ANALYZING THE EVOLUTION OF SHIP ACCIDENT RESEARCH, RECURRENT ACCIDENTS AND SHIP'S LIFESPAN

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Analyzing the Evolution of Ship Accident Research, Recurrent Accidents and Ship's Lifespan

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A thesis submitted in partial fulfilment of the requirements for the degree of Doctor of Philosophy

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CERTIFICATE OF ORIGINALITY

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Sung-Ho Shin (Name of student)

For those who lost their precious lives

in the cold ocean

and their family

Abstract

This thesis consists of three parts and focuses on the analysis of ship accidents and ship lifespan. Half a century (1965 to 2014) of research developments with respect to maritime accidents are summarized, and future directions are presented. This comprehensive literature review includes 572 papers published in 125 peer-reviewed journals with the following topics: i) the evolution of the geographic location, disciplines, main topics, and dimensions of research; ii) the major causes of maritime accidents, and iii) trends in the methods used and the evolution of data sources. On the basis of the identified research patterns, in this thesis, the focal research topics on maritime accidents were found to have shifted over the past 50 years from navigational issