5 Points: 6-10 years; 10 Points: 11-15 years; 10+1 point for each year exceeding 15 years: 16-20 years; 15+2 points for each year exceeding 20 years: > 20 years
Ship Type	4 Points: A ship with codes 13, 30, 40, 55, 60, 61, 70, 71 and of 15 years of age and over; 0 Point: All others
Ship Flag	1 Point for each percentage point in excess (decimal number rounded up) based upon 3 year rolling average figure
Deficiencies	0.6 Point for each deficiency found in last 4 initial inspections or follow up with new deficiency
Detentions	Depending on number of detentions in last 4 initial inspections: 15 Points: 1 detention; 30 Points: 2 detentions; 60 Points: 3 detentions; 100 Points: 4 detentions
Classification Society	10 Points: Non IACS (The members of IACS are ABS, BV, CCS, DNV, GL, KR, LR, NK, RS, and RINA).
Outstanding deficiencies	2 Points for each outstanding deficiency: A deficiency recorded in the APCIS in the last initial inspection or associated follow-up ones and not marked as rectified
Time since last initial inspection	3 Points: 6-12 months; 6 Points: 12-24 months; 50 Points: Over 24 months or never inspected in TMOU region (including new ships)
Total	The target factor is the sum of TFV

Resource: [4]

Table 3-4: Priority of Ship Targeting System

Priority Level	TFV
Priority 1 (very high)	>100
Priority 2 (high)	41-100
Priority 3 (medium)	11-40
Priority 4 (low)	0-10

Resource: [4]

3.3.3 Inspection Regime Used by the Paris MOU

According to a piece of news ‘Change of Helm At the Paris MOU’ on May 8th , 2005, the Paris MOU Committee agreed to adopt a new risk-based inspection regime to scrap its 25% inspection regime. The regime aims at full coverage of risky ships visiting the region while top quality operators will be rewarded with less frequent attention. The target factors and value and criteria [67] are listed in Table 2-5.

Table 3-5: Target Factors of Inspection Regime

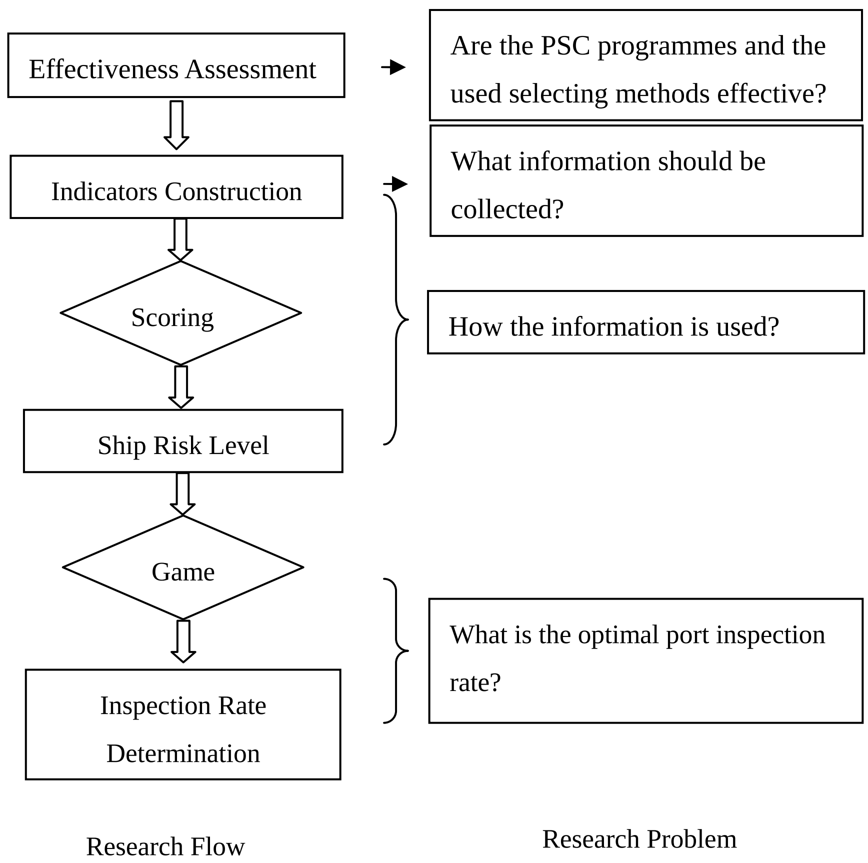
Factor Type	Factor	Criteria
Generic Factor	Flag State	4 Points -Medium risk, yardstick + 3%; 8 Points- Medium to High risk, yardstick + 6%; 14 Points- High risk, yardstick + 9%; 20 Points- Very High risk, yardstick + 12%
	Flag State has not ratified all conventions	1 Point
	Ship Type	5 Points: (1) Bulk carrier more than 12 years old; (2) Gas Carrier more than 10 years old; (3) Chemical Tanker more than 10 years old; (4) Oil tanker GT>3000 and more than 15 years old; and (5) Passenger ship/ro-ro ferry more than 15 years old.
	Classification Society	A three-year average record of detentions above the average classification detention value using the excess of average rate as yardstick. 0 Point: ≤ 0 ; 1 Point: 0%-2%; 2 Points: 2%-4%; 3 Points: >4%
	Non-EU recognised classification society	3 Points
	Ship Age	3 Points: > 25 years; 2 Points: 21-24 years; 1 Point: 13-20 years
History Factor	Time since last initial inspection	20 Points: No inspection recorded in the database in the last 12 months; 10 Points: No inspection recorded in the database in the last 6 months.
	Number of deficiencies	-15 Points: 0; 0 Points: 1-5; 5 Points: 6-10; 10 Points: 11-20; 15 Points: ≥ 21
	Outstanding deficiencies from last inspection	1 Point :For each listed action taken “rectify deficiency at next port” or “Master instructed to rectify deficiency before departure” and for every two listed action taken “rectify deficiency within 14 days” and /or “other (specify in clear text)”; -2 Points: In case “all deficiencies rectified” is noted on the report.
Overall Target Factor		Adding the Generic and History Factor but cannot be less than the Generic Factor.

4 Methodology

4.1 Research Framework

The research problem defined in this study is investigated through the following research flow shown in Figure 3-1. The left part in the Figure is the research flow and the right part is the corresponding research problem.

Figure 4-1: Research Flow and Research Problem



Quantitative analysis and qualitative analysis are combined in this study. Detailed description of the methods used in each problem is to be stated in the corresponding chapters. The following is a summary of the methods adopted in each problem:

(1) Methods used in effectiveness assessment

Under the guideline of understanding the truth of phenomena in philosophy, statistical techniques are used to analyse the indicators which represent the maritime safety level and the efficiency of each selection methods. The indicators representing the maritime safety level include total loss number and total loss rate and the indicators representing the efficiency of each selection methods include inspection number, detention number and detention-inspection rate which is defined in this study. Statistical techniques include growth rate, mean comparison, hypothesis test and standard deviation.

(2) Methods used in forming an indicator system

The literature review method is adopted to form a risk indicator system. Since it is not necessary or cost-effective to control all indicators, statistical analysis is adopted. Chi-square test is adopted to test whether the distribution of casualty based on a risk indicator is independent with the distribution of the whole world fleet based on the same risk indicator. Below is the form of the indicator system:

$$\begin{array}{c} \\ \text{ship } 1 \\ \text{ship } 2 \\ \cdots \\ \text{ship } m \end{array} \begin{array}{c} \begin{array}{cccc} \text{indicator } 1 & \text{indicator } 2 & \cdots & \text{indicator } n \end{array} \\ \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1n} \\ x_{21} & x_{22} & \cdots & x_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ x_{m1} & x_{m2} & \cdots & x_{mn} \end{bmatrix}_{m \times n} \end{array}$$

(3) A method used in building a scoring model– a MCDM approach

A Multi-Criteria Decision Making (MCDM) approach is a procedure that specifies how indicator information is to be processed in order to arrive at a choice. A MCDM problem is one with m alternatives that are evaluated by n attributes. In this study, alternatives represent specific ships and attributes represent risk indicators.

The Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) is adopted from the branch of the MADM methods. TOPSIS is viewed as a geometric system with m points in the n-dimensional space, and the chosen alternative should have the shortest distance from the positive-ideal solution and longest distance from the negative-ideal solution.

There is no involved research conducted in the risk assessment and maritime safety control, so a review about MCDM methods is provided in the following part.

A MCDM problem has no optimal solution in Maths, however, such problems have a real economic meaning and have often to be solved [12]. Two kinds of methods are essentially considered: aggregation methods and outranking methods.

The weighted-sum model (WSM) and the weighted-product model (WPM) are included in aggregation methods. The WSM could be the simplest method to single-dimensional decision-making problem, but are not appropriate when complex decision-making problems are considered [93]. Note that the WPM is very similar to the WSM. The WPM is sometimes called dimensionless analysis because its structure eliminates any units of measure [93].

The outranking methods consist of a compromise between the too poor dominance relations and those that have been excessively generated by utility functions [12]. It includes ELCTRE methods (Elimination et Choice Translation Reality) [8, 12, 40, 76-80] and TOPSIS [38, 43, 44, 105, 107]. The ELECTRE methods are rather intricate because they require a lot of parameters, the values of which are to be fixed by decision-makers and analyists [13]. Concordance discrepancies and discrimination thresholds in the ELECTRE methods playing an essential role in the procedures only have a technical character and their influence on the results is not always well understood. Moreover, in the ELECTRE methods the notion of "degree of credibility" is rather difficult for practitioners.

The main criticism to TOPSIS method is that it does not consider the relative importance of the distances from these points [16, 52, 65]. In fact, the chosen alternative has the maximum value of criteria with the intention to minimize the distance from the ideal solution and to maximize the distance from the negative-ideal solution [91]. TOPSIS method is adopted in many research studies, such as Deng, Yeh and Willis [23], river basins analysis [87] and risk assessment during the process of production [10].

(4) A methods used in optimal inspection rate – a game theory approach

The inspection policy of port authorities and the maintenance policies of shipowners can be modelled as a Stackelberg game.

According to a inspection rate announced by a port State, each shipowner decides how much money will be spent on maintenance. If a shipowner spends more money on the maintenance of a ship, the probability of passing the inspection is higher, and thus the expected penalty cost for not passing the inspection is less. Therefore, the shipowner would select the budget to be spent on maintenance, which is to minimize the sum of the maintenance cost and the expected penalty cost.

Knowing the responses of the shipowners to each inspection rate in a set of feasible inspection rates, the port States' purpose is to select an optimal inspection rate to induce shipowners to maintain satisfactory levels of safety as well as to minimize inspection costs.

4.2 Scope and Source of Data

Research objects are sea-going ships. For this, this study adopts Li's definition [55], i.e. ships are sea-going construction engaged in the transport of cargo or passengers for the purpose of trade or employed for any other commercial purpose.

Rare data are collected from Casualty Return (Annually, from 1973-1993) and World Casualty Statistics (Annually, from 1994-2003) published by Lloyd's Register of Shipping, Shipping Statistics Yearbook (Annually, from 1973-2003) published by Institute of Shipping Economics and Logistics, and annual reports of PSC inspections published by the USCG (from 1998-2005), the Paris MOU (from 1994-2005) and the Tokyo MOU (from 1994-2005). Data in publications are always corrected with updated information each year and considered to be an authentic source worldwide.

5 Effectiveness of Port State Control and the Adopted Selection Methods

The IMO introduced the first PSC programme in 1982. After that the PSC programmes are under rapid development, which are organized by nine regional PSC programmes (, covering most ports and coastlines [40]. It is accepted that the PSC programme is a measure to consolidate the former maritime safety control net since the former net, constructed by flag States and classification societies, can not work effectively [62, 65], so the PSC programme is often referred to as the ‘last safety net’ [88].

On-board inspections delay the fast turnover rate. Each regional PSC programme adopts a method to detect potential substandard ships in advance. The method helps port States decrease the influence produced by ship inspections on the efficiency of logistics.

In a word, the PSC programmes have been regarded as the main measure to improve maritime safety level, and methods for selecting ships to be inspected are necessary part of the PSC programmes due to their effectiveness. The above points of view are a matter of common sense, so little attempt is conducted to investigate the truth of the common sense.

This Section 4 is to investigate the effectiveness of the PSC programmes and the effectiveness of methods for selecting ships to be inspected, and the following questions are studied: (i) After the introduction of the PSC programmes, do the PSC programmes work effectively to improve the safety level of maritime transport? (ii) Are the methods of selecting ships to be inspected effective? Does the effective level of each method indicate increase, decrease or produce no change?

The rest parts in this Section 4 are organized as follows: Section 4.1 first presents the theory framework and then outlines more than 30 years of safety records of the world fleet (from 1973-2003) to analyse the effectiveness of the PSC programmes. In Section 4.2, the effectiveness of the methods of selecting ships to be inspected is investigated. The theory framework is presented first and then the three methods, adopted by the USCG, the Paris MOU and the Tokyo MOU as the three representatives among all the different regional methods, are analysed from a 10-year data collection of the three regions. In Section 4.3, the main findings are summarized and some suggestions are provided.

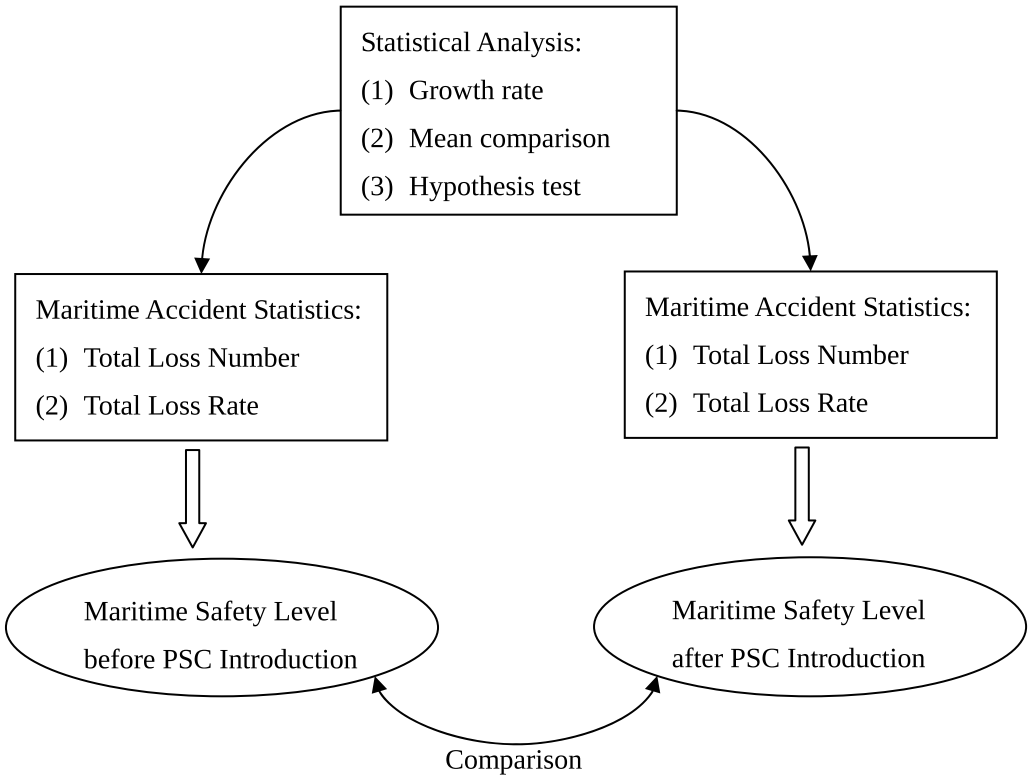
5.1 Effectiveness of the PSC Programmes

5.1.1 Theory for Maritime Safety Level Analysis

To investigate the variation of the maritime safety level before and after introduction of the PSC programmes, two aspects are combined (cf. Figure 4-1). One aspect is related to the indicators that represent the whole maritime safety level and the other aspect focuses on the variation of the whole safety level during the two periods.

Maritime accident statistics analysis is a main part of maritime safety level analysis which is one of research directions of risk assessment in maritime transport [84]. The standard approach to calculate total risk can be simply stated by multiplying consequence with probability of occurrence [50, 56]. In theory, it would entail the estimation of probability and consequence. In practice, however, probability and consequence are difficult to estimate in quantitative terms. One main reason is that the calculation of the probabilities from accidents is difficult, as they are typically very rare events [33]. Maritime accident statistics analysis is one way to overcome these difficulties [33, 84]. Studies based on maritime accident statistics can provide an overall view of maritime safety level.

Figure 5-1: Framework for Maritime Safety Level Analysis



Total loss, adopted in many research studies [2, 57], is used to represent the maritime safety level in maritime accident statistics and remains adopted in this study. By definition, total loss of a ship, as a direct result of being a shipping accident, means that the ship has ceased to exist, 'either by virtue of the fact that the ship is irrecoverable or has subsequently been broken up'. Ships which have been declared constructive total losses but which are undergoing or have undergone repairs are not included. Ships broken up, but not as a consequence of casualty, are categorized as disposals, and are not included in the category of total loss either [102].

Total loss is measured by the involved ship number in this study, which is called total loss number. The total loss can be measured by the involved ship number or the involved gross tonnage. Individual ship is the subject of maritime safety management, so the number of ships involved in shipping accidents is sensible in terms of social, economical and safety studies. The total loss number is calculated by counting the ships involved in the total loss. This indicator can express intuitive information on the safety records. In terms of safety, it is better that the value of the indicator per year is as low as possible.

The total loss rate is a relative indicator to show the maritime safety level. The influence of the number of world trading fleets is removed from this indicator, since the number of world trading fleets is a factor to influence the amount of the occurrence of shipping accidents, which is measured by the total loss number in this study. The bigger the number of world trading fleet, the bigger the total loss number. The total loss rate can be calculated as the following:

$$Total\ loss\ rate = \frac{total\ loss\ number}{number\ of\ world\ trading\ fleet}. \quad (4\text{-}1)$$

This indicator can be used to compare the safety level at different time. In terms of safety, the lower the value of the indicator, the better is the maritime safety level.

To investigate the variation of the maritime safety level of before and after the introduction of the PSC programmes, growth rate, mean comparison and hypothesis test were conducted on the two indicators which are total loss number and total loss rate. Growth rate is to show the developmental trend of the maritime safety level. Mean comparison is to investigate the differences of the maritime safety level of the two periods of before and after the introduction of the PSC programmes. A hypothesis test is to verify that the differences of the means have statistical significance.

The growth rates are calculated based on the methods proposed in the research of Li and Wonham [57]. In this study the decrease rates are calculated, so a minus is added in each calculation to indicate the improved maritime safety level. Accordingly, the equations of growth rate are stated as: the growth rate is equal to $-(M_{y2}-M_{y1})/M_{y2}$, in which M_{y1} is the measurement value in the previous year, and M_{y2} is the measurement value in the present year. An average growth rate is the average of the growth rates per year.

Means were calculated and compared before and after the introduction of the PSC programmes. A hypothesis is assumed that the maritime safety levels are different during the two periods. T test was adopted to investigate the statement.

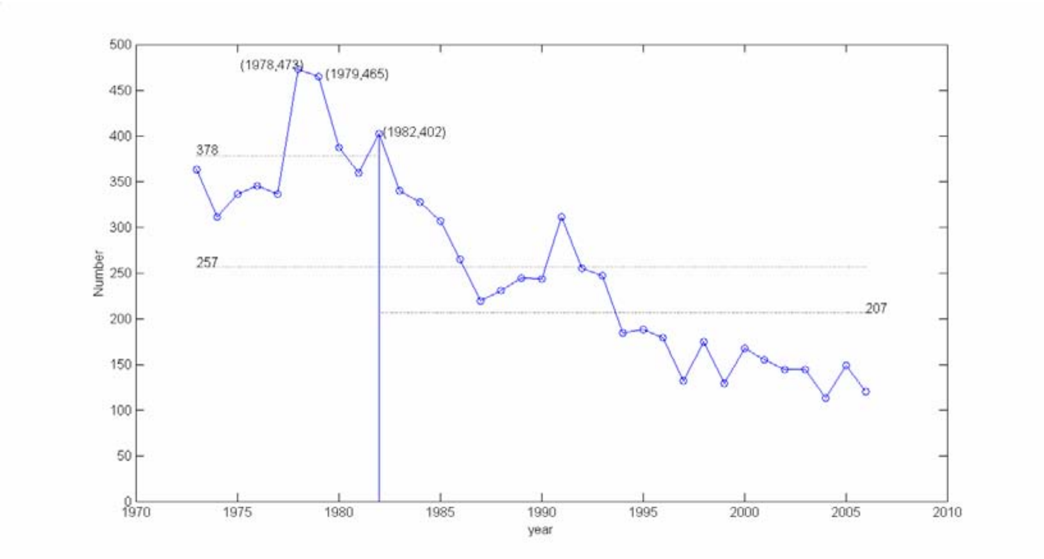
This study focuses on propelled sea-going merchant ships. Rare data are collected from Casualty Return (Annually, from 1973-1993) and World Casualty Statistics (Annually, from 1994-2006) published by Lloyd's Register of Shipping, Shipping Statistics Yearbook (Annually, from 1973-2006) published by Institute of Shipping Economics and Logistics.

5.1.2 Reduction of the Total Loss Number

The total loss number has a reduced trend over the time period from 1973 until 2006, from 363 in 1973 to the 120 in 2006 (cf. Figure 4-2). The total loss number per year decreased by a rate of 3.2% and the average total loss number was 257. In other words, the safety record of world trading fleets has improved as displayed by the total loss number.

The extent of the shift differs over the two time periods of 1973-1982 and 1983-2003. An interesting observation in Figure 4-2 is that the four years which total loss number were more than 400 happened over the time period of 1973-1982. The average total loss number (207) over the time period of 1982-2006 was lower than the value over the time period of 1973-1982 (378), with the degressive range of 171 and the decreasing rate of more than 40%.

Figure 5-2: Total Loss Number over the Time Period from 1973 until 2006



Source: Casualty Return [14] and World Casualty Statistics [102].

It is expected that there is a significant difference in the means of the total loss number over the two time periods of 1973-1982 and 1983-2006. By using T test to compare the means of the two time periods, the results were $t = 7.645$ (0.000) under $df = 32$ (cf. Table 4-1).

Table 5-1: Means of the Total Loss Number - Independent Sample Test

	Periods	N	Mean	Std. Deviation	Std. Error Mean
Number	1973-1982	10	377.70	54.713	17.302
	1983-2006	24	207.00	69.149	14.115

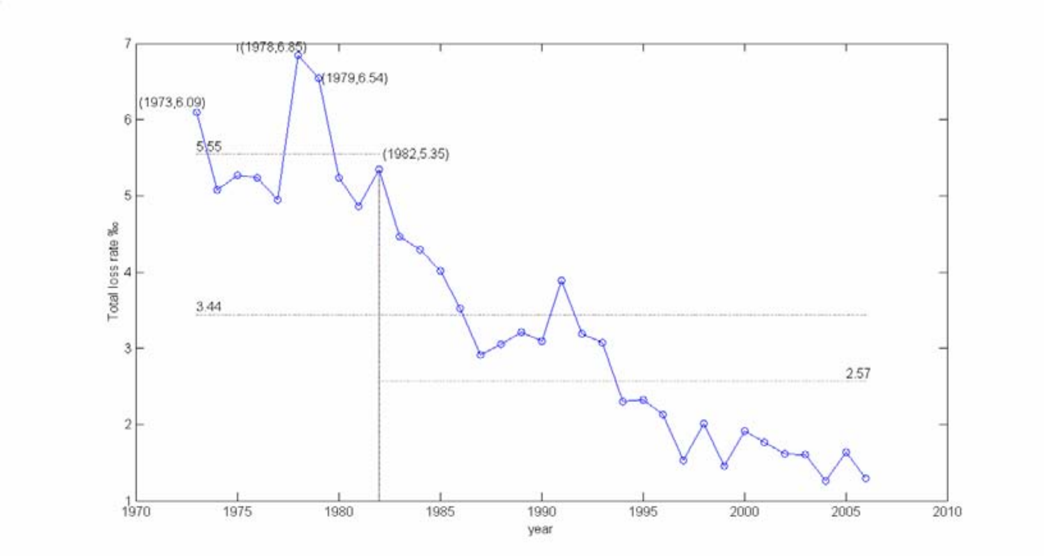
		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
									Lower	Upper
Number	Equal variances assumed	1.734	.197	6.933	32	.000	170.700	24.620	120.551	220.849
	Equal variances not assumed			7.645	21.278	.000	170.700	22.329	124.301	217.099

These results reveal that the means of the total loss number of the two periods have a significant difference. According to the T test, $t = 7.645 \ (0.000)$, the assumption, that the means of total loss number of the two time periods studied are equal, were rejected and there was a significant difference over the time period of 1983-2006.

5.1.3 Reduction of the Total Loss Rate

The total loss rate has been steadily reduced over the time period of 1973-2006, from 6.09‰ in 1973 to 1.61‰ in 2006 (cf. Figure 4-3). Each year the total loss rate per thousand ships decreased by a rate of 1.30‰, with an average total loss rate of 3.44‰. In other words, the safety record of the world trading fleets has improved as reflected by the total loss rate.

Figure 5-3: Total Loss Rate over the Time Period from 1973 until 2006



Source: Casualty Return [14], World Casualty Statistics [102], and Shipping Statistics Yearbook [82].

There are many differences in the safety records over the two time periods from 1973-1982 and 1983-2006. An interesting observation shown in Figure 4-3 is that the minimum value of the total loss rate (4.86‰) over the time period of 1973-1982 is bigger than the maximum value (4.30‰) over the time period of 1983-2006. The mean total loss rate is 5.55‰ over the time period of 1973-1982, while it was 2.57‰ over the time period of 1982-2006, the decreasing rate of more than 50%, which is lower than the value over the time period of 1973-1982.

A significant difference is expected on the means of the total loss rate over the two time periods of 1973-1982 and 1983-2006. The safety record during the period of 1983-2006 is expected to improve, or in this case, the lower number of total loss rate than the one over the time period of 1973-1982. The T test results comparing the means over the two time periods show that $t = 9.941$ (0.000) under $df = 32$ (cf. Table 4-2).

The results reveal that the means of the total loss rate of the two periods have a significant difference. According to the T test, $t = 9.941$ (0.000), the assumption, that the means of the total loss rate of the two periods are equal, is rejected, and the mean of the total loss rate over the time period of 1983-2006 shows a significant decrease.

Table 5-2: Means of Total Loss Rate - Independent Sample Test

	Periods	N	Mean	Std. Deviation	Std. Error Mean
Rate	1973-1982	10	5.5470	.69356	.21932
	1983-2006	24	2.5667	. 1.0013	.20438

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference Lower	Upper
rate	Equal variances assumed	3.669	.064	8.559	32	.000	2.98033	0.34820	2.27107	3.68960
	Equal variances not assumed			9.941	24.259	.000	2.98033	0.29979	2.36195	3.59872

5.1.4 Improvement of Safety Record

The improvement of the maritime safety level, shown by the manifestation of the total loss number and the total loss rate over the time period of 1973-2006, can be attributed to the enforcement of the PSC programmes to strengthen the safety net of maritime transport.

After 1982, the major measure to strength the maritime safety net is to establish and spread the PSC programmes. The greater border of the enforcement of the programmes, the more effective is the control of the shipping accidents. It also cannot be explained by the influence of the number of the world trading fleets, since it is opposite to common case, that the total loss number increases when the world trading fleets expand.

On the first question, it can be summed up that the PSC programmes work effectively to improve the safety level of maritime transport. It was proven by the fact that there were significant differences in the safety record of the world trading fleets between the periods before and after 1982.

5.2 Assessment of Selection Methods

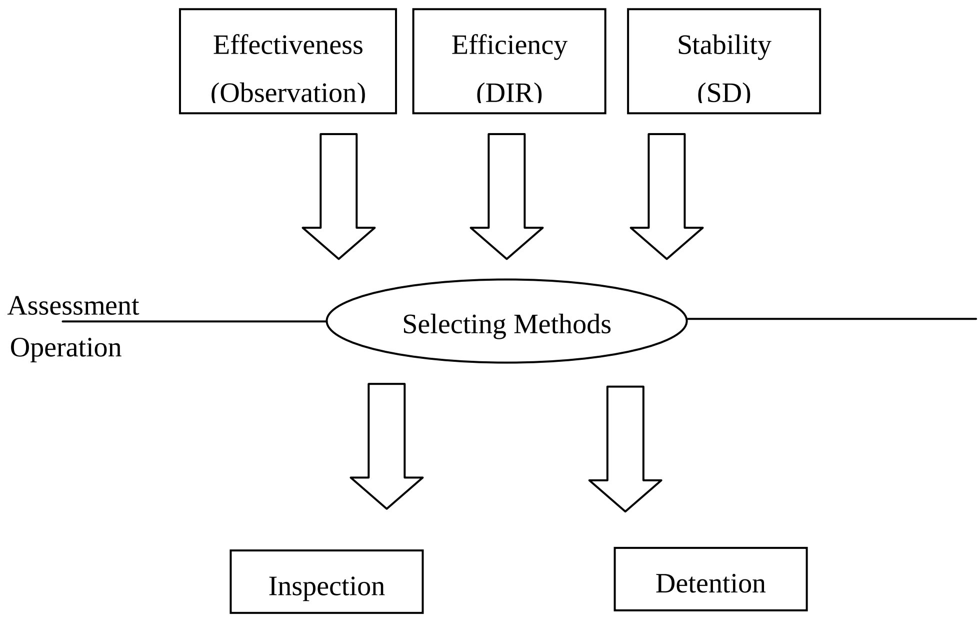
5.2.1 Theory for Assessment of Selection Methods

There are three typical selecton methods used by the USCG, the Paris MOU and the Tokyo MOU, since the three regions are advanced in the implementation of the PSC programmes and have developed complete selection methods.

Three concepts were used to assess the effectiveness of the selection methods. The concepts effectiveness, efficiency and stability. Effectiveness is the power of the selection methods to target substandard ships in advance. Efficiency means that the inspected ships based on the selection methods are highly likely to be substandard ships. Stability means that the efficiency can remain at a fixed value at any time. An ideal selection method can be an effective one with high efficiency and high stability.

The three concepts combining with the operation of the selection methods construct framework (cf. Figure 4-4).

Figure 5-4: Framework for Assessing Selecting Methods



Inspection number and detention number are the two main items to present the practice of the selection methods (cf. Figure 4-4). The two indicators were used in former studies [18, 54], and annual reports issued by the USCG, the Paris MOU and the Tokyo MOU. Inspection number is the number of inspected ship selected on the basis of these methods. Detention is a result of ship inspections. A detained ship is regarded as a substandard ship. The detention number is the number of substandard ships. In this study, inspection number and detention number were adopted.

To investigate the effectiveness of the selection methods, inspection number and detention number were observed. The effectiveness can be judged directly when the condition is satisfied that after checking the ships according to the selection methods, the port State authorities can find substandard ships.

To investigate the efficiency of these selecting methods, a detention-inspection rate (DIR) was used. The concept of efficiency is borrowed from Economics, and economic efficiency is a general term for the value assigned to a situation under which a measure is designed to reduce the amount of waste. Economic efficiency is achieved though dividing the produced output by the cost. In this study, the selection methods are the measures for decreasing the amount of inspections conducted on substandard ships. Inspection number can be regarded as cost and the detention number is the output. A DIR per year can be calculated by using the following formula:

$$DIR = 100\% \times \frac{No_{detention}}{No_{inspcetion}} \tag{4-2}$$

For example, the USCG inspected 12,448 ships inspected in 1998 and detained 373 ships. Substituting these data in the above formula, a DIR value of the USCG in 1998 can be obtained:

$$DIR = 100\% \times {}^{373}\!/_{12448} \approx 3.00\% .$$

The efficiency of the selection methods means that the big value of DIR is better than the small value. The reason for this criterion is that the production of a unit of goods or services is termed economically efficient when that unit of goods or services is produced at the lowest possible cost.

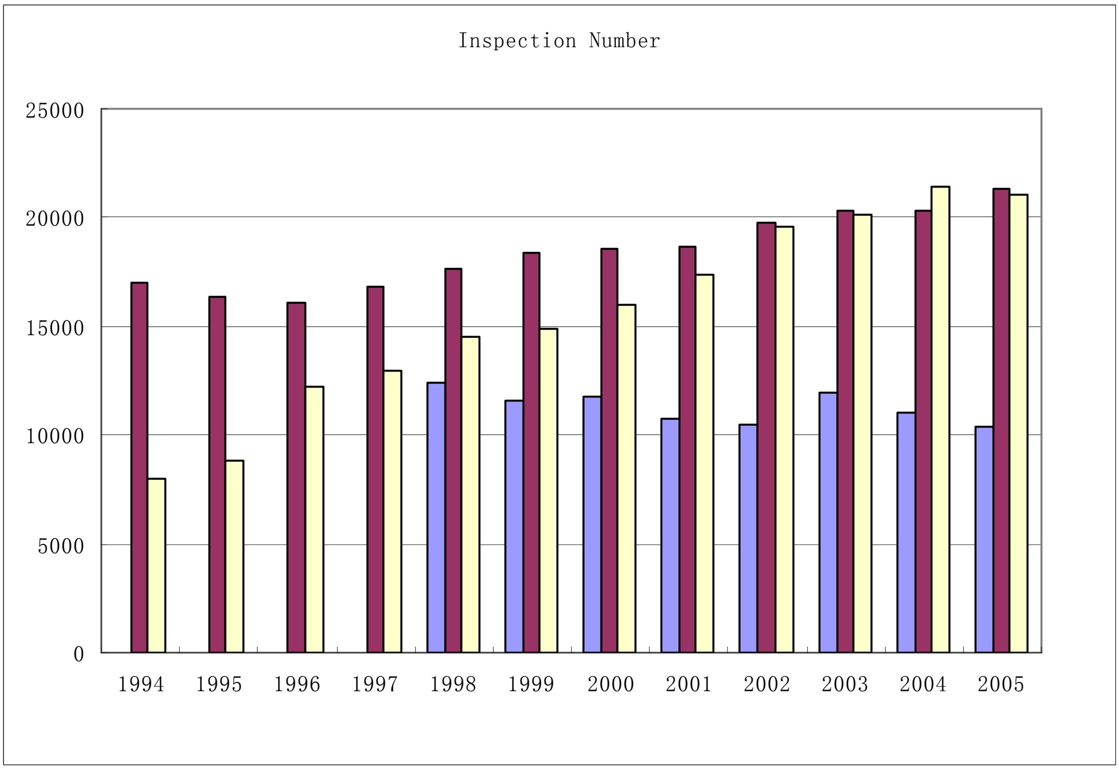
For stability of the selection methods, standard deviation (SD) was adopted. Since the variation of DIR obtained from each selection method shows the method's stability, the standard deviation of each selection method was used to measure the variation range. A method with low stability has a greater standard deviation.

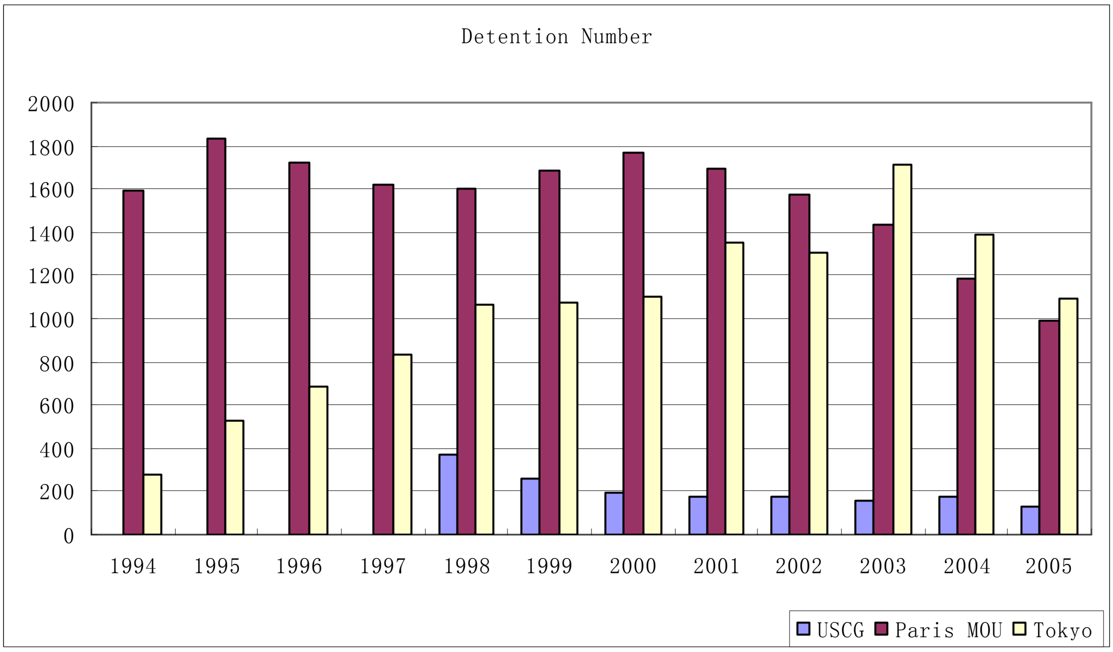
This study focuses on propelled sea-going merchant ships. Rare data are collected from annual reports of PSC inspections published by the USCG (from 1998-2005), the Paris MOU (from 1994-2005) and the Tokyo MOU (from 1994-2005).

5.2.2 Effective Selection Methods

The power of the selection methods can be manifested by observing the inspection number and the detention number (cf. Figure 4-5). Guided by the selection methods, in 2005 the USCG inspected 10,430 ships and detained 127 ships, the Paris MOU inspected 21,302 ships and detained 994 ships, and the Tokyo MOU inspected 21,058 ships and detained 1,097 ships. The observation for the inspection number and the detention number shows that the selection methods have the power to help port States identify substandard ships in advance.

Figure 5-5: Inspection Number and Detention Number



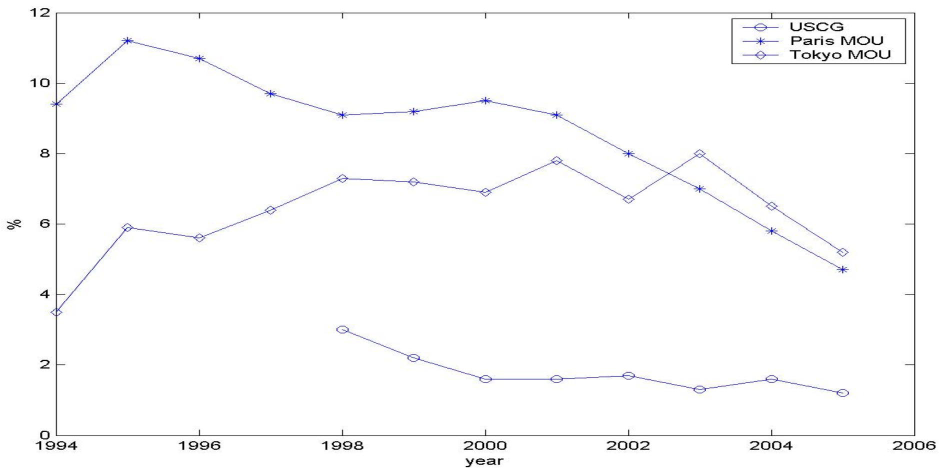


Resource: Tokyo MOU Annual report [3], Paris MOU Annual Report [67], and USCG Annual Report [69].

5.3.3 Variant Efficiency and Stability of Selection Methods

DIR is calculated based on equation 4-1 and the results are shown in Figure 4-6. The three lines represent the DIR yearly changes for each selection method adopted by the USCG, the Paris MOU and the Tokyo MOU respectively.

Figure 5-6: DIR of the Three Regional PSC



The yearly DIR values of the USCG are lower than the values of either the Paris MOU or the Tokyo MOU, since the USCG's line lies at the bottom of the figure. On the other hand, the USCG has the highest stability since it has the lowest SD value (SD_{USCG}=0.0057). It indicates that no matter what ships enter into the United States' water, there is a relatively fixed percentage to identify substandard ships. These results show that the selection method of the USCG is stable but the effective level is low.

The selection methods adopted by the Paris MOU and the Tokyo MOU have relatively high efficient level, since their lines lie in the upper part of the figure. However, the trends of the two lines are downward. The DIR of the Paris MOU was from 9.5% in 1994 to 4.7% in 2005. The downward trend of the Tokyo MOU's DIR was shown since 2003, from 8% in 2003 to 5.2% in 2005. There is a low stability of these two types of methods ($SD_{Paris} = 0.0192$; $SD_{Tokyo} = 0.0123$), compared with the stability of the USCG. Therefore the methods of the Paris MOU and the Tokyo MOU have relatively high effective levels with low stability shown in downwards trends.

Another interesting observation is that there is a convergence between the methods of the Paris MOU and the Tokyo MOU. In 1994, for example, the DIR of the Paris MOU was 9.4%, the Tokyo MOU's was 3.5%, and the difference between them was 5.9%. In 2005, the difference was reduced to 0.5% since the values of DIR of the Paris MOU and the Tokyo MOU were 4.7% and 5.2%

respectively. This indicates that there is some reason that causes the effectiveness of these two methods possibly to have the same developmental trend.

5.3.4 Comparison among the Selection Methods

The selection methods are effective with different efficient levels and stability. The selection method adopted by the USCG is of a low efficient level and high stability. Comparatively, the methods adopted by the Paris MOU and the Tokyo MOU are of higher efficient level and low stability.

This is caused by the differences between the selection methods adopted by the USCG, the Paris MOU and the Tokyo MOU. The method adopted by the USCG is different from the methods adopted by the Paris MOU and the Tokyo MOU. The method used by the Tokyo MOU is similar to the one used by the Paris MOU.

The primary differences are constructive principles behind the selection methods. The risk-controllers idea is the principle to construct the USCG's method. The principle is controlling the safety performance produced by administrative organizers who are the units involved in ship safety management.

These risk controllers include shipowners, flag States, and classification society. This principle is mainly adopted by the USCG.

Besides the risk-controllers principle, the other principle is characteristics abstracted from shipping accident investigation. A ship with old age, for example, is frequently observed in maritime accidents. This principle is mainly adopted by the Paris MOU and the Tokyo MOU, and the Paris MOU has a leading position in the development of regional MOU and the Tokyo MOU is the follower.

The detailed manifestations of the differences among the three selection methods are risk indicator systems (cf. Table 4-3) and risk level determination approaches in these methods.

4.3.3.1 Comparison of Risk Indicators

The detailed differences in risk indicators among these three selection methods are reflected in Table 4-3. The second column in Table 4-3 lists the risk indicators in the three selection methods and the third, forth and fifth columns show the risk indicators of the three selecting methods respectively. From the aspect of quantity, the USCG has nine indicators, the Paris MOU has ten and the Tokyo MOU has eight.

Table 5-3: Risk Indicators Comparison

Risk Dimensions	Risk indicators	USCG	Paris MOU	Tokyo MOU
Ship Management (RD_1)	A ship owner/manager/charterer detention ratio	○	×	×
Flag State (RD_2)	A flag State detention ratio	○	○	○
	Flag State has not ratified all conventions.	×	○	×
Classification society (RD_3)	A classification society detention ratio	○	○	×
	Non recognized classification society	×	○	○
Vessel history (RD_4)	Detention number	○	○	○
	Other operation control number (i.e. Customs hold)	○	×	×
	Casualty number	○	×	×
	Time since last initial inspection	○	○	○
	Deficiency	○	○	○
	Outstanding deficiencies	×	○	○
Ship type and ship age (RD_5)	Ship type and ship age	○	○	×
	Ship age	×	○	○
	Ship type	×	×	○

Note: ○ means that this factor is considered; × means that this factor is not considered

Source: the USCG Marine Safety Manual [96], the Paris MOU's Target Factor [90] and Asia-Pacific Port State Control Manual [4].

The Tokyo MOU has a relatively simple version of the risk indicators of the Paris MOU. The risk indicators of the Tokyo MOU can be included in those of the Paris MOU, except one indicator, ship type. Yet the indicator, ship type and ship age of the Paris MOU is a more complicated indicator than ship type. Meanwhile, the Paris MOU has more risk indicators than the Tokyo MOU.

The range of the collected information on a vessel is different among the three selection methods. Four risk indicators included only in the Paris MOU are flag State that has not ratified all conventions; non-recognized classification society; outstanding deficiencies; and ship age. Three risk indicators include only in the USCG are a ship owner/manager/charterer detention ratio; other operation control number (i.e. Customs hold); and casualty number.

The range of vessels' information collected by the USCG is the widest among the three selection methods. The USCG-collecting information involves a ship owner/manager/charterer, the Customs and historical casualty of a ship. On the other hand, the Paris MOU collects more detailed information than the USCG. Non-recognized classification society, for example, indicates a poor technical control by a classification society on a ship and is often observed in the casualties.

In summary, in terms of the risk indicator system, the Tokyo MOU has a simpler version of the risk indicator system used by the Paris MOU, and relatively detailed information is included in the Paris MOU and a relatively wide range of information is collected by the USCG.

4.3.3.2 Comparison of Risk Level Determination Approach

There are differences in the risk level determinations approaches between the method adopted by the USCG and the methods adopted by the Paris MOU and the Tokyo MOU. Giving mark to every risk indicator and summing them up are the approaches used by the Paris MOU and the Tokyo MOU. The total mark represents the whole risk level of a ship. The weakness of this type of approach is that some unusual change in one of risk factors may be hidden in the whole.

The USCG's risk level determination takes into account the whole risk level and the individual risk dimension listed in the first column in Table 4-1. The risk level is determined by the following equations:

$$(1)\ V_{RD_i} \geq C \text{ and } \forall i \quad i = 1,2,3,4,5 \quad ; \quad \text{or } (2)\ \sum_{i=1}^{5} V_{RD_i} \geq C .$$

in which RD represents risk-controllers shown in table 4-1, C is the risk level benchmark and the value adopted by the USCG in 2007 is 7.

The first equation realizes to control the individual risk dimension. It means that if only one of the risk dimensions involved in a ship is higher than the regulated risk level (C), the ship must be inspected. The second equation is used to control the whole risk level under condition that each risk dimension has a relatively low risk mark. The case is that if the whole risk level is higher than the regulated risk level (C), the ship must be inspected. Hence this method is sensitive to every risk dimension and the whole risk level.

In summary, from the aspect of the risk level determination approach, the USCG has a more complicated approach which is sensitive to every risk dimension and the whole risk level, and the Paris MOU and the Tokyo MOU adopt a summing method which takes into consideration just the whole risk level.

Additionally, the convergence of the DIR lines between the Paris MOU's and the Tokyo MOU's could be explained by the similarity of the two methods: (1) they have the same constructive principle, i.e. identified characteristics from shipping accident investigations; (2) risk indicators of the Tokyo MOU is a simpler version of the those of the Paris MOU; and (3) they have the same risk level determination approach, i.e. giving mark to every risk indicator and summing them up. The convergence proves an economic assumption that under the same context the similar system produces similar efficiency after a long time running. It is sensible to predict that a selection method combining of the selection method used by the USCG and the one used by the Paris MOU is of higher efficiency with higher stability.

5.3.5 Assessment the Selection Methods in General

These selection methods are effective with different efficient levels and stability. The selection method adopted by the USCG is low efficient level and high stability. Comparatively, the methods adopted by the Paris MOU and the Tokyo MOU are higher efficient level and low stability.

This result is caused by the significant differences between the USCG's selection method and the methods adopted by the Paris MOU and the Tokyo MOU. The selection method used by the Tokyo MOU is similar with the one of the Paris MOU.

The selection method adopted by the USCG is based on the risk-controllers principle, so the risk indicator system and risk level determination approach in this method are sensitive to each risk-controller. The Paris MOU and the Tokyo MOU construct their methods on the basis of characteristics abstracted form shipping accidents investigations, so the risk indicator systems and risk level determination approaches focus on each identified characteristics and the whole risk level of a ship. Meanwhile, the selection method used by the Tokyo MOU is a simple vision of the Paris MOU's.

As a general rule, it is expected that an ideal method not only has the high level of efficiency but also high stability. The whole evidence shown by analyzing DIR and SD of the three selection methods indicates that none of the methods has high level of efficiency and high stability, and these methods have one of them. The USCG has the most stability without high efficient level, since its lower values of DIR and SD. Conversely the methods of the Paris MOU and the Tokyo MOU have the relative high efficient level with downwards trends and low stability.

Logically, a combined method to possess the two features is to be expected. The convergence of the DIR lines between the Paris MOU's and the Tokyo MOU's could be explained by the similarity of the two methods. It is worth noting that the convergence proves an economic assumption that generally under the same context the similar system produces similar efficiency after a long time running. It is sensible to predict that a proposed method through combination of the methods of the USCG and the Paris MOU may produce high efficiency with high stability.

The context, especially reflected in reduced total loss rate, further magnify the importance of reliability of a selecting method, since the improved safety record of the world fleets increases the difficulty to find the substandard ships. Considering this fact, it is more worth noting the high effective stability of the USCG's method. Conversely, it explains the downward trend of the Paris MOU and the Tokyo MOU. Even so, the latter still has higher effective levels, which all should be noted.

5.3 Conclusions and Suggestions

The analysis of safety records of world trading fleets yields evidence that the maritime safety level is improved after the introduction of the PSC programme. After taking into account the maritime safety net construction and the development of world trading fleets, the improved maritime safety mainly contributes to the enforcement of the PSC programmes. So these findings allow us to answer the first question, that the PSC programmes are effective in raising the maritime safety level.

The detention inspection rate of a selection method has been very useful in revealing the efficient level and stability of the different selection methods adopted by the USCG, the Paris MOU and the Tokyo MOU. The three methods have quite variant efficient levels and stability. In detail, the method adopted by the USCG has high stability and the methods used by the Paris MOU and the Tokyo MOU have high efficient levels. So these methods are all effective, however, there are different efficient level and stability.

These findings suggest that the methods need to be improved and also suggest combining these three selecting methods to strengthen the enforcement of the PSC programmes.

Meanwhile with the development of information technology, regional PSC database is built on the basis of the method of targeting inspection ships [88]. However there are barriers among these regional PSC databases to share information because of the different targeting inspection methods. Therefore a uniform selection method is required to share vessels' information.

6 Construction of a Risk Indicator System – a New Approach

6.1 Principles of Construction

Port State authorities want to identify substandard ships before the occurrence of shipping accidents. This behavior is of pre-control in management field.

Control is one of the managerial functions like planning, organising, staffing and directing [27], and in management means setting standards, measuring actual performance and taking corrective action. It helps to check the errors and to take the corrective action, so that deviation from standards are minimised and the stated goals of the organisation are achieved in a desired manner. According to modern concepts, control can be divided into pre-control and post-control.

The causes of occurrence of substandard ships can be due to not only economic interest and lack of safety culture pursed by shipowners, but also the maritime administrative authorities' ignorance of their safety responsibilities. Port State authorities, to protect their safety in their water, put attention on substandard shipowners and substandard maritime authorities, which can help port State authorities identify substandard ships. So risk indicators, which are used to measure the safety management performance of the units who are responsible for maritime safety management, can guide the port State authorities to notice those units with poor safety management record.

Some common causes often emerge from casualty investigation. These causes can be seen as predictive index to predict a ship with high risk level. Predictive index is a management tool, in organizational behavior, for predicting, describing and measuring the work behavior and potential of individuals and groups at all organizational levels [70].

It has been introduced in risk assessment in maritime transport for a long time. On the basis of the primary maritime accident statistics, specific research, reflecting the distinction of safety in the different types of ships, ship sizes, ages etc, has been included. Thus, risk indicators include these common causes which are abstracted from casualty investigation.

6.2 Indicators from Actors in Maritime Safety Net

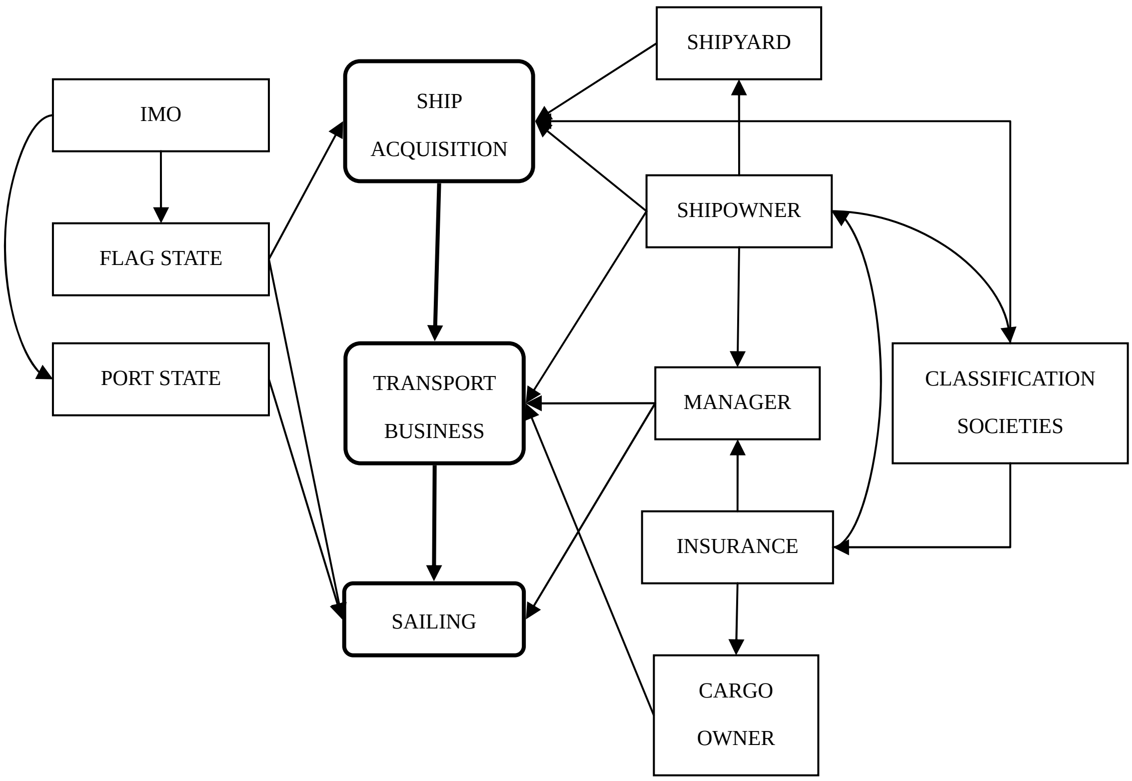
6.2.1 The Structure of Maritime Safety Net

The maritime safety net is a complicated system. The operation of a ship is divided into three parts: ship acquisition, transport business, and sailing. Based on these three parts, the interactions among controller in maritime safety net are shown (cf. Figure 5-1). These controllers have different safety criteria due to their own interests and there are conflicts among them.

The left part in Figure 5-1 shows the maritime administers: IMO, flag State and port State. IMO publish Conventions to guide flag State and port State to control shipping safety. After a ship registers in a state, the flag State has the responsibility the safety of the ship which is reflected in ship acquisition and ship sailing. Port State has the right to conduct safety inspection on foreign visiting ships in its ports, so its safety control is involved in ship sailing.

Bergannino and Marlow [9], through analysing the decision-making process of shipowners when adopting flags of registration, point out that FOC is mainly done for economic reason either to enjoy fiscal advantages or to reduce overall costs. And they also mentioned that there is a relation between FOC and maritime disasters. LI and Wonham's research [58] further confirms that the FOC ships tend toward substandard ships.

Figure 6-1: Actors in Maritime Safety Net



Source: Kristiansen [50].

The right part in figure 5-1 shows the controllers in shipping business, including shipyard, shipowner, manager, insurance, cargo owner, and classification society. These controllers have the nature of the business in mind, so they are all interest driven. Shipyard influences hull quality which is required by ship acquisition. A shipowner can choose shipyard, ship manager and classification society, and is a major safety controller. Generally, a substandard shipowner chooses substandard partners since the substandard shipowner may not necessarily have a long-term perspective of his business [50].

Here are the indicators showing the safety performance of these controllers to identify substandard controllers in advance.

6.2.2 Indictors

It is known that the maritime safety controllers include flag States, classification societies, shipbuilder, shipowner, ship manger, ship insurance and cargo owner, as are shown in Figure 5-1. It must be taken into account that these risk controllers can not be measured directly, and measurable indicators need be formed to assess safety records of these risk controllers.

Here detention number is a result to assess a ship’s safety level. After conducted a port State inspection, deficiencies or detention on a ship may be recorded. Deficiency means that the items, regulated by the international conventions on maritime safety, are not obeyed. Detention is another result of on-board inspections conducted by the port State authorities. If a ship is detained, it means certain serious deficiencies on this ship and the ship can be regarded as a substandard one. So detention is a strong signal of safety threat. Time since last inspection is an auxiliary indicator.

The vessel inspection history shows the shipowner's attitude to maritime safety, since ship manager, hired by shipowner, operates the ship on the sea and has the direct responsibility for the safety level. Vessel inspection history includes the detention numbers, the deficiencies number, the casualty number, other operation control number (i. e., Customs hold), and time since last initial inspection.

To measure each risk controllers in maritime safety net, the following indicators are introduced:

(1) flag State detention ratio;

This indicator measures the power of a Flag State to control its registered ships, which can be calculated as the following:

$$A\ flag\ state\ detention\ ratio = \frac{number\ of\ detentions\ under\ a\ flag\ state}{number\ of\ vessels\ under\ its\ registry}$$

(2) classification society detention ratio;

This indicator measures the enforcement of safety standards conducted by a classification society to its classified ships, which can be calculated as the following:

$$A\,classification\,society\,detention\,ratio == \frac{number\,of\;\;class\text{-}related\;\;detentions}{number\,of\;\;vessels\,under\,its\,classification}$$

(3) ship-owner detention ratio;

This indicator measures the safety management level of a ship-owner, which can be calculated as the following:

$$A\,ship\text{-}owner\,detention\,ratio = \frac{number\,of\;\;detentions\,under\,a\,ship\text{-}owner}{number\,of\;\;vessels\,under\,a\,ship\text{-}owner}$$

(4) shipbuilder detention ratio

This indicator measures ship quality built by a shipbuilder, which can be calculated as the following:

$$A\,shipbuilder\,detention\,ratio = \frac{number\,of\;\;detentions\,under\,a\,shipbuilder}{number\,of\;\;vessels\,built\,by\,a\,shipbuilder}$$

(5) ship insurance detention ratio

This indicator shows the ship insurance's attitude to maritime safety, since the value of this indicator, higher than average value, means this ship insurance is more profit driven. This indicator can be calculated as the following:

$$A\, ship\; insurance\; detention\; ratio = \frac{number\; of\;\; detentions\; under\; a\; ship\; insurance}{number\; of\;\; vessels\; under\; a\; ship\; insurance}$$

(6) cargo owner detention ratio

This indicator shows the cargo owner's attitude to maritime safety, since the value of this indicator, higher than average value, means this ship insurance is more profit driven. This indicator can be calculated as the following:

$$A\, cargo\; owner\; detention\; ratio = \frac{number\; of\;\; detentions\; under\; a\; cargo\; owner}{number\; of\;\; vessels\; under\; a\; cargo\; owner}$$

The judgmental criteria of this ratio is that the higher value obtained, the poorer the management performance.

6.3 Indicators from Casualty Investigation

Faragher et al. (1979) studies the effect of age on the casualty rate for structural failure and machinery breakdown casualties. Pronce [72] analysed the relationship between marine vessel total losses and selected vessel population characteristics such as ship age and registration flag. Thyregod and Nielsen (1993) have studied the age effect for the total yearly casualty rate.

The indicators, ship age and ship type are often observed from casualty investigation. The data, used to explain whether these two indicators should be included in the risk indicators, are collected from Shipping Statistics yearbook (Annually, from 1988 until 2006) [82] and World Casualty Statistics (Annually, from 1987 until 2005) [102].

6.3.1 Indicators

(1) Ship Age

Ship age is considered as a major risk indicator to identify substandard ships [15-16]. Here two facts are explained: whether (1) age distribution in casualty is correlated with age distribution of the whole ship; and (2) means of casualty occurrence probability in different age groups are the same.

To the first question, Chi-square test is adopted to test whether the age distribution of casualty is independent with the age distribution of the whole world fleet. The numbers collected over the time period from 1987 u 2005 are tested based on each year, and it concludes that there is they are independent (cf. Table 5-1). So this result indicates that risk age can be seen as an independent indicator to reflect potential maritime risks.

Table 6-1: Chi-square Test on Age Distribution

year		Value	df	Asymp. Sig. (2-sided)	year		Value	df	Asymp. Sig. (2-sided)
1987	Pearson Chi-Square	40.622	5	.000	1997	Pearson Chi-Square	44.150	5	.000
	Likelihood Ratio	43.267	5	.000		Likelihood Ratio	47.791	5	.000
	Linear-by-Linear Association	23.506	1	.000		Linear-by-Linear Association	41.325	1	.000
	N of Valid Cases	33735				N of Valid Cases	38500		
1988	Pearson Chi-Square	23.127	5	.000	1998	Pearson Chi-Square	213.649	5	.000
	Likelihood Ratio	23.342	5	.000		Likelihood Ratio	182.100	5	.000
	Linear-by-Linear Association	12.589	1	.000		Linear-by-Linear Association	173.095	1	.000
	N of Valid Cases	33130				N of Valid Cases	38564		
1989	Pearson Chi-Square	27.016	5	.000	1999	Pearson Chi-Square	58.489	5	.000
	Likelihood Ratio	26.410	5	.000		Likelihood Ratio	63.506	5	.000
	Linear-by-Linear Association	10.901	1	.001		Linear-by-Linear Association	50.146	1	.000
	N of Valid Cases	33104				N of Valid Cases	38917		
1990	Pearson Chi-Square	39.585	5	.000	2000	Pearson Chi-Square	73.068	5	.000
	Likelihood Ratio	42.949	5	.000		Likelihood Ratio	87.896	5	.000
	Linear-by-Linear Association	32.733	1	.000		Linear-by-Linear Association	71.356	1	.000
	N of Valid Cases	33964				N of Valid Cases	39007		
1991	Pearson Chi-Square	61.084	5	.000	2001	Pearson Chi-Square	58.194	5	.000
	Likelihood Ratio	63.410	5	.000		Likelihood Ratio	61.282	5	.000
	Linear-by-Linear Association	54.635	1	.000		Linear-by-Linear Association	50.848	1	.000
	N of Valid Cases	34330				N of Valid Cases	39113		
1992	Pearson Chi-Square	63.240	5	.000	2002	Pearson Chi-Square	54.288	5	.000
	Likelihood Ratio	70.887	5	.000		Likelihood Ratio	55.394	5	.000
	Linear-by-Linear Association	57.832	1	.000		Linear-by-Linear Association	45.892	1	.000
	N of Valid Cases	34743				N of Valid Cases	39415		
1993	Pearson Chi-Square	63.167	5	.000	2003	Pearson Chi-Square	46.688	5	.000
	Likelihood Ratio	70.596	5	.000		Likelihood Ratio	50.156	5	.000
	Linear-by-Linear Association	52.227	1	.000		Linear-by-Linear Association	43.532	1	.000
	N of Valid Cases	35156				N of Valid Cases	39665		

1994	Pearson Chi-Square	36.736	5	.000	2004	Pearson Chi-Square	53.910	5	.000
	Likelihood Ratio	37.533	5	.000		Likelihood Ratio	56.706	5	.000
	Linear-by-Linear Association	27.406	1	.000		Linear-by-Linear Association	48.598	1	.000
	N of Valid Cases	36250				N of Valid Cases	39932		
1995	Pearson Chi-Square	28.498	5	.000	2005	Pearson Chi-Square	75.874	5	.000
	Likelihood Ratio	32.129	5	.000		Likelihood Ratio	80.435	5	.000
	Linear-by-Linear Association	24.735	1	.000		Linear-by-Linear Association	64.979	1	.000
	N of Valid Cases	37016				N of Valid Cases	41110		
1996	Pearson Chi-Square	47.234	5	.000					
	Likelihood Ratio	49.613	5	.000					
	Linear-by-Linear Association	38.672	1	.000					
	N of Valid Cases	37965							

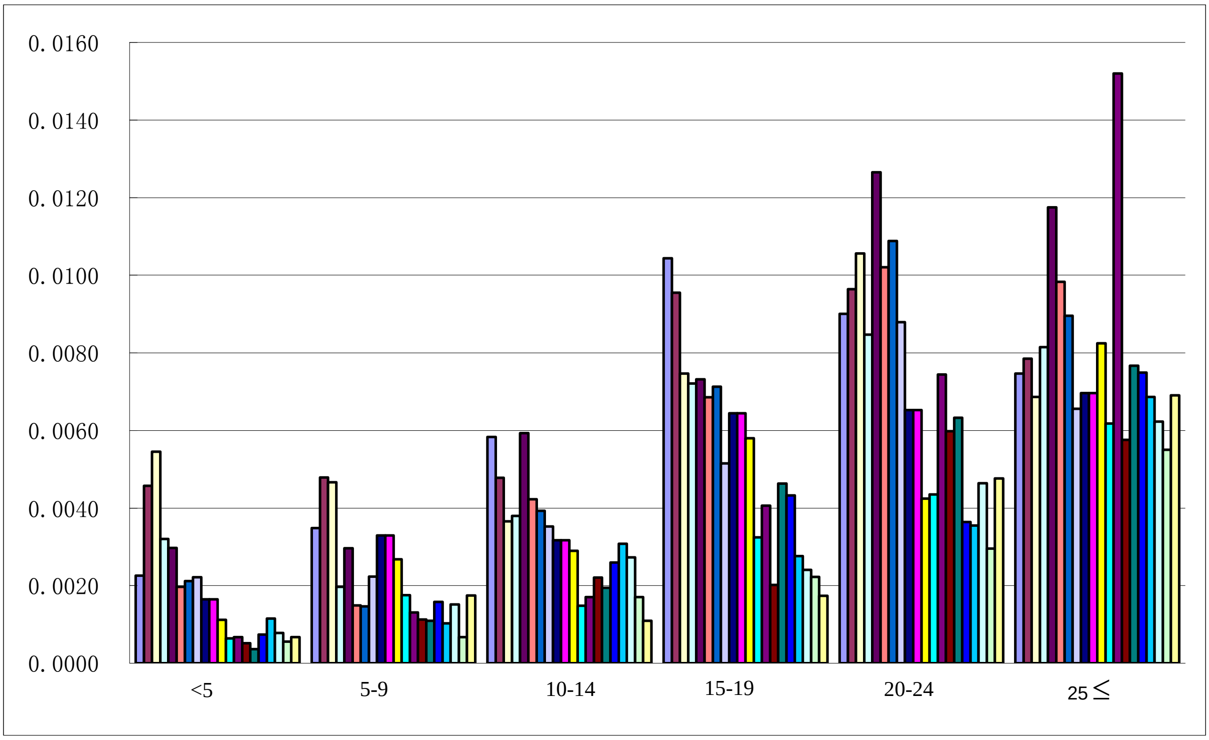
To the second question, T test is adopted to test whether the means of casualty occurrence probability are the same at the different age levels. The casualty occurrence probability is calculated by dividing the casualty number by the number of the whole world fleet. The data collected from 1987 to 2005 are tested, and it concludes that the means of casualty occurrence probability are significantly different at the different age levels (cf. Table 5-2).

Table 6-2: Means Test on Each Casualty Age Group

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
Age Pair					Lower	Upper			
Pair 1	<5 ～ 5-9	-.0008490	.0008041	.0000042	-.0008573	-.0008407	-200.727	36140	.000
Pair 2	<5 ～ 10-14	-.0013616	.0004310	.0000023	-.0013661	-.0013572	-600.661	36140	.000
Pair 3	<5 ～ 15-19	-.0037898	.0011431	.0000060	-.0038016	-.0037780	-630.284	36140	.000
Pair 4	<5 ～ 20-24	-.0053997	.0018004	.0000095	-.0054183	-.0053812	-570.164	36140	.000
Pair 5	<5 ～ 25≦	-.0071342	.0032407	.0000170	-.0071676	-.0071007	-418.503	36140	.000
Pair 6	5-9 ～ 10-14	-.0005126	.0008756	.0000046	-.0005217	-.0005036	-111.296	36140	.000
Pair 7	5-9 ～ 15-19	-.0029408	.0012677	.0000067	-.0029539	-.0029277	-441.011	36140	.000
Pair 8	5-9 ～ 20-24	-.0045508	.0025213	.0000133	-.0045767	-.0045248	-343.134	36140	.000
Pair 9	5-9 ～ 25≦	-.0062852	.0033953	.0000179	-.0063202	-.0062502	-351.911	36140	.000
Pair 10	10-14 ～ 15-19	-.0024282	.0007869	.0000041	-.0024363	-.0024200	-586.583	36140	.000
Pair 11	10-14 ～ 20-24	-.0040381	.0018259	.0000096	-.0040570	-.0040193	-420.441	36140	.000
Pair 12	10-14 ～25≦	-.0057725	.0033636	.0000177	-.0058072	-.0057379	-326.263	36140	.000
Pair 13	15-19 ～ 20-24	-.0016100	.0020313	.0000107	-.0016309	-.0015890	-150.680	36140	.000
Pair 14	15-19 ～ 25≦	-.0033444	.0034581	.0000182	-.0033800	-.0033087	-183.858	36140	.000
Pair 15	20-24 ～ 25≦	-.0017344	.0033167	.0000174	-.0017686	-.0017002	-99.413	36140	.000

Based on this result, a judgmental criteria to ship age is obtained, which is that an older is a higher maritime risk (cf. Figure 5-2).

Figure 6-2: Casualty Occurrence Probability Distribution in Age Range



(2) Ship type

The ship type is considered as a major risk indicator to identify substandard ships. Here two facts are explained: whether (1) ship type distribution in casualty is correlated with ship type distribution of the whole fleet; and (2) means of casualty occurrence probability in different ship type are the same.

Table 6-3: Ship Type Category

Code	Ship Type	Ship Type in Shipping Statistics yearbook	Ship Type in World Casualty Statistics
t1	Oil tanker	Oil tanker	Crude oil tanker
			Oil products tanker
t2	Chemical tanker	Chemical tanker	chemical
t3	Carrier	Liquid gas carrier	Liquid gas
		Ore/bulk/oil carrier	Buck/dry/oil
		Ore/bulk carrier	Buck dry
t4	Refrigerated cargo ship	Refrigerated cargo ship	Refrigerated cargo
t5	Ro-ro cargo ship	Ro-ro cargo ship	Ro-ro cargo
t6	General cargo ship	General cargo ship (single- deck)	General cargo
		General cargo ship (double- deck)	
t7	General cargo/passenger/ro-ro ship	General cargo/passenger/ro-ro ship	Passenger/general cargo
			Passenger/ro-ro cargo
t8	Container ship	Container ship	Container
t9	Passenger ship	Passenger ship	passenger

Before analysing the two questions, the ship type categories in two data resource, Shipping Statistics yearbook and World Casualty Statistics, need to be standardized. The different names in the two resources are listed in Table 5-3 and the ship type categories in the second column in this table are used in this study.

To the first question, Chi-square test is adopted to test whether the ship type distribution of casualty is independent with the ship type distribution of the whole world fleet. The numbers collected from 1991 to 2005 are tested based on each year, and it concludes that there is they are independent (cf. Table 5-4). So this result indicates that ship type can be seen as an independent indicator to reflect potential maritime risks.

Table 6-4: Chi-square Test on Ship Type Distribution

year		Value	df	Asymp. Sig. (2-sided)	year		Value	df	Asymp. Sig. (2-sided)
1990	Pearson Chi-Square	42.567	8	.000	1998	Pearson Chi-Square	55.215	8	.000
	Likelihood Ratio	46.069	8	.000		Likelihood Ratio	72.499	8	.000
	Linear-by-Linear Association	16.797	1	.000		Linear-by-Linear Association	13.777	1	.000
	N of Valid Cases	32229				N of Valid Cases	37476		
1991	Pearson Chi-Square	25.972	8	.001	1999	Pearson Chi-Square	53.343	8	.000
	Likelihood Ratio	28.009	8	.000		Likelihood Ratio	57.614	8	.000
	Linear-by-Linear Association	11.612	1	.001		Linear-by-Linear Association	10.244	1	.001
	N of Valid Cases	39119				N of Valid Cases	37796		
1992	Pearson Chi-Square	49.613	8	.000	2000	Pearson Chi-Square	43.134	8	.000
	Likelihood Ratio	51.948	8	.000		Likelihood Ratio	50.861	8	.000
	Linear-by-Linear Association	18.747	1	.000		Linear-by-Linear Association	10.382	1	.001
	N of Valid Cases	32891				N of Valid Cases	37868		
1993	Pearson Chi-Square	256.838	8	.000	2001	Pearson Chi-Square	69.126	8	.000
	Likelihood Ratio	235.183	8	.000		Likelihood Ratio	75.195	8	.000
	Linear-by-Linear Association	7.289	1	.007		Linear-by-Linear Association	14.381	1	.000
	N of Valid Cases	33517				N of Valid Cases	37985		
1994	Pearson Chi-Square	20.237	8	.009	2002	Pearson Chi-Square	43.311	8	.000
	Likelihood Ratio	25.422	8	.001		Likelihood Ratio	48.855	8	.000
	Linear-by-Linear Association	5.016	1	.025		Linear-by-Linear Association	10.306	1	.001
	N of Valid Cases	35330				N of Valid Cases	38215		
1995	Pearson Chi-Square	50.911	8	.000	2003	Pearson Chi-Square	59.242	8	.000
	Likelihood Ratio	57.717	8	.000		Likelihood Ratio	66.578	8	.000
	Linear-by-Linear Association	12.184	1	.000		Linear-by-Linear Association	13.543	1	.000
	N of Valid Cases	35984				N of Valid Cases	38426		
1996	Pearson Chi-Square	40.989	8	.000	2004	Pearson Chi-Square	45.361	8	.000

	Likelihood Ratio	41.388	8	.000		Likelihood Ratio	51.542	8	.000
	Linear-by-Linear Association	16.435	1	.000		Linear-by-Linear Association	5.340	1	.021
	N of Valid Cases	37099				N of Valid Cases	38717		
1997	Pearson Chi-Square	57.886	8	.000	2005	Pearson Chi-Square	53.751	8	.000
	Likelihood Ratio	74.989	8	.000		Likelihood Ratio	54.002	8	.000
	Linear-by-Linear Association	9.057	1	.003		Linear-by-Linear Association	13.917	1	.000
	N of Valid Cases	37419				N of Valid Cases	39814		

To the second question, T test is adopted to test whether the means of casualty occurrence probability are the same in the different ship type category. The data are tested, and it concludes that the means of casualty occurrence probability are significantly different at the different age levels (cf. Table 5-5).

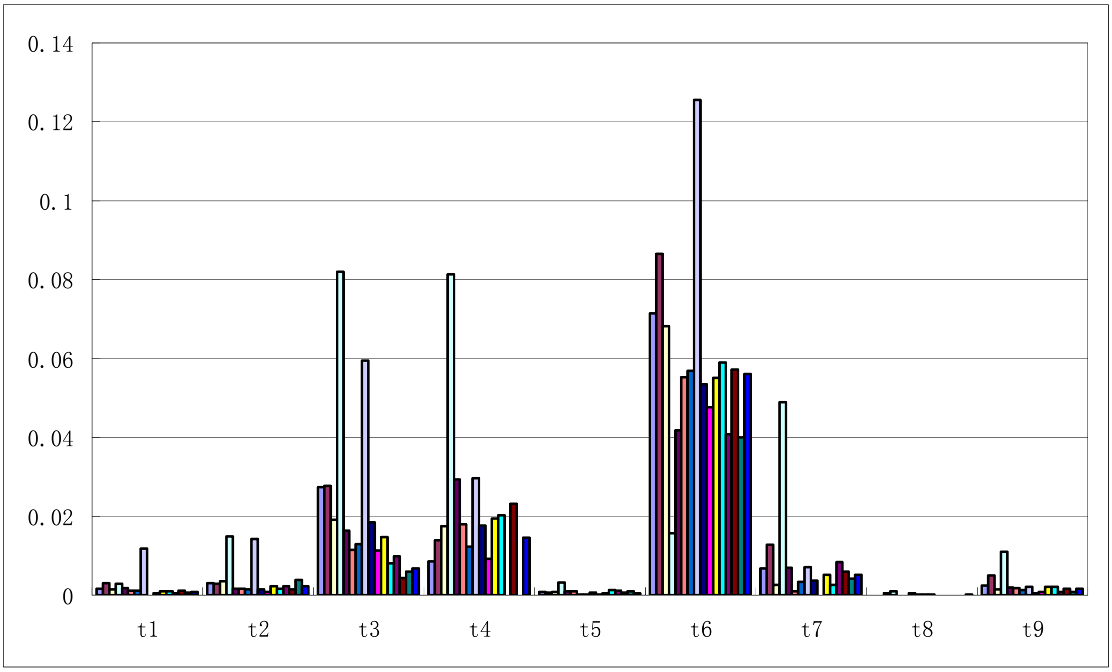
Table 6-5: Means Test on Each Casualty Age Group

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	t1 - t2	-.0024534735	.0031736865	.0002216599	-.0028905116	-.0020164354	-11.069	204	.000
Pair 2	t1 - t3	-.0333232979	.0219032737	.0015297910	-.0363395269	-.0303070688	-21.783	204	.000
Pair 3	t1 - t4	-.0213177293	.0186398959	.0013018668	-.0238845691	-.0187508894	-16.375	204	.000
Pair 4	t1 - t5	.0049540437	.0054285059	.0003791433	.0042065017	.0057015857	13.066	204	.000
Pair 5	t1 - t6	-.0768112200	.0341755154	.0023869215	-.0815174198	-.0721050202	-32.180	204	.000
Pair 6	t1 - t7	-.0045484244	.0138170514	.0009650247	-.0064511259	-.0026457229	-4.713	204	.000
Pair 7	t1 - t8	.0054675943	.0049693960	.0003470777	.0047832749	.0061519138	15.753	204	.000
Pair 8	t1 - t9	.0027041802	.0059658114	.0004166703	.0018826475	.0035257128	6.490	204	.000
Pair 9	t2 - t3	-.0308698243	.0194966981	.0013617085	-.0335546517	-.0281849970	-22.670	204	.000
Pair 10	t2 - t4	-.0188642558	.0158791894	.0011090507	-.0210509277	-.0166775839	-17.009	204	.000
Pair 11	t2 - t5	.0074075172	.0061341334	.0004284265	.0065628055	.0082522289	17.290	204	.000
Pair 12	t2 - t6	-.0743577465	.0354530715	.0024761499	-.0792398745	-.0694756185	-30.030	204	.000
Pair 13	t2 - t7	-.0020949509	.0114948846	.0008028376	-.0036778743	-.0005120275	-2.609	204	.010
Pair 14	t2 - t8	.0079210678	.0059665088	.0004167191	.0070994392	.0087426965	19.008	204	.000

Pair 15	t2 - t9	.0051576537	.0058287818	.0004070998	.0043549909	.0059603164	12.669	204	.000
Pair 16	t3 - t4	.0120055686	.0167007511	.0011664310	.0097057621	.0143053751	10.293	204	.000
Pair 17	t3 - t5	.0382773415	.0250625894	.0017504472	.0348260533	.0417286297	21.867	204	.000
Pair 18	t3 - t6	-.0434879221	.0363650819	.0025398475	-.0484956401	-.0384802042	-17.122	204	.000
Pair 19	t3 - t7	.0287748734	.0206061050	.0014391928	.0259372733	.0316124736	19.994	204	.000
Pair 20	t3 - t8	.0387908922	.0250708433	.0017510236	.0353384673	.0422433170	22.153	204	.000
Pair 21	t3 - t9	.0360274780	.0238911656	.0016686314	.0327375028	.0393174533	21.591	204	.000
Pair 22	t4 - t5	.0262717729	.0183095486	.0012787943	.0237504242	.0287931217	20.544	204	.000
Pair 23	t4 - t6	-.0554934907	.0464754995	.0032459897	-.0618934816	-.0490934998	-17.096	204	.000
Pair 24	t4 - t7	.0167693049	.0099334513	.0006937823	.0154014014	.0181372084	24.171	204	.000
Pair 25	t4 - t8	.0267853236	.0186887239	.0013052771	.0242117598	.0293588874	20.521	204	.000
Pair 26	t4 - t9	.0240219094	.0167652619	.0011709367	.0217132194	.0263305995	20.515	204	.000
Pair 27	t5 - t6	-.0817652637	.0392232587	.0027394712	-.0871665719	-.0763639554	-29.847	204	.000
Pair 28	t5 - t7	-.0095024681	.0116174120	.0008113952	-.0111022644	-.0079026718	-11.711	204	.000
Pair 29	t5 - t8	.0005135507	.0006941553	.0000484819	.0004179608	.0006091405	10.593	204	.000
Pair 30	t5 - t9	-.0022498635	.0019884914	.0001388823	-.0025236922	-.0019760348	-16.200	204	.000
Pair 31	t6 - t7	.0722627956	.0455256527	.0031796495	.0659936050	.0785319862	22.727	204	.000
Pair 32	t6 - t8	.0822788143	.0386543088	.0026997340	.0769558543	.0876017743	30.477	204	.000
Pair 33	t6 - t9	.0795154002	.0397917717	.0027791779	.0740358038	.0849949965	28.611	204	.000
Pair 34	t7 - t8	.0100160187	.0121370140	.0008476858	.0083446697	.0116873677	11.816	204	.000
Pair 35	t7 - t9	.0072526046	.0097782406	.0006829419	.0059060747	.0085991345	10.620	204	.000
Pair 36	t8 - t9	-.0027634142	.0024640607	.0001720975	-.0031027320	-.0024240963	-16.057	204	.000

Based on this result, a judgmental criteria to ship type is obtained, which is that Based on the means of casualty occurrence probability ship type are ranked from high risk to low risk as the following: general cargo ship (t6), carrier (t3), refrigerated cargo ship (t4), general cargo/passenger/ro-ro ship (t7), chemical tanker (t2), oil tanker (t1), passenger ship (t9), ro-ro cargo ship (t5), and container ship (t8) (cf. Figure 5-3).

Figure 6-3: Casualty Occurrence Probability Distribution in Ship Type



6.4 Risk Indicator System Summary

Two principles of construction risk indicator system are (1) indicators from maritime safety control net, which is based on control in managerial functions of management knowledge; (2) indicators from casualty investigation, which is based on the concept of predictive index in organizational behavior.

The proposed risk indicator system in this study includes the following indicators: flag State detention ratio; classification society detention ratio;

ship-owner detention ratio; shipbuilder detention ratio; ship insurance detention ratio and cargo owner detention ratio; detention number; deficiency; time since last inspection; ship age and ship type.

It is difficult to construct a complete risk indicator system because of the lack of transparency in the shipping industry. For reasons of commercial secrecy or whither consent of the owner, some flag States are reluctant to disclose information in relation to the corporate background of individual involved with the ownership of any given vessel, classification societies maintain records relating to ship deficiencies, and similarly, underwriters have maintained the confidentiality of their databases. An inability to ascertain the identity of the parties responsible for the operation of substandard ships results in major problems in determining accountability.

Recently, the way to overcome lack of transparency on information is to build up PSC databases to keep inspection records. For example, CGMIX (United States Coast Guard Maritime Information Exchange) is the USCG's database, SIReNac database, operated in French, is built by the Paris MOU and the Tokyo MOU's database is APCIS (the Asia Pacific Computerized Information System). Canada has linked its own coastguard PSC inspection database to the European system. Recently the development of database building is to provide international coordination in relation to PSC data.

7 Risk Level Determination

Since 1980s freight rates have shown a steady downward trend, shipowners have developed different strategies combined with open registers to cut costs wherever possible. Consequently substandard ships largely occurred. To prevent maritime accidents, inspection of substandard ships is the most important means. PSC programmes have been established around the world to implement international maritime safety and security law. Tokyo MOU is established in 1994 and conducted the PSC measures in the Asia-Pacific region. The target inspection rate of Tokyo MOU is 75%, higher than ones of Paris MOU and USCG, but the detention rate is the lowest. It means that the higher inspection number do not ensure the elimination of the substandard ships [15]. Especially under the influence of Globalization the international shipping shows a trend which is from industrialized countries to emerging markets in Asia [6]. Tokyo MOU meets more and more prosperous shipping transportation and high quality PSC inspection guarantees safe transportation.

Choosing ships to be checked is a part of PSC. Li [54] suggested a score system to classify the risky ships by the method of the weighted-sum model

(WSM). Currently the method adopted by Tokyo MOU is the WSM and takes eight attributes into account. The involved attributes are ship age, type, flag, deficiencies, detentions, classification society, outstanding deficiencies and time since last initial inspection. WSM can be a very powerful approach when there are no important complementarities between attributes [43]. It is obvious that this condition is difficult to satisfy. To eliminate this restriction, we introduce the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS model). This method is developed by Yoon [102] and Hwang & Yoon [43] and advocated by Zeleny [107] and Hall [38]. Recently, it was enriched by Opricovic & Tzeng [65] and Triantaphyllou [91]. Now it is widely used, such as Deng, Yeh, & Willis [23], Srdjevic, Medeiros, & Faria [87], Braglia, Frosolini, & Montanari [10] and so on. Especially Braglia et al. [10] introduce TOPSIS into assessment of the risks of production process.

This chapter is organized in four parts. Section 1 is an introduction. Section 2 shows the research framework and gives a simple number case to explain the method application. Section 3 compares the performance of two methods, WSM and TOPSIS, under the real situation. Section 4 reaches conclusions.

7.1 TOPSIS

7.1.1 Model

The TOPSIS model for the prioritization of the inspected ships is described as follows. Let $SHIP = \{ship_i \mid i = 1, \cdots, m\}$ be a finite set of alternatives to be inspected, and $A = \{a_j \mid j = 1, \cdots, n\}$ be a finite set of attributes. According to the two sets, the desirability of an alternative is to be judged. Let $X = \{x_{ij} \mid i = 1, \cdots, m; j = 1, \cdots, n\}$ be the $m \times n$ decision matrix, in which x_{ij} is the performance rating of alternative $ship_i$ with respect to attribute a_i. A TOPSIS problem can be expressed in matrix format:

$$X = \begin{matrix} & \begin{matrix} a_1 & a_2 & \cdots & a_n \end{matrix} \\ \begin{matrix} ship_1 \\ ship_2 \\ \cdots \\ ship_m \end{matrix} & \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1n} \\ x_{21} & x_{22} & \cdots & x_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ x_{m1} & x_{m2} & \cdots & x_{mn} \end{bmatrix}_{m \times n} \end{matrix}$$

The algorithm of TOPSIS includes six steps shown as the follows [43]:

Step1 Construct the normalized decision matrix; the purpose of this step is to facilitate intra-attribute comparisons by eradicating the effect of dimensions so all criteria are measured in dimensionless unit.

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}}, \quad i = 1,\cdots,m; \quad j = 1,\cdots,n.$$

Step2 Construct the weighted normalized decision matrix;

$$v_{ij} = w_j \cdot r_{ij} \quad i = 1,\cdots,m; \quad j = 1,\cdots,n, \quad W = \{w_j \mid \sum_{j=1}^{n} w_j = 1\}$$

Step3 Determine the positive-ideal and negative-ideal solutions;

$$A^* = \{v_1^*, v_2^*, \cdots, v_j^*, \cdots, v_n^*\} = \{(\min_i v_{ij} \mid j \in 1,\cdots,n) \mid i = 1,\cdots,m\}$$

$$A^- = \{v_1^-, v_2^-, \cdots, v_j^-, \cdots, v_n^-\} = \{(\max_i v_{ij} \mid j \in 1,\cdots,n) \mid i = 1,\cdots,m\}$$

Step4 Calculate the separation measure;

$$S_i^* = \sqrt{\sum_{j=1}^{n} (v_{ij} - v_j^*)^2}, \quad i = 1,\cdots,m. \qquad S_i^- = \sqrt{\sum_{j=1}^{n} (v_{ij} - v_j^-)^2}, \quad i = 1,\cdots,m.$$

Step5 Calculate the relative closeness to the ideal solution;

$$C_i^* = S_i^- \big/ (S_i^* + S_i^-), \quad i = 1,\cdots,m$$

Step6 Rank the preference order.

7.1.2 Number Case

It is supposed that there is a port and ten pieces of ships visit this port every day.

PSC office has four officers to conduct inspection and each officer can check one ship a day with the limitation of time. So four ships are to be inspected a day. Given that the four PSC officers face ten ships every day, but they need to choose four out of the ten to be inspected.

Table 7-1: Decision Matrix

SHIP	**age**	**type**	**flag**	**Deficiency**	**detention**	**classification**	**Outstanding deficiency**	**Time since last inspection**
$ship_1$	27	0	0	9	0	0	2	1
$ship_2$	47	4	7.08	47	0	10	14	4
$ship_3$	0	4	0	7	0	0	2	5
$ship_4$	14	4	10.77	22	1	10	0	4
$ship_5$	41	4	16.11	21	0	10	0	1
$ship_6$	5	4	0	0	0	0	1	9
$ship_7$	13	4	0	4	1	0	0	4
$ship_8$	10	4	0	7	0	0	0	5
$ship_9$	23	4	0	41	1	10	6	2
$ship_{10}$	25	4	1.36	26	2	0	0	2

Table 6-1 shows the decision matrix. The first column in this table includes ten alternatives. The first row of this table is the set of attributes. Eight attributes are chosen according to the ship targeting system of Tokyo MOU for simplicity. The calculation of each x_{ij} value is also based on the Tokyo MOU's system. The count modes of these two attributes, detention and time since last inspection, are little different from the Tokyo MOU's. We directly adopt the frequency to reflect detentions and use the month span to reflect time since last inspection.

Now the decision matrix is formed. The computation based on TOPSIS follows the procedures mentioned in the above section as follows:

(1) Construct the normalized decision matrix

$$R = \begin{bmatrix} 0.341 & 0 & 0 & 0.119 & 0 & 0 & 0.128 & 0.068 \\ 0.594 & 0.316 & 0.342 & 0.621 & 0 & 0.5 & 0.894 & 0.273 \\ 0 & 0.316 & 0 & 0.092 & 0 & 0 & 0.128 & 0.342 \\ 0.177 & 0.316 & 0.521 & 0.291 & 0.378 & 0.5 & 0 & 0.273 \\ 0.518 & 0.316 & 0.779 & 0.277 & 0 & 0.5 & 0 & 0.068 \\ 0.063 & 0.316 & 0 & 0 & 0 & 0 & 0.064 & 0.615 \\ 0.164 & 0.316 & 0 & 0.053 & 0.378 & 0 & 0 & 0.273 \\ 0.126 & 0.316 & 0 & 0.092 & 0 & 0 & 0 & 0.342 \\ 0.291 & 0.316 & 0 & 0.541 & 0.378 & 0.5 & 0.383 & 0.137 \\ 0.316 & 0.316 & 0.066 & 0.343 & 0.756 & 0 & 0 & 0.137 \end{bmatrix}$$

(2) Construct the weighted normalized decision matrix.

Assume that the relative importance of attributes is given by the decision maker as $W = \{0.143, 0.071, 0.143, 0.143, 0.143, 0.143, 0.143, 0.071\}$ .The weighted normalized decision matrix is then

$$V = \begin{bmatrix} 0.049 & 0 & 0 & 0.017 & 0 & 0 & 0.018 & 0.005 \\ 0.085 & 0.023 & 0.049 & 0.089 & 0 & 0.071 & 0.128 & 0.020 \\ 0 & 0.023 & 0 & 0.013 & 0 & 0 & 0.018 & 0.024 \\ 0.025 & 0.023 & 0.074 & 0.042 & 0.054 & 0.071 & 0 & 0.020 \\ 0.074 & 0.023 & 0.111 & 0.040 & 0 & 0.071 & 0 & 0.005 \\ 0.009 & 0.023 & 0 & 0 & 0 & 0 & 0.009 & 0.044 \\ 0.023 & 0.023 & 0 & 0.008 & 0.054 & 0 & 0 & 0.020 \\ 0.018 & 0.023 & 0 & 0.013 & 0 & 0 & 0 & 0.024 \\ 0.042 & 0.023 & 0 & 0.077 & 0.054 & 0.071 & 0.055 & 0.010 \\ 0.045 & 0.023 & 0.009 & 0.049 & 0.108 & 0 & 0 & 0.010 \end{bmatrix}$$

(3) Determine positive-ideal and negative-ideal solutions.

The positive-ideal solution is

$$A^* = \{\min_i v_{i1}, \min_i v_{i2}, \min_i v_{i3}, \min_i v_{i4}, \min_i v_{i5}, \min_i v_{i6}, \min_i v_{i7}, \min_i v_{i8}\}$$
$$= \{0, 0, 0, 0, 0, 0, 0, 0.005\}$$

The negative-ideal solution is

$$A^- = \{\max_i v_{i1}, \max_i v_{i2}, \max_i v_{i3}, \max_i v_{i4}, \max_i v_{i5}, \max_i v_{i6}, \max_i v_{i7}, \max_i v_{i8}\}$$
$$= \{0.085, 0.023, 0.111, 0.089, 0.108, 0.071, 0.128, 0.044\}$$

(4) Calculate the separation measure.

$$S_i^* = \sqrt{\sum_{j=1}^{8}(v_{ij} - v_j^*)^2}, \quad i = 1, \cdots, 10. \qquad S_i^- = \sqrt{\sum_{j=1}^{8}(v_{ij} - v_j^-)^2}, \quad i = 1, \cdots, 10.$$

	$Ship_1$	$Ship_2$	$Ship_3$	$Ship_4$	$Ship_5$	$Ship_6$	$Ship_7$	$Ship_8$	$Ship_9$	$Ship_{10}$
S_i^*	0.055	0.199	0.037	0.129	0.158	0.047	0.065	0.037	0.139	0.129
S_i^-	0.223	0.127	0.233	0.164	0.179	0.238	0.218	0.237	0.154	0.190

(5) Calculate the relative closeness to the ideal solution.

$C_{1*} = S_{1-} / (S_{1*} + S_{1-}) = 0.803$, $C_{2*} = 0.390$, $C_{3*} = 0.862$, $C_{4*} = 0.560$,

$C_{5*} = 0.531$, $C_{6*} = 0.836$, $C_{7*} = 0.770$, $C_{8*} = 0.864$, $C_{9*} = 0.527$,

$C_{10*} = 0.595$.

(6) Rank the preference order.

According to the increasing order of C_{i*}, the preference order is $Ship_2$, $Ship_9$, $Ship_5$, $Ship_4$.

7.2 Comparative Research

7.2.1 Experimental Design

The WSM method is a current method used in the Tokyo MOU. Here the ability of finding the detained ships is adopted as a criterion in order to compare the performances of these two methods, WSM and TOPSIS, in the application of PSC, and an experiment is designed.

A scene of one experiment unit could be set satisfying the following assumptions:

Assumption 1: Ten ships could call at a port in a day, four of which could be checked.

The common situation of the enforcement of the PSC ship inspection is that number of ships calling at a port is greater than the number of officers conducted the PSC ship inspections, so ten ships and inspecting four of them are set in one experiment unit.

Assumption 2: At least one of the ten ships definitely should be a substandard one.

Substandard ships were included in the ten ships in order to compare the performances of the two methods, WSM and TOPSIS. In one experiment unit, there were more than or at least one substandard ship(s). Under the same situation, the performances of the two methods can be observed though the number of targeted substandard ships.

An experiment unit is designed after considering Assumption 1 and 2. The one ship, which is definitely to be detained, is randomly chosen from the list of published detained ships during a certain period. The rest of nine ships are randomly chosen from the list of the inspection ships during the same period as the one when the detained ship is chosen. The real PSC inspection records kept by the Tokyo MOU during the period from March 1st to 31st 2006 were adopted as the selected population. There were 146 ships on the list of detained ships and 2078 ships on the list of inspection during this period. Each chosen ship was calculated by the two methods, WSM and TOPSIS, respectively. The information used in the calculations was collected before March 1st, 2006.

To evaluate the performances of these two methods, we adopt the real inspection results in March 2006 as the experimental results. It means that if the chosen ship is detained in March 2006, then we also consider this ship detained in the experiment. So we can evaluate the ability of these two methods to find detained ships by comparing the chosen ships picked by the different two methods to be checked with the real inspection results. If a method picks a ship and this ship is also detained in an actual inspection, then we think the method to find the detained ship is successful.

Here we define two indexes to evaluate the performance of these two methods. One is successful rate, which reflects the ability to pick detained ships. So the success rate is denoted

$$SR_i = \frac{No.\,of\ \ the\ \text{detained}\ ships\ \ picked\ by\ method_i}{No.\,of\ \ all\ \text{detained}\ ships} \qquad i = \begin{cases} 1 & WSM \\ 2 & TOPSIS \end{cases}$$

The other is comparative rate. This index reflects the comparative ability to pick detained ships. If $method_i$ is more accurate than the other method, then we think that $method_i$ is more efficient in an experimental unit and we count 1. This index is presented as

$$CR_i = \frac{No.\,of\ \ method_i\ better\ than\ method_j}{No.\,of\ \ all\ experimental\ unit}\ and\ i \neq j \quad i, j = \begin{cases} 1 & WSM \\ 2 & TOPSIS \end{cases}$$

7.2.2 Experimental results

The 50 experiments are repeated and the results are obtained in following table.

EU	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
Detained	1	1	3	3	2	2	1	1	3	1	1	1	1	1	1	1	2	2	2	1	1	2	2	3	1
WSM	1	0	0	2	2	0	1	1	2	1	1	0	1	1	1	1	1	2	2	1	0	1	1	0	1
TOPSIS	1	0	0	2	2	1	0	1	3	1	1	0	1	1	1	1	1	2	1	1	1	1	1	1	1

EU	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50
Detained	2	1	2	1	1	1	2	2	2	1	1	2	1	1	1	3	1	2	2	1	1	2	1	1	2
WSM	2	1	1	1	1	0	2	1	2	1	1	2	1	1	1	2	0	2	1	0	1	2	1	1	1
TOPSIS	2	1	1	1	1	0	2	1	2	1	1	2	1	1	0	2	1	2	1	0	1	2	1	1	1

In this table, the ‘Detained’ row indicates the actual count of detained ships out of ten in one experimental unit. The numbers, filled in the item ‘WSM’ on the third line in this table, reflect the count of detained ships from four ships picked by WSM to be inspected. The numbers in the bottom row reflect the count of detained ships from four ships to be inspected picked by TOPSIS. Then we can calculate SR as follows $SR_1 = 53/77 \approx 68.8\%$ and $SR_2 = 55/77 \approx 71.4\%$. Since $SR_1 < SR_2$, we think that the TOPSIS method has higher successful rate than the WSM method. It means that the TOPSIS method is more efficient in picking detained ships.

From the table, it is obvious that there are five times when the number of detained ships picked by TOPSIS method is bigger than the number when picked by WSM method. The five experimental units are 6, 9, 21, 24 and 42. On the other side, there are three times when the number picked by WSM method is bigger than picked by TOPSIS method. The three experimental units are 7, 19 and 40. Then we can calculate CR as follows $CR_1 = 3/50 = 6\%$ and $CR_2 = 5/50 = 10\%$. Since $CR_1 < CR_2$, we think that the TOPSIS method has higher comparative rate than the WSM method. It means that the TOPSIS method has more power to pick detained ships.

7.2.3 Discussion

We take EU9 as an example to show the characteristic of the two different methods. This basic information is shown in the table below.

SHIP	**age**	**type**	**flag**	**deficiency**	**detention**	**classification**	**Outstanding deficiency**	**Time since last inspection**	**WSM**		**TOPSIS**	
									Value	**Rank**	**Value**	**Rank**
$ship_1$	24	4	16.11	31	2	10	1	2	103.71	1	0.354	1
$ship_2$	39	4	0.36	6	0	0	0	4	60.96	2		
$ship_3$	4	4	9.54	12	0	10	8	5	46.74	4	0.557	2
$ship_4$	17	4	0	20	0	0	0	1				
$ship_5$	2	4	0	5	0	0	0	5				
$ship_6$	17	0	0	1	1	0	0	9				

$ship_7$	10	4	9.54	19	0	10	0	3			0.648	3
$ship_8$	30	4	0	29	0	0	0	9	59.4	3	0.654	4
$ship_9$	11	0	0	4	0	0	0	4				
$ship_{10}$	6	4	0	3	0	0	0	7				

The dark shade in this table represents the detained ships. There are three detained ships in the table and the WSM method finds two of them and the TOPSIS method finds three.

The characteristic of the WSM method is that it is easily influenced by some bigger values and ignores the possible connections among the attributes. For example, ship 8 has two bigger values ship age 30 and deficiencies 29, so it gets a higher aggregate value than some alternatives which have average distribution values in every attributes. This is obviously reflected in the formulation and presented as $AG_i = \sum_{j=1}^{8} w_j x_j, \quad i = 1,2,\cdots,10$, where w_j is the weight of the i_{th} attribute.

Therefore, although the WSM method is probably the best-known and most widely used method in decision making and can be applied without difficult in single-dimensional cases where all units of measurement are identical, Triantaphyllou and Lin [93] suggest that the WSM are not appropriate when complex decision-making problems are considered.

The C_{i*} value of the TOPSIS method is influenced by two aspects, one of which is the value of each attribute and the other of which is the potential relationship between these attributes. Take the ship 7 as an example. Although the values of ship age and deficiencies of ship 7 are smaller than ship 8, the TOPSIS method takes other aspects into account, such as ship type, flag, classification society and so on. Although these values are not big, they show a potential relation with the possibility of detention.

7.3 Conclusions

According to the comparison between the TOPSIS and WSM methods, we reach the two conclusions. Firstly, the TOPSIS method can include more aspects among attributes than the WSM method. The values and the potential relations among attributes are considered in the approach of TOPSIS. The WSM only consider the values and so it is easily affected by some bigger values and losses in the right direction. Secondly, the TOPSIS method is more efficient in taking advantage of the given information than the WSM. In our experiments, under the same limitation of information, the TOPSIS method is more powerful in finding the detained ships than the WSM method.

8 Optimal Inspection Rate Formulation

Detrimental environmental and social impacts caused by shipping accidents threaten the interest of port States. Examples of accidents are easy to recollect; the grounding of the *Exxon Valdez*, the capsize of the *Herald of Free Enterprise*, and the *Estonia* passenger ferry are some of the most widely publicized accidents in maritime transportation.

Inspection of ship safety is an administrative measure to reduce the occurrence of shipping accidents [59, 97]. So port State authorities, under the guide of the Port State Control (PSC) programmes, conduct port inspections to prevent shipping accidents from occurring in their water.

Having to decide what should be the proper port inspection level, port State authorities face a tradeoff, since they generally do not have enough resources to guarantee checking each calling ship within their water [21]. Furthermore, port inspections may do harm to economic development of a port. For example, inventory cost is one of identified losses due to delay and the cost will be transferred ultimately to customers [35]. Hence, the tradeoff indicates the need for a balanced policy that guarantees low losses no matter resulting from either shipping accidents or port inspections. The process of determining port inspection policies should seek the balance between the outcomes of too many or too few inspections.

The existing main mathematical tools that assist in setting port inspection policies are the selection methods. The three representatives include the target matrix method [96], shipping targeting system [4] and the inspection regime [68]. Attempts to improve these selection methods in use were conducted by Li [54], Xu, Lu, WJLi, Li and Zheng [103], Knapp [46] and Knapp and Franses [47, 48] . These tools help port State authorities identify risky ships to be inspected.

Other attempts focus on the introduction of new technical or management measures. An optimal monitoring technique that combines the satellite information is suggested [31]. An optimal contract that mixes penalties based on the amount of pollution ex post with penalties based on the extent of noncompliance ex ante was analysed in recent research [34]. An integrated inspection support system was investigated [39]. Few attempts were conducted to determine port inspection rates.

This research attempts to propose a tool that takes into account the considerations of both shipowners and port authorities. Formulation of a noncooperative game theory is used since this theory handles situations where different parties with different objectives are involved in a decision-making mechanism. This study is an extension of the research of Li and Cullinane [56]. To make a safe regulation effectively, the behaviors of the shipowners and the port state authority are considered together [56].

The chapter is divided into 6 sections. Section 1 is an introduction. Section 2 briefly summarizes the history of port inspection policies during the development of PSC programmes. Section 3 is the proposal on a making-decision tool based on game theory for the port authority to determine the optimal inspection rate is outlined. First, the principles and assumptions on which the proposed game is based are described. Second, the game is constructed. After proving that there is an optimal inspection rate, the steps to solve the game are listed. In part 4 a simple form game is defined to investigate the effect of the changes of decision-making circumstances on the results of the proposed game. Section 5 contains empirical discussions and Section 6 ends with a summary and possible extensions.

8.1 Setting the Port Inspection Rate: Abbreviated Review

Before the 1980s, decisions concerning port inspections, which are currently a main measure of the enforcement of port state control, were not regarded as a potential means of making shipping safer. Originally, there were no conventions to guarantee the enforcement of port state control, which refers to a state's jurisdiction over ships in its ports. Traditionally, a ship is legally regarded as a floating island of the Flag State's territory and hence the ship must be subject to the exclusive jurisdiction of its Flag State. 'Flag State' generally refers to the state whose flag a ship flies and whose nationality a ship bears. Flag State jurisdiction was be restricted by the enforcement of port state control and hence legal conflict could arise between them. It took a long time to deal with such issues and to determine the content of port state jurisdiction. The final text of the provisions on "Enforcement by Port States" was completed and included in Art.218 of the United Nations Convention on the Law of the Sea 1982 (UNCLOS 1982).

Although the concept of port state control is quite new, there is a flourishing development of port state control. Based on the provisions of

UNCLOS 1982, regional port state control organizations appeared, such as the Paris MOU based on the Paris Memorandum of Understanding on Port State Control 1982, and the Tokyo MOU based on the Memorandum of Understanding on Port State Control in the Asia-Pacific Region 1993. These organizations conduct port inspections and determine the target inspection rates in different regions. For example, the target inspection rate of the Paris MOU is 25%. The target annual inspection rate of the Tokyo MOU is 75%, increasing from the original target of 50% since it was achieved in 1996.

Port inspections are effective in decreasing the frequency of shipping accidents after the first port state control programme was enforced in 1982. To maintain the effectiveness of port inspections, it is common today in port States to try to further increase the frequency of port inspections and hence to force the shipowners' to increase effort levels to keep their ships at higher safe levels.

Certain problems accompany the increase in port inspection rates. Firstly, there are a large number of ship visits at ports at any one time, and the port state has limited resources to conduct on-board inspections of each ship. Secondly, it is clear that on-board inspections can delay the fast turn-over that characterizes the modern logistics system. Finally, increasing frequent port inspections could not only involve immediate costs, but also push up the shipowners' inventory costs, which will be passed on ultimately to customers through increasing prices.

These problems emphasize the need for a balanced policy that guarantees low losses regardless of whether the costs were caused by a shipping accident or a port inspection. The process of determining port inspection policies should therefore seek some tradeoff between the outcomes of too many or too few inspections.

However, the methods that are currently used in this process do not meet this need. The existing main mathematical tools that assist in setting inspection policies are risk indicators. These tools include the two-class vessel-rating policy adopted by the USCG (USCG Marine Safety Manual, Vol. II, Section D, and Chapter 4), the target factors used in the Paris MOU and risk factors of the Tokyo MOU (Asia-Pacific port state control manual, 2004, Section 4-3). The two-class vessel-rating policy adopted by the USCG, for example, regulates that port entry may be restricted before the conduct of a port inspection if the ship is listed in the first priority. These tools help the port authority identify the risk ships to be inspected, but do not assist in deciding how many port inspections should be provided.

8.2 A Game for Setting the Port Inspection Rate

8.2.1 Definitions and Assumptions

An attempt is made here to formulate a tool for determining the port inspection rate. The processes of decision-making are that (1) the port state authority chooses its port inspection rate first; (2) then the shipowners, whose ships will be inspected by the authority, adjust their effort levels based on their interests under the given port inspection rate. The effort level means the effort and expenditure afforded by a ship-owner for maintenance of its ship at a certain level of safety; and (3) next, the authority, to achieve the minimum expected (hereafter, abbreviated to exp.) social loss, decides the optimal inspection rate after taking into account the predicted effect of its choice on the shipowners. The Stackelberg game can include the whole decision-making process and the two players of the game are the port state authority and the shipowners whose ships are to be inspected by the authority (afterwards, we substitute ship-owner or shipowners for those whose ships are to be inspected by the authority). For analytic convenience, it is assumed that one ship is an independent decision unit.

Each possible decision that the port state authority may choose for the port inspection rate creates a different transportation setting, where each ship-owner has to choose his effort level based on his exp. loss. The loss includes the exp. maritime accident cost (M), the exp. detention cost (Q) and the effort level (e).

The accident costs from shipping accidents include aspects such as compensation for the cost of clearing up oil spills after a collision. This receives little attention from a shipowner, since the shipowner, due to lack of evidence and to a lack of homogeneity in national rules [31], is rarely convicted. The detention cost is an extra cost caused by port inspections. When a ship is to be inspected, a ship-owner bears three kinds of costs: first, the daily expenses such as seafarers' salaries and operational expenses during the inspection period; second, if the ship fails to pass the inspection and is detained, the daily expenses during the detention period; third, the cost caused by loss of future business, since if the ship often fails to pass port inspections, a cargo owner may choose another ship to transport his cargo. The effort level is the only cost which can be directly determined by a shipowner.

The exp. accident cost (M) is influenced by the effort level (e). In principle, the increase in e means improving the ship's safety level and hence decreasing the frequencies of shipping accidents, so the exp. accident cost (M)

is decreased. Further, it is quite common in economics that the effect level follows the law of diminishing returns, which means that with increasing effort level, the ability to lower frequencies of shipping accidents decreases: $dM/de < 0$ and $d^2M/de^2 > 0$.

Since the exp. detention cost (Q) is caused by port inspections and is an added pressure on shipowners to make them increase their effort levels, it is influenced by the effort level (e) and the port inspection rate (r). Generally the more port inspections that are conducted, the higher the exp. detention cost: $\partial Q/\partial r > 0$. Meanwhile, the shipowners can decrease their exp. detention cost by passing port inspection without delay, if the shipowners want to increase their effort levels. Further, in economics, the decreased level follows the law of diminishing returns, which means that with increasing effort level, the ability to lower the frequencies of ship detentions decreases: $\partial Q/\partial e < 0$ and $\partial^2 Q/\partial e^2 > 0$.

When a ship-owner chooses the effort level, the exp. loss is

$$F(e,r) = M(e) + Q(e,r) + e$$

where $F =$ the exp. loss function of a ship-owner; $M =$ the exp. accident cost function; $Q =$ the exp. detention cost function; $e =$ the effort level; $dM/de < 0$,

$d^2M/de^2 > 0$ and $\partial Q/\partial e < 0$, $\partial^2 Q/\partial e^2 > 0$ mean that the exp. accident cost and the exp. detention cost decrease with an increasing effort level, and the marginal effects on the two costs which are produced by the effort level decreases; and $\partial Q/\partial r > 0$ means that the exp. detention cost increases when the inspection rate increases. The objective of a ship-owner is to minimize this expression.

We also need to define the objective of the port state authority. The port state authority determines his inspection rate based on the exp. social loss. The involved losses are the exp. damage and recovery cost, and the exp. inspection cost.

In the damage and recovery cost, the chief concern of the port state authority, is a loss caused by shipping accidents. Since the shipowner's effort level（e）can influence the frequency of shipping accidents, the exp. damage and recovery cost decreases with e increasing. Further, based on the common economic assumption, the law of diminishing returns still works for the effect of the effort level（e）on the exp. damage and recovery cost (D), so the relationship between D and e can be written as $dD/de < 0$ and $d^2D/de^2 > 0$.

The inspection cost is caused by port inspections. It is composed of two types of costs. The first one is such costs as operational costs for a port inspection. The second one is the losses resulting from the delay of flow of commodities. For example, since the ships are detained by port inspections, the inventory cost of the cargo is pushed up and is shown in the ultimate price borne by customers, or a shipowner may choose another port with a low port inspection rate, even worse a manufacturer pursuing a just-in-time goal may change its location. Generally, the more port inspections are conducted, the greater the exp. inspection cost (C) is caused: $dC/dr > 0$. Further, the effect of the inspection cost caused by the slow flow of commodities is more obvious after more port inspections are conducted, it is therefore the case that the exp. inspection cost (C) tends to rise less rapidly at a lower port inspection rate than at higher rates: $d^2C/dr^2 > 0$.

The port state authority calculates its exp. social loss function by summing up the exp. social loss caused by individual shipowners. The exp. social loss function of the port state authority is

$$G(r, e_1, \ldots, e_N) = \sum_{i=1}^{N} [D_i(e_i) + C_i(r)] \qquad (1)$$

where $G =$ the exp. social loss function; $N =$ number of visiting ships; $D =$ the exp. damage and recovery cost function; $C =$ the exp. inspection cost function;

$r =$ the inspection rate variable that the port state authority can determine; e_i = the effort level determined by the i_{th} ship-owner; $dD/de < 0$ and $d^2D/de^2 > 0$ means that with the effort level increasing, the exp. damage and recovery cost decreases and the ability of effort level to lower the cost also decreases; and $dC/dr > 0$ and $d^2C/dr^2 > 0$ means that with the inspection rate increasing, the inspection cost increases and a higher inspection cost is caused to achieve a higher inspection rate. The objective of the port state authority is to minimize the exp. social loss.

8.2.2 Formulation of the General Game

A Stackelberg game is adopted and the port state authority and shipowners are the two players. The port state authority, the "Stackelberg leader", chooses his port inspection rate (r) first, and the shipowners observe r before choosing their own effort levels ($e_1, \ldots, e_N$). We can define a Nash equilibrium of this game in the obvious way: as a strategy profile such that neither player can gain by switching to a different strategy. Let us consider two particular Nash equilibria of this game.

Since the shipowners observe the port state authority's choice of port inspection rate (r) before choosing their effort levels ($e_1, \ldots, e_N$), in principle the shipowners could condition their choice of ($e_1, \ldots, e_N$) on the observed level of r. The objective of a shipowner, for a given inspection rate (r), is to minimize his exp. loss, denoted as $\min_{e_i} F_i(e_i, r) = \min_{e_i}[Q_i(e_i, r) + M_i(e_i) + e_i]$. We define $e_i^*(r)$ as the optimal effort level at the condition of r to minimize the shipowner's exp. loss and the resolved processes are as follows:

$$\because \quad F_i(e_i, r) = Q_i(e_i, r) + M_i(e_i) + e_i$$

$$\therefore \quad \frac{\partial F_i}{\partial e_i} = \frac{\partial Q_i}{\partial e_i} + \frac{dM_i}{de_i} + 1 \quad \text{and} \quad \frac{\partial^2 F_i}{\partial e_i^2} = \frac{\partial^2 Q_i}{\partial e_i^2} + \frac{d^2 M_i}{de_i^2}$$

$$\because \quad \frac{\partial^2 Q_i}{\partial e_i^2} > 0 \qquad \frac{d^2 M_i}{de_i^2} > 0 \quad e_i \geq 0$$

$$\therefore \quad \frac{\partial^2 F_i}{\partial e_i^2} > 0$$

$\therefore$ The form of a ship-owner's exp. loss function is convex when $e_i \geq 0$.

$$\because \quad \frac{\partial Q_i}{\partial e_i} < 0, \quad \frac{dM_i}{de_i} < 0 \quad \text{and} \quad \frac{\partial F_i}{\partial e_i} = \frac{\partial Q_i}{\partial e_i} + \frac{dM_i}{de_i} + 1$$

In the real context, the ship-owner can adjust his effort level (e_i) to minimize exp. loss under different port inspection rates (r). So the common case is that the optimal effort level $e_i^*(r)$ is resolved by letting $\frac{\partial F_i}{\partial e_i} = 0$.

The first equilibrium gives rise to the Stackelberg effort levels and the port inspection rate. In this equilibrium, each ship-owner's strategy $e_i^*(r)$ is to choose, for each r, the level of e_i that solves $\min_{e_i} F_i(e_i, r)$.

The objective of the port state authority is to minimize its exp. social loss. Since Nash equilibrium requires that the authority's strategy minimize its exp. loss given that $e_i^*(r)$, the function (1) is rewritten as $\min_r G(r, e_1^*(r), \cdots, e_n^*(r)) = \sum_{i=1}^{N} [D_i(e_i^*(r)) + C_i(r)]$. In the real context, the port state authority can determine its port inspection rate (r) to make minimize exp. social loss. We assume that r^* is the optimal inspection rate for minimization.

The outcome of the Stackelberg game is the solution (r^*, $e_1^*(r^*)$, …, $e_N^*(r^*)$). So we identified two Nash equilibria for the game where the port state authority chooses the port inspection rate first: one equilibrium with the "Stackelberg port inspection rate and effort levels" and one where the port inspection rate and the effort levels are decided as if the two players are moving simultaneously.

The general formulation of the proposed game is as follows:

$$\min_r G(r, e_1^*(r), \cdots, e_N^*(r)) = \sum_{i=1}^{N} [D_i(e_i^*(r)) + C_i(r)]$$

$s.t.$

$$e_i^*(r) = \arg\min_{e_i} F_i(e_i, r) = \arg\min_{e_i} [Q_i(e_i, r) + M_i(e_i) + e_i]$$

$i = 1, \cdots, N$

$$D_i(e_i^*(r)) \geq M_i(e_i)$$

$$0 \leq r \leq 1; \quad e_i \geq 0$$

where $r =$ the port inspection rate variable that the port state authority can determine; $e =$ the effort level variable that a ship-owner can decide; $N =$ number of visiting ships; $F =$ the exp. loss function of a ship-owner; $e^*(r) =$ the ship-owner's optimal effort level which minimizes F under different r; $Q =$ the exp. detention cost function; $M =$ the exp. accident cost function; $G =$ the exp. social loss function; $G(r, e_1^*(r), \cdots, e_N^*(r)) =$ the exp. social loss function under the condition of the feasible effort levels afforded by each ship-owner; $D =$ the exp. damage and recovery cost function; $C =$ the exp. inspection cost function; and $T =$ any given set of constraints.

The inspection rate variable r is defined here as the possibility of inspecting a ship. Each value of r, $0 \leq r \leq 1$, is a feasible choice of the port state authority. The ship-owner effort level variable e is defined here as an input of a shipowner to keep his ship at a certain safety level. Each value of e, $e \geq 0$, is a feasible choice of the ship-owner.

The exp. damage and recovery cost is no less than the exp. accident cost, since the former cost takes into account such external effects as sea pollution, and thereby the constraint $D_i(e_i^*(r)) \geq M_i(e_i)$ is added. Exxon, for example, settled with the state of Alaska, and the United States Government in 1991 spent approximately one billion dollars, and spent an additional two billion dollars on the clean up. The vessel spilled only twenty percent of its fifty-three million gallon cargo of crude.

The required input for the game are the functions for each exp. cost (M, D, Q, C), and the number of visiting ships (N). The outputs are the recommended values of the inspection rate variable (r) and the ship-owner's effort level (e).

The process of solving this game is presented as the following:

Step 1: Count the number of visiting ships during a period. The period can be a month or a year. It is common to adopt the fiscal year.

Step 2: Define the function of each exp. cost (M, D, Q, C). The functions must satisfy the above described relationship: $dD/de < 0$ and $d^2D/de^2 > 0$; $dM/de < 0$ and $d^2M/de^2 > 0$; $\partial Q/\partial e < 0$ and $\partial^2 Q/\partial e^2 > 0$; and $dC/dr > 0$ and $d^2C/dr^2 > 0$.

Step 3: Get each ship-owner's feasible effort level function ($e_i^*(r)$). Based on a ship-owner's exp. loss function, let the first-order $\partial F_i / \partial e_i = 0$ then $e_i^*(r)$ can be derived. Repeat this process and obtain N shipowners' feasible effort levels shown as $e_1^*(r), e_2^*(r), \cdots, e_N^*(r)$.

Step 4: Get the optimal inspection rate (r^*). Put the $e_1^*(r), e_2^*(r), \cdots, e_N^*(r)$ into the exp. social loss function to obtain r^*. This can be solved by using software such as Microsoft Excel.

Step 5: Put the r^* into $e_1^*(r), e_2^*(r), \cdots, e_N^*(r)$ then obtain the final resolution (r^*, $e_1^*(r^*)$, …, $e_N^*(r^*)$).

8.3 The Specific Game

In this section a simple form of the game is to be constructed to investigate (1) the existence of the optimal solution in the game; and (2) the effects of the parameter variations on the optimal solution.

8.3.1 Formulation

Construct the exp. cost functions based on the basic relations listed in the general game: (1) $dM/de < 0$, $d^2M/de^2 > 0$; (2) $\partial Q/\partial e < 0$, $\partial^2 Q/\partial e^2 > 0$, $\partial Q/\partial r > 0$; (3) $dD/de < 0$ $d^2D/de^2 > 0$; and (4) $dC/dr > 0$, $d^2C/dr^2 > 0$. Although many function forms can show these relations, for simplicity, here we adopt a common form since we want to investigate whether it is likely to obtain an optimal solution in our simple game after satisfying these basic relations.

In principle, the more effort level (e_i) a ship-owner inputs, the less likely the ship is to be detained. So the exp. detention cost decreases. Meanwhile, the more port inspections conducted by the port state authority on the ship, the more likely the ship is to be detained, and hence the exp. detention cost increases. Here we assume the first.

Assumption 1: $Q_i(e_i, r) = \alpha_{1(i)} \cdot \dfrac{r}{e_i + 1}$, in which $\alpha_{1(i)}$ is a given parameter and $\alpha_{1(i)} > 0$.

The more effort level (e_i) a ship-owner inputs, the less likely shipping accidents are to occur. The second assumption is obtained.

Assumption 2: $M_i(e_i) = \alpha_{2(i)} \cdot \frac{1}{e_i + 1}$, in which $\alpha_{2(i)}$ is a given parameter and $\alpha_{2(i)} > 0$.

Based on Assumption 1 and Assumption 2, a ship-owner's esp. loss function can be written as

$$F_i(e_i, r) = \alpha_{1(i)} \cdot \frac{r}{e_i + 1} + \alpha_{2(i)} \cdot \frac{1}{e_i + 1} + e$$

Since the objective of the shipowner is to minimize his exp. loss function through adjusting his effort level (e_i), the processes to realize the objective are the following:

$$\because F_i(e_i, r) = \alpha_{1(i)} \cdot \frac{r}{e_i + 1} + \alpha_{2(i)} \cdot \frac{1}{e_i + 1} + e$$

$$\therefore \frac{\partial F_i}{\partial e_i} = -\alpha_{1(i)} \cdot \frac{r}{(e_i + 1)^2} - \alpha_{2(i)} \cdot \frac{1}{(e_i + 1)^2} + 1$$

Let $\frac{\partial F_i}{\partial e_i} = 0$ then $e_i^*(r) = \sqrt{\alpha_{1(i)} r + \alpha_{2(i)}} - 1$

$$\because \left.\frac{\partial^2 F_i}{\partial e_i^2}\right|_{e_i = e_i^*(r)} = \left[2\alpha_{1(i)} \cdot \frac{r}{(e_i + 1)^3} + 2\alpha_{2(i)} \cdot \frac{1}{(e_i + 1)^3}\right]\Bigg|_{e_i = e_i^*(r)}$$

$$= 2\alpha_{1(i)} \cdot \frac{r}{(\sqrt{\alpha_{1(i)} r + \alpha_{2(i)}})^3} + 2\alpha_{2(i)} \cdot \frac{1}{(\sqrt{\alpha_{1(i)} r + \alpha_{2(i)}})^3}$$

$$\because \alpha_{1(i)} > 0, \quad \alpha_{2(i)} > 0, \quad r \geq 0$$

$$\therefore \left.\frac{\partial^2 F_i}{\partial e_i^2}\right|_{e_i = e_i^*(r)} > 0$$

$\therefore$ there is the optimal effort level ($e_i^*(r) = \sqrt{\alpha_{1(i)}r + \alpha_{2(i)}} - 1$) to minimize $F_i(e_i, r)$.

Next, construct the exp. social loss of the port state authority. Generally, the more effort level (e_i) a ship-owner inputs, the less likely shipping accidents are to occur. The exp. damage and recovery cost, therefore, decreases. The third assumption is the following:

Assumption 3: $D_i(e_i) = \frac{\alpha_{3(i)}}{e_i + 1}$, in which $\alpha_{3(i)}$ is a given parameter and $\alpha_{3(i)} > 0$.

The more port inspections conducted by the port state authority on the ship, the more likely the exp. inspection cost are to increase. Further, the cost tends to rise less rapidly at a lower port inspection rate than at a higher rate considering the effect of slow flow of commodities. So Assumption 4 is as follows:

Assumption 4: $C_i(r) = \alpha_{4(i)}r^2$ in which $\alpha_{4(i)}$ is a given parameter and $\alpha_{4(i)} > 0$.

Nash equilibrium requires that the authority minimize his exp. social loss given the behavior of a ship-owner ($e_i^*(r)$). So based on Assumption 3 it is obtained $D_i(e_i^*(r)) = \frac{\alpha_{3(i)}}{e_i^*(r) + 1}$, in which $\alpha_{3(i)}$ is a given parameter and

$\alpha_{3(i)} > 0$.

Put $D_i(e_i^*(r)) = \frac{\alpha_{3(i)}}{e_i^*(r)+1}$ and Assumption 4 into the exp. social loss of the port state authority, then obtain $G(r, e_1^*(r), \cdots, e_N^*(r)) = \sum_{i=1}^{N}[\frac{\alpha_{3(i)}}{e_i^*(r)+1} + \alpha_{4(i)} \cdot r^2]$. The objective of the port state authority is to minimize his exp. loss function, by determining the port inspection rate r. So the processes to realize the objective are:

$$\because G(r, e_1^*(r), \cdots, e_N^*(r)) = \sum_{i=1}^{N}[\frac{\alpha_{3(i)}}{e_i^*(r)+1} + \alpha_{4(i)} \cdot r^2] \text{ and } e_i^*(r) = \sqrt{\alpha_{1(i)}r + \alpha_{2(i)}} - 1$$

$$\therefore G(r, e_1^*(r), \cdots, e_N^*(r)) = \sum_{i=1}^{N}[\frac{\alpha_{3(i)}}{\sqrt{\alpha_{1(i)}r + \alpha_{2(i)}}} + \alpha_{4(i)} \cdot r^2]$$

$$\therefore \frac{dG}{dr} = \sum_{i=1}^{N}[-\frac{1}{2}\alpha_{1(i)}\alpha_{3(i)} \cdot \left(\alpha_{1(i)}r + \alpha_{2(i)}\right)^{-\frac{3}{2}} + 2\alpha_{4(i)}r]$$

$$\frac{d^2G}{dr^2} = \sum_{i=1}^{N}[\frac{3}{4}\alpha_{1(i)}^2\alpha_{3(i)} \cdot \left(\alpha_{1(i)} \cdot r + \alpha_{2(i)}\right)^{-\frac{5}{2}} + 2 \cdot \alpha_{4(i)}]$$

$$\because \alpha_{1(i)} > 0,\ \alpha_{2(i)} > 0, \alpha_{3(i)} > 0, \alpha_{4(i)} > 0,\ r \geq 0,\ i = 1, \ldots, N$$

$$\therefore \frac{d^2G}{dr^2} > 0$$

$\therefore$ The form of the function of PSC social loss is convex when $r \geq 0$.

In the real context, the port state authority can adjust his port inspection rate (r) to minimize the exp. social loss. So the common case is that there is an optimal inspection rate r^* ($0 \le r^* \le 1$) which is resolved by letting $\frac{dG}{dr} = 0$.

$$\therefore \sum_{i=1}^{N} [-\frac{1}{2}\alpha_{1(i)}\alpha_{3(i)} \cdot \left(\alpha_{1(i)}r^* + \alpha_{2(i)}\right)^{-\frac{3}{2}} + 2\alpha_{4(i)}r^*] = 0$$

$$\because \quad \alpha_{1(i)} > 0, \ \alpha_{2(i)} > 0, \alpha_{3(i)} > 0, \alpha_{4(i)} > 0, \ 0 \le r^* \le 1, \ i = 1, \ldots, N$$

If $r^* = 0$ then $\sum_{i=1}^{N} [-\frac{1}{2}\alpha_{1(i)}\alpha_{3(i)} \cdot \left(\alpha_{1(i)}r^* + \alpha_{2(i)}\right)^{-\frac{3}{2}} + 2\alpha_{4(i)}r^*] \ne 0$

$$\therefore r^* > 0$$

The optimal inspection rate of the port state authority is the following: $0 < r^* \le 1$ and let $\left.\frac{dG}{dr}\right|_{r=r^*} = 0$

We form the simple game presented as the following:

$$\min_r \sum_{i=1}^{N} [\frac{\alpha_{3(i)}}{e_i^*(r)+1} + \alpha_{4(i)} \cdot r^2]$$

$s.t.$

$$e_i^*(r) = \arg\min_{e_i^*} [\alpha_{1(i)} \cdot \frac{r}{e_i+1} + \alpha_{2(i)} \cdot \frac{1}{e_i+1} + e_i] \qquad i = 1, \cdots, N$$

$$\alpha_{1(i)}, \alpha_{2(i)}, \alpha_{3(i)}, \alpha_{4(i)} > 0; \quad \alpha_{3(i)} \ge \alpha_{2(i)}$$

$$0 \le r \le 1; \quad e_i \ge 0$$

The decision-making environment is formed by the values of known $\alpha_{1(i)}$, $\alpha_{2(i)}$, $\alpha_{3(i)}$, $\alpha_{4(i)}$, $i = 1, \cdots, N$ in the proposed simple game. $\alpha_{1(i)}$ means the penalty from ship detention. $\alpha_{2(i)}$ means the penalty from the consequences, which are borne by a shipowner and caused by a ship accident. $\alpha_{3(i)}$ means the penalty from the consequences, which are borne by the port state and caused by a ship accident. $\alpha_{4(i)}$ means the penalty from the slow flow of commodities caused by port inspections. Here we define $\alpha_1 = [\alpha_{1(1)}, \ldots, \alpha_{1(N)}]^T$, $\alpha_2 = [\alpha_{2(1)}, \ldots, \alpha_{2(N)}]^T$, $\alpha_3 = [\alpha_{3(1)}, \ldots, \alpha_{3(N)}]^T$, $\alpha_4 = [\alpha_{4(1)}, \ldots, \alpha_{4(N)}]^T$, and name α_1 , α_2 , α_3 , α_4 the penalty cost parameters, so the decision-making environment of this game is rewritten as [α_1 α_2 α_3 α_4]. The parameters per ship [$\alpha_{1(i)}$ $\alpha_{2(i)}$ $\alpha_{3(i)}$ $\alpha_{4(i)}$] need to be estimated based on the safety record of each ship.

During the processes of construction of the simple game, we conclude the following inferences:

Inference 1: there is an optimal effort level of a shipowner to minimize his exp. loss. (The process of proof refers to the process of the solution of minimizing the exp. loss.)

Inference 2: The feasible effort level of a shipowner increases necessarily increasing with the port inspection rate.

Prove:

$$\because \quad e_i^*(r) = \sqrt{\alpha_{1(i)} r + \alpha_{2(i)}} - 1$$

$$\therefore \quad \frac{de_i^*}{dr} = \frac{\alpha_{1(i)}}{2\sqrt{\alpha_{1(i)} r + \alpha_{2(i)}}}$$

$\because r \geq 0$, $\alpha_{1(i)} > 0$, $\alpha_{2(i)} > 0$

$$\therefore \quad \frac{de_i^*}{dr} > 0$$

Inference 3: there is an optimal inspection rate. (The process of proof refers to the process of the solution of minimizing the exp. social loss.)

8.3.2 Effects of the Penalty Cost Parameter Variation

We have discussed that there is an optimal port inspection rate given the cost parameter in the specific game. In this section, we discuss three issues: change of one of the known cost parameters, the relationship between the cost parameter variation and the optimal solutions. For example, after the port state authority publishes a policy, such as increasing the fines after oil spills, each shipowner may increase his accident penalty cost parameter $\alpha_{2(i)}$. Although the increased level of each shipowner is different, we define, in this case, that the cost parameter α_2 is increased. Here we want to know whether after the penalty cost parameter α_2 is increased, the variations of the optimal port inspection rate and the final optimal effort level of each shipowner increase, decrease, or show no change.

Here we assume that all shipowners behaviour equally. Based on the assumption of the same behaviour of the shipowners, the parameters can be induced as the following: (1) $\alpha_{1(1)} = \alpha_{1(2)} = \ldots = \alpha_{1(N)}$; (2) $\alpha_{2(1)} = \alpha_{2(2)} = \ldots = \alpha_{2(N)}$;(3) $\alpha_{3(1)} = \alpha_{3(2)} = \ldots = \alpha_{3(N)}$; and (4) $\alpha_{4(1)} = \alpha_{4(2)} = \ldots = \alpha_{4(N)}$. We use α_1, α_2, α_3, α_4 to simplify the parameters in the four equations.

A shipowner's exp. loss function is written as $F(e,r) = [\alpha_1 \cdot \frac{r}{e+1} + \alpha_2 \cdot \frac{1}{e+1} + e]$. To minimize a shipowner's exp. loss, based on Inference 1, when $\frac{\partial F}{\partial e} = 0$, the feasible effort level at different port inspection rates is detained $e^*(r) = \sqrt{\alpha_1 r + \alpha_2} - 1$.

The port state authority exp. social loss is written as

$$G(r, \underbrace{e^*(r), \cdots, e^*(r)}_{N}) = \sum_{i=1}^{N} [\frac{\alpha_{3)}}{e^*(r)+1} + \alpha_4 \cdot r^2] = N[\frac{\alpha_3}{e^*(r)+1} + \alpha_4 \cdot r^2]$$

. To minimize the exp. social loss, the processes are as follows:

(1) Put $e^*(r) = \sqrt{\alpha_1 r + \alpha_2} - 1$ into the exp. social loss function, then

$$G(r, \underbrace{e^*(r), \cdots, e^*(r)}_{N}) = N[\frac{\alpha_3}{\sqrt{\alpha_1 r + \alpha_2}} + \alpha_4 \cdot r^2]$$

(2) $\frac{dG}{dr} = N[-\frac{1}{2}\frac{\alpha_1\alpha_3}{(\alpha_1 r+\alpha_2)^{\frac{3}{2}}} + 2\alpha_4 \cdot r]$ $\frac{d^2G}{dr^2} = N[\frac{3}{4}\frac{{\alpha_1}^2\alpha_3}{(\alpha_1 r+\alpha_2)^{\frac{5}{2}}} + 2\alpha_4] > 0$

$\because \left.\frac{dG}{dr}\right|_{r=0} = N[-\frac{1}{2}\frac{\alpha_1\alpha_3}{(\alpha_2)^{\frac{3}{2}}}] < 0$

$\because \frac{d^2G}{dr^2} > 0$

$\therefore$ if $\left.\frac{dG}{dr}\right|_{r=1} < 0$, there is no $0 \le r' \le 1$ which lets $\left.\frac{dG}{dr}\right|_{r=r'} = 0$ then $r^* = 1$

$\therefore$ if $\left.\frac{dG}{dr}\right|_{r=1} \ge 0$, there is $0 \le r' \le 1$ which lets $\left.\frac{dG}{dr}\right|_{r=r'} = 0$ then $r^* = r'$

$$\because \left.\frac{dG}{dr}\right|_{r=1} = N[-\frac{1}{2}\frac{\alpha_1\alpha_3}{(\alpha_1+\alpha_2)^{\frac{3}{2}}} + 2\alpha_4] < 0 \Rightarrow \alpha_1+\alpha_2 < (\frac{\alpha_1\alpha_3}{4\alpha_4})^{\frac{2}{3}}$$

$$\left.\frac{dG}{dr}\right|_{r=1} = N[-\frac{1}{2}\frac{\alpha_1\alpha_3}{(\alpha_1+\alpha_2)^{\frac{3}{2}}} + 2\alpha_4] \ge 0 \Rightarrow \alpha_1+\alpha_2 \ge (\frac{\alpha_1\alpha_3}{4\alpha_4})^{\frac{2}{3}}$$

$$\therefore \quad r^* = \begin{cases} r' & if\ \alpha_1+\alpha_2 \ge (\frac{\alpha_1\alpha_3}{4\alpha_4})^{\frac{2}{3}}\ and\ \alpha_1(r')^{\frac{5}{3}} + \alpha_2(r')^{\frac{2}{3}} = \left(\frac{\alpha_1\alpha_3}{4\alpha_4}\right)^{\frac{2}{3}} \\ 1 & if\ \alpha_1+\alpha_2 < \left(\frac{\alpha_1\alpha_3}{4\alpha_4}\right)^{\frac{2}{3}} \end{cases}$$

At the above function, the situation $\alpha_1+\alpha_2 < \left(\frac{\alpha_1\alpha_3}{4\alpha_4}\right)^{\frac{2}{3}}$ refers to a kind of real context, where before the serious consequences caused by shipping accidents to life and the environment are recognized, a shipowner received a small penalty relative to the serious consequences caused by his ship. So in this situation, it is natural for the port state authority to conduct 100% port inspection. In the modern world, however, environment al protection has a high profile. The reality forces a shipowner to take greater responsibility after an accident and so 100% port inspection is not necessary. Since this situation is now common, here we assume that the optimal inspection rate r^* which can be reduced from $\alpha_1(r^*)^{\frac{5}{3}} + \alpha_2(r^*)^{\frac{2}{3}} = \left(\frac{\alpha_1\alpha_3}{4\alpha_4}\right)^{\frac{2}{3}}$ and $r^* \in (0,1]$.

The optimal solutions of this game can be summarized as the following:

The optimal inspection rate (r^*): $\alpha_1(r^*)^{\frac{5}{3}} + \alpha_2(r^*)^{\frac{2}{3}} = \left(\frac{\alpha_1\alpha_3}{4\alpha_4}\right)^{\frac{2}{3}}$ and $r^* \in (0,1]$.

Put r^* into the optimal effort level to obtain the final optimal effort level: $e^*(r^*) = \sqrt{\alpha_1 r^* + \alpha_2} - 1$.

We investigate the effect of the variation of each cost parameter on the optimal solutions. Based on the optimal solutions of the simple game, the following characteristics are obtained (shown in table 7-1).

Since the exp. detention cost is a cost caused by port inspections, the pressure on the shipowner comes from the combination of the value of the detention penalty cost parameter (α_1) and the frequency of port inspections.

Generally, the relationship between them is that when the value of α_1 is not great enough to force the ship-owner to improve his safety level, the port state authority needs improve the port inspection rate after taking into account its social loss; therefore, when the value of α_1 is great enough, the port state authority can decrease the port inspection rate. This point of view is revealed in Proposition 1.

Proposition 1: When the detention penalty cost parameter (α_1) increases, the optimal inspection rate (r^*) increases when $0 < r^* \le \left(\frac{\alpha_3^{\ 2}}{54\alpha_1 \cdot \alpha_4^{\ 2}}\right)^{\frac{1}{5}}$; or the optimal inspection rate (r^*) decreases when $1 \ge r^* > \left(\frac{\alpha_3^{\ 2}}{54\alpha_1 \cdot \alpha_4^{\ 2}}\right)^{\frac{1}{5}}$.

Prove:

$$\alpha_1 (r^*)^{\frac{5}{3}} + \alpha_2 (r^*)^{\frac{2}{3}} = \left(\frac{\alpha_1 \alpha_3}{4\alpha_4}\right)^{\frac{2}{3}} \qquad \Rightarrow$$

$$(r^*)^{\frac{5}{3}} + \frac{5}{3}\alpha_1 (r^*)^{\frac{2}{3}} \frac{dr'}{d\alpha_1} + \frac{2}{3}\alpha_2 (r^*)^{-\frac{1}{3}} \frac{dr'}{d\alpha_1} = \frac{2}{3}\left(\frac{\alpha_1 \alpha_3}{4\alpha_4}\right)^{-\frac{1}{3}} \frac{\alpha_3}{4\alpha_4} \qquad \Rightarrow$$

$$[\frac{5}{3}\alpha_1 (r^*)^{\frac{2}{3}} + \frac{2}{3}\alpha_2 (r^*)^{-\frac{1}{3}}] \frac{dr'}{d\alpha_1} = \left(\frac{\alpha_3^{\ 2}}{54\alpha_1 \alpha_4^{\ 2}}\right)^{\frac{1}{3}} - (r^*)^{\frac{5}{3}} \Rightarrow$$

$$\frac{dr^*}{d\alpha_1} = \left[\left(\frac{\alpha_3^{\ 2}}{54\alpha_1 \alpha_4^{\ 2}}\right)^{\frac{1}{3}} - (r^*)^{\frac{5}{3}}\right] \Bigg/ [\frac{5}{3}\alpha_1 (r^*)^{\frac{2}{3}} + \frac{2}{3}\alpha_2 (r^*)^{-\frac{1}{3}}]$$

$$\because 1 \geq r^* > 0\,,\ \ \alpha_1 > 0\,,\ \ \alpha_2 > 0\,, \alpha_3 > 0\,, \alpha_4 > 0$$

$$\therefore \frac{dr^*}{d\alpha_1} = \begin{cases} \geq 0 & 0 < r^* \leq \left(\dfrac{\alpha_3{}^2}{54\alpha_1 \cdot \alpha_4{}^2} \right)^{\frac{1}{5}} \\ < 0 & 1 \geq r^* > \left(\dfrac{\alpha_3{}^2}{54\alpha_1 \cdot \alpha_4{}^2} \right)^{\frac{1}{5}} \end{cases}$$

When the detention penalty cost parameter (α_1) increases, the shipowner's exp. loss may increase. In these circumstances, the shipowner increases his optimal effort level ($e^*(r^*)$ to decrease the pressure from the increase in α_1. This point of view is revealed in Proposition 2.

Proposition 2: When the detention penalty cost parameter (α_1) increases, the final optimal effort level ($e^*(r^*)$) increases.

Prove:

$$\because \ \ e^*(r^*) = \sqrt{\alpha_1 r^* + \alpha_2} - 1$$

$$\therefore \ \frac{\partial e^*}{\partial \alpha_1} = \frac{\alpha_1 \dfrac{dr^*}{d\alpha_1} + 1}{2\sqrt{\alpha_1 r^* + \alpha_2}}$$

$$\because \alpha_1 (r^*)^{\frac{5}{3}} + \alpha_2 (r^*)^{\frac{2}{3}} = \left(\frac{\alpha_1 \alpha_3}{4\alpha_4} \right)^{\frac{2}{3}}$$

$$\frac{dr^*}{d\alpha_1} = \left[\left(\frac{{\alpha_3}^2}{54\alpha_1{\alpha_4}^2} \right)^{\frac{1}{3}} - (r^*)^{\frac{5}{3}} \right] \Big/ [\frac{5}{3}\alpha_1 (r^*)^{\frac{2}{3}} + \frac{2}{3}\alpha_2 (r^*)^{-\frac{1}{3}}]$$

$$\therefore \frac{\partial e^*}{\partial \alpha_1} = \frac{1 + \alpha_1 \left\{ \left[\left(\frac{{\alpha_3}^2}{54\alpha_1{\alpha_4}^2} \right)^{\frac{1}{3}} - (r^*)^{\frac{5}{3}} \right] \Big/ [\frac{5}{3}\alpha_1 (r^*)^{\frac{2}{3}} + \frac{2}{3}\alpha_2 (r^*)^{-\frac{1}{3}}] \right\}}{2\sqrt{\alpha_1 r^* + \alpha_2}}$$

$$= \frac{1 + \alpha_1 \left\{ \left[\left(\frac{{\alpha_3}^2}{2\alpha_1{\alpha_4}^2} \right)^{\frac{1}{3}} - 3(r^*)^{\frac{5}{3}} \right] \Big/ [5\alpha_1 (r^*)^{\frac{2}{3}} + 2\alpha_2 (r^*)^{-\frac{1}{3}}] \right\}}{2\sqrt{\alpha_1 r^* + \alpha_2}}$$

$$= \frac{[5\alpha_1 (r^*)^{\frac{2}{3}} + 2\alpha_2 (r^*)^{-\frac{1}{3}}] + \alpha_1 \left[\left(\frac{{\alpha_3}^2}{2\alpha_1{\alpha_4}^2} \right)^{\frac{1}{3}} - 3(r^*)^{\frac{5}{3}} \right]}{2[5\alpha_1 (r^*)^{\frac{2}{3}} + 2\alpha_2 (r^*)^{-\frac{1}{3}}]\sqrt{\alpha_1 r^* + \alpha_2}}$$

$$= \frac{\alpha_1 (r^*)^{\frac{2}{3}}[5 - 3r^*] + 2\alpha_2 (r^*)^{-\frac{1}{3}} + \alpha_1 \left(\frac{{\alpha_3}^2}{2\alpha_1{\alpha_4}^2} \right)^{\frac{1}{3}}}{2[5\alpha_1 (r^*)^{\frac{2}{3}} + 2\alpha_2 (r^*)^{-\frac{1}{3}}]\sqrt{\alpha_1 r^* + \alpha_2}}$$

$$\because 0 < r^* \le 1,\ \ \alpha_1 > 0,\ \ \alpha_2 > 0, \alpha_3 > 0, \alpha_4 > 0$$

$$\therefore \frac{\partial e^*}{\partial \alpha_1} > 0$$

The increase in the accident penalty cost parameter α_2 is stressful for a shipowner. It is therefore natural that the ship-owner increases his effort level to decrease the pressure on his interest. Hence the port state authority can lower port inspection rate to reduce inspection costs. This point of view is revealed in Proposition3.

Proposition 3: When the accident penalty cost parameter (α_2) increases, the optimal inspection rate (r^*) decreases.

Prove:

$$\alpha_1(r^*)^{\frac{5}{3}} + \alpha_2(r^*)^{\frac{2}{3}} = \left(\frac{\alpha_1\alpha_3}{4\alpha_4}\right)^{\frac{2}{3}} \qquad \Rightarrow$$

$$\frac{5}{3}\alpha_1(r^*)^{\frac{2}{3}}\frac{dr^*}{d\alpha_2} + (r^*)^{\frac{2}{3}} + \frac{2}{3}\alpha_2(r^*)^{-\frac{1}{3}}\frac{dr^*}{d\alpha_2} = 0 \qquad \Rightarrow$$

$$\frac{dr^*}{d\alpha_2} = -\frac{3(r^*)^{\frac{2}{3}}}{5\alpha_1(r^*)^{\frac{2}{3}} + 2\alpha_2(r^*)^{-\frac{1}{3}}}$$

$$\because 1 \geq r^* > 0\,,\quad \alpha_1 > 0\,,\quad \alpha_2 > 0$$

$$\therefore \frac{dr^*}{d\alpha_2} < 0$$

When the accident penalty cost parameter α_2 increases, the shipowner's exp. loss may increase. In theses circumstances, the ship-owner increases his final optimal effort level ($e^*(r^*)$) to decrease the pressure from the increase in α_2.

This point is also revealed in Proposition 4.

Proposition 4: When the accident penalty cost parameter (α_2) increases, the final optimal effort level ($e^*(r^*)$) increases.

Prove:

$$\because \quad e^*(r^*) = \sqrt{\alpha_1 r^* + \alpha_2} - 1$$

$$\therefore \frac{\partial e^*}{\partial \alpha_2} = \frac{\alpha_1 \frac{dr^*}{d\alpha_2} + 1}{2\sqrt{\alpha_1 r^* + \alpha_2}}$$

$$\because \alpha_1 (r^*)^{\frac{5}{3}} + \alpha_2 (r^*)^{\frac{2}{3}} = \left(\frac{\alpha_1 \alpha_3}{4\alpha_4} \right)$$

$$\because \frac{dr^*}{d\alpha_2} = -\frac{3(r^*)^{\frac{2}{3}}}{5\alpha_1 (r^*)^{\frac{2}{3}} + 2\alpha_2 (r^*)^{-\frac{1}{3}}}$$

$$\therefore \quad \frac{\partial e^*}{\partial \alpha_2} = \frac{1 - \frac{\alpha_1 3(r^*)^{\frac{2}{3}}}{5\alpha_1 (r^*)^{\frac{2}{3}} + 2\alpha_2 (r^*)^{-\frac{1}{3}}}}{2\sqrt{\alpha_1 r^* + \alpha_2}} = \frac{1 - \frac{3}{3 + 2(1 + \frac{\alpha_2}{\alpha_1 r^*})}}{2\sqrt{\alpha_1 r^* + \alpha_2}}$$

$$\because r^* > 0, \quad \alpha_1 > 0, \quad \alpha_2 > 0$$

$$\therefore \frac{\partial e^*}{\partial \alpha_2} > 0$$

The increase in the damage and recovery cost parameter (α_3) increases the exp. social loss, so the port state authority improves the inspection rate to reduce the loss. This point of view is revealed in Proposition 5.

Proposition 5: When the damage and recovery cost parameter (α_3) increases, the optimal inspection rate (r^*) increases.

Prove:

$$\alpha_1(r^*)^{\frac{5}{3}} + \alpha_2(r^*)^{\frac{2}{3}} = \left(\frac{\alpha_1\alpha_3}{4\alpha_4}\right)^{\frac{2}{3}} \qquad \Rightarrow$$

$$\frac{5}{3}\alpha_1(r^*)^{\frac{2}{3}}\frac{dr^*}{d\alpha_3} + \frac{2}{3}\alpha_2(r^*)^{-\frac{1}{3}}\frac{dr^*}{d\alpha_3} = \left(\frac{\alpha_1^{\ 2}}{54\alpha_4^{\ 2}\alpha_3}\right)^{\frac{1}{3}} \qquad \Rightarrow$$

$$\Rightarrow \frac{dr^*}{d\alpha_3} = \frac{\left(\frac{\alpha_1^{\ 2}}{54\alpha_4^{\ 2}\alpha_3}\right)^{\frac{1}{3}}}{[\frac{5}{3}\alpha_1(r^*)^{\frac{2}{3}} + \frac{2}{3}\alpha_2(r^*)^{-\frac{1}{3}}]}$$

$\because \quad r^* > 0,\ \alpha_1 > 0,\ \alpha_2 > 0, \alpha_3 > 0, \alpha_4 > 0$

$\because \quad \therefore \dfrac{dr^*}{d\alpha_3} > 0$

The shipowner's final optimal effort level is increased since the port inspection rate increases with the increase in the damage and recovery cost parameter α_3. This point of view is revealed in Proposition 6.

Proposition 6: When the damage and recovery cost parameter α_3

increases, the final optimal effort level $e^*(r^*)$ increases.

Prove:

$$\because \quad e^*(r^*) = \sqrt{\alpha_1 r^* + \alpha_2} - 1$$

$$\because \quad \therefore \frac{\partial e^*}{\partial \alpha_3} = \frac{\alpha_1 \dfrac{dr^*}{d\alpha_3}}{2\sqrt{\alpha_1 r^* + \alpha_2}}$$

$$\because \quad \because \frac{dr^*}{d\alpha_3} > 0$$

$$\because \quad \therefore \frac{\partial e^*}{\partial \alpha_3} = \frac{\alpha_1 \dfrac{dr^*}{d\alpha_3}}{2\sqrt{\alpha_1 r^* + \alpha_2}} > 0$$

The increase in the inspection penalty cost parameter α_4 increases the exp. inspection cost, so the port state authority tries to lower the optimal inspection rate r^* as a trade-off. This point of view is revealed in Proposition 7.

Proposition 7: When the inspection cost parameter α_4 increases, the optimal port inspection rate r^* decreases.

Prove:

$$\alpha_1 (r^*)^{\frac{5}{3}} + \alpha_2 (r^*)^{\frac{2}{3}} = \left(\frac{\alpha_1 \alpha_3}{4\alpha_4} \right)^{\frac{2}{3}} \qquad \Rightarrow$$

$$\frac{5}{3}\alpha_1(r^*)^{\frac{2}{3}}\frac{dr^*}{d\alpha_4}+\frac{2}{3}\alpha_2(r^*)^{-\frac{1}{3}}\frac{dr^*}{d\alpha_4}=\frac{2}{3}\left(\frac{\alpha_1\alpha_3}{4\alpha_4}\right)^{-\frac{1}{3}}\left(-\frac{\alpha_1\alpha_3}{4\alpha_4{}^2}\right) \quad \Rightarrow$$

$$\Rightarrow \frac{dr^*}{d\alpha_4}=-\frac{2\left(\frac{\alpha_1\alpha_3}{4\alpha_4}\right)^{-\frac{1}{3}}\left(\frac{\alpha_1\alpha_3}{4\alpha_4{}^2}\right)}{[5\alpha_1(r^*)^{\frac{2}{3}}+2\alpha_2(r^*)^{-\frac{1}{3}}]}$$

$\because \quad r^*>0,\ \alpha_1>0,\ \alpha_2>0, \alpha_3>0, \alpha_4>0$

$\because \quad \therefore \dfrac{dr^*}{d\alpha_4}<0$

When the port state authority, after taking into account the increase in the inspection cost, conducts fewer port inspections, a shipowner’s effort level generally decreases. This point of view is revealed in Proposition 8.

Proposition 8: When the inspection penalty cost parameter (α_4) increases, the final optimal effort level ($e^*(r^*)$) decreases.

Prove:

$$\because \ e^*(r^*)=\sqrt{\alpha_1 r^*+\alpha_2}-1$$

$$\therefore \frac{\partial e^*}{\partial \alpha_4}=\frac{\alpha_1\frac{dr^*}{d\alpha_4}}{2\sqrt{\alpha_1 r^*+\alpha_2}}$$

$$\because \frac{dr^*}{d\alpha_4}<0$$

$$\therefore \frac{\partial e^*}{\partial \alpha_4} = \frac{\alpha_1 \dfrac{dr^*}{d\alpha_4}}{2\sqrt{\alpha_1 r^* + \alpha_2}} < 0$$

All these propositions are listed in table 7-1.

The analysis of the relationships between the variation of each cost parameter and the optimal inspection rate, and the variation of each cost parameter and the optimal effort level can help the port state authority to adjust its choice of the port inspection rate through changing each cost parameter. For example, the increase in the accident penalty cost parameter α_2 can not only increase the shipowner's effort level, and also decrease the port inspection rate.

Table 8-1: Relation between Penalty Cost Parameters and the Optimal Solutions

Parameter	$e^*(r^*)$	r^*
Detention cost parameter α_1 ↑	↑	↑ if $0 < r^* \le \left(\frac{\alpha_3^2}{54\alpha_1 \cdot \alpha_4^2}\right)^{\frac{1}{5}}$ or ↓ if $1 \ge r^* > \left(\frac{\alpha_3^2}{54\alpha_1 \cdot \alpha_4^2}\right)^{\frac{1}{5}}$
Accident cost parameter α_2 ↑	↑	↓
Damage and recovery cost parameter α_3 ↑	↑.	↑
Inspection cost parameter α_4 ↑	↓	↓

8.4 Discussion

The current development of port inspections is changing from the initial zero port inspection stage to the overly frequent stage, as discussed in Section 7.2. Here our proposed game is adopted to analyse the characteristics of the different stages, and hence provide some suggestions on determining the port optimal inspection rate.

We add the moderate inspection $0 < r^* < 100\%$ scenario to the current scenarios: the zero inspection ($r = 0$) scenario, the 100 percent inspection ($r = 100$) scenario for comparison. The zero inspection scenario means that no port inspection is conducted and therefore there are no inspection costs and no detention losses. The second scenario of 100 percent inspection indicates that the port state authority inspects each visiting ship in its waters. The third scenario of moderate inspection means that the port state authority considers the balance between the effort level and the inspection rate, and the inspection rate and the exp. social loss.

We compared the ship-owner's effort level ($e_i^{*'}$) and the exp. social loss (G_i) in the three scenarios when the est. costs are the same. The shipowner is profit driven and hence decides his effort level based on minimizing his exp. loss function. In the three scenarios, the results of the effort level and the exp. social loss are calculated based on the simple game and are listed in Table 7-2.

Table 8-2: The Effort Level and the Exp. Social Loss in Three Scenarios

Scenario (i)	1	2	3
	No inspection $r=0$	100 percent inspection $r=100\%$	Moderate inspection $0<r^*<100\%$
Effort level $e_i^*(r)$	$\sqrt{\alpha_2}-1$	$\sqrt{\alpha_1+\alpha_2}-1$	$\sqrt{\alpha_1 r^*+\alpha_2}-1$
Exp. social loss G_i	$\frac{\alpha_3}{\sqrt{\alpha_2}}$	$\frac{\alpha_3}{\sqrt{\alpha_1+\alpha_2}}+\alpha_4$	$\frac{\alpha_3}{\sqrt{\alpha_1 r^*+\alpha_2}}+\alpha_4\cdot(r^*)^2$

The changes of the optimal effort level and the exp. social loss in the three scenarios are different. The optimal effort level increases when the increase in port inspections because of $e_2^{*'}>e_3^{*'}>e_1^{*'}$. However, the minimum exp. social loss is not the scenario with the highest effort level. In fact, based on the previous proven interference, scenario 3 has the minimum exp. social loss with an intermediary effort level.

Here we take an example. The Exxon accident shipped fifty-three million gallon cargo of crude. The price per gallon is about $1.08. The est. cargo value is $57,240,000. The freight is estimated as $3,090,960, estimated by multiplying the cargo value $57,240,000 by 5.4%, a percentage of freight cost of import value as published by the Review of Maritime Transport (2005 Table 41). The detention cost included the daily cost estimated at $30,000 (Investment of European and American ports, Modern weekly business, 2007/6/2, in Chinese) and freight loss. So the detention cost is estimated as $\alpha_1 =$ \$3,120,960. The penalty asked in 1997 of the Song San, for polluting extensive areas of Singapore's beaches, which received the heaviest sentence in maritime history for oil pollution, included $450,000 for the tanker owner. The accident cost is estimated as $\alpha_2 =$ \$450,000.

We know that after the Exxon accident, the United States spent approximately three billion dollars, which included the damage and clear costs where $\alpha_3 =$ \$3,000,000,000 is assumed. The Exxon accident spilled twenty of a fifty-three million gallon cargo of crude. The loss of cargo $(1.08 \times 53{,}000{,}000 \times 20\%)$ is used as a base cost. Since the estimated part of the inspection cost resulting in delays in the international trade is difficult to calculate, the base cost is enlarged and added to the direct spent inspection cost for operational cost per port inspection. In this way, the inspection cost is estimated as $\alpha_4 =$ \$200,000. We put these estimated costs in Table 7-2, and the results are shown in Table 7-3.

Table 7-3: The effort level and the exp. social loss in three scenarios

Scenario (i)	1	2	3
	No inspection $r = 0$	100 percent inspection $r = 100\%$	Moderate inspection $r^* = 46\%$
Effort level $e_i^*(r)$	\$670	\$1,889	\$1,368
Exp. social loss G_i	\$4,472,135	\$3,587,554	\$2,607,839

($\alpha_1 = \$3,120,960$, $\alpha_2 = \$450,000$, $\alpha_3 = \$3,000,000,000$, $\alpha_4 = \$200,000$)

The results shown here are reasonable and make good sense. By describing the decision-making of the port inspection rate problem as a game, the port state authority ensures that its decision does not weaken port welfare. It is therefore recommended that this game be used as a tool to assist in determining the optimal port inspection rate.

The port authority can adjust its choice of the port inspection rate by changing cost parameters. Following the above example, the shipowner takes little responsibility should an accident occur compared to the responsibility taken by the port state authority since the value of est. accident cost is far smaller than the est. damage and recovery cost. The port state authority may take measures to force the shipowner to assume greater accident cost. The effect of such measures on the optimal inspection rate and the effort level can be listed as follows.

Accident cost parameter α_2	1	2
	$\alpha_2 = \$450,000$	$\alpha_2 = \$2,250,000$
Optimal Effort level $e_i^*(r^*)$	\$1,368	\$1,694
Optimal port inspection rate r^*	46%	20%
Exp. social loss G_i	\$2,607,839	\$1,865,552

($\alpha_1 = \$3,120,960,\ \ \alpha_3 = \$3,000,000,000,\ \ \alpha_4 = \$200,000$)

After increasing the accident cost parameter, it is shown that the shipowner improves his optimal effort level $e_i^*(r^*)$ and the port state authority can conduct fewer port inspections and suffer less exp. social loss.

8.5 Summary

There is a lack of tools that optimize the port state authority's goal while taking into account shipowners' behavior. An optimization tool is proposed here, assuming that the port state authority minimizes the exp. social loss and the shipowners minimize their exp. losses.

We also reveal the relationships between the variation of each cost parameter and the optimal inspection rate, and the variation of each cost parameter and the optimal effort level. The port state authority can make use of the relationship to adjust its inspection choice.

The relationships include (1) the increase in the detention cost parameter increases the optimal effort level while the changes of the optimal inspection rate are of three types: no change, increasing and decreasing and which type is shown depends on the exact decision conditions; (2) the increase in the accident cost parameter increases the optimal effort level and decreases the optimal inspection rate; (3) the increase in the damage and recovery cost parameter increases the optimal inspection rate and the optimal effort level; and (4) the increase in the inspection cost parameter decreases the optimal inspection rate and the optimal effort level.

The principles of determining port inspection rate using game theoretic formulations are introduced here, but both the theory and the practice presented above should be now taken further. The required theoretical developments include a more detailed discussion of different inspection rates based on ship risk levels; and a broader framework that incorporates penalties on substandard ships. On the practical side, the game should be implemented in real-life situations, and more attention should be paid to the calibration of the cost parameters and the influence of effort level on reducing shipping accidents.

9 Conclusions

This study helps the port State authorities make use of the vessels' historical safety records to identify potential substandard ships before conducting inspections and determining the appropriate port inspection rates. Thus this research contributes to the existing maritime safety policy and risk management in three aspects.

First, this study endeavours to address the effectiveness of the PSC programmes and to assess the methods which are used to select ships for inspection. Data on ship total loss (annually, from 1973-2006) and on the PSC inspection records (annually, from 1994-2005) were collected and analysed. The analysis of safety records of world fleets yields evidence that the maritime safety level is improved after the introduction of the PSC programme. After taking into account the maritime safety net construction and the development of world fleets, the improved maritime safety mainly contributes to the enforcement of the PSC programmes.

The detention inspection rate of the methods has been useful in revealing that the efficient level and stability of the different method. In detail, the method adopted by the USCG has high stability and the methods used by the Paris MOU and the Tokyo MOU have high efficient levels. These methods are all effective, but there are different efficient level and stability. The findings suggest that the methods need to be improved and also suggest combining these three selecting methods to strengthen the enforcement of the PSC programmes.

Secondly, a risk assessment system, to help the port State authorities identify substandard ships, is developed. This system includes two parts: risk indicator system and risk level determination approach. Based on the theory of managerial function and the theory of predictive index in organizational behavior, two propositions are made to improve risk indicator system: (1) strengthening the responsibilities of the actors within the maritime safety net; and (2) observing the characteristics abstracted from maritime accidents investigation. Guided by the two principles a new risk indicator system is proposed and can help port State authorities construct a unified information collection database. The proposed risk indicator system in this study includes the following indicators: flag State detention ratio; classification society detention ratio; ship-owner detention ratio; shipbuilder detention ratio; ship insurance detention ratio and cargo owner detention ratio; detention number; deficiency; time since last inspection; ship age and ship type. It is difficult to construct a complete risk indicator system because of the lack of transparency in the shipping industry. The way to overcome lack of transparency on information is to build up PSC databases to keep inspection records.

To improve the risk level determination method, the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) model is introduced. According to the comparison between the TOPSIS and WSM methods, the two conclusions are obtained. Firstly, the TOPSIS method can include more information among attributes than the WSM method. The values and the potential relations among attributes are considered in the approach of TOPSIS. The WSM only consider the values and so it is easily affected by some bigger values and losses in the right direction. Secondly, the TOPSIS method is more efficient in taking advantage of the given information than the WSM. Under the same limitation of information, the TOPSIS method is more powerful in finding the detained ships than the WSM method. The TOPSIS model can improve the efficiency of identifying substandard ships, and even no changes are required in the current PSC information collection database.

Finally, for the first time, a tool, based on the Stackelberg game, is proposed to construct the process of deciding an optimal port inspection rate. It is proven that, at the equilibrium of the game, there are an optimal port inspection rate and an optimal ship-owner's effort level. The result can help the port State authorities deploy minimum resources to achieve maximum social welfare and motivate shipowners to implement a better safety maintenance policy. It was also revealed that the relationships between the variation of each cost parameter and the optimal inspection rate, and the variation of each cost parameter and the optimal effort level. The port state authority can make use of the relationship to adjust its inspection choice.

The principles of determining port inspection rate using game theoretic formulations are introduced here, but both the theory and the practice presented above should be now taken further. The required theoretical developments include a more detailed discussion of different inspection rates based on ship risk levels; and a broader framework that incorporates penalties on substandard ships. On the practical side, the game should be implemented in real-life situations, and more attention should be paid to the calibration of the cost parameters and the influence of effort level on reducing shipping accidents.

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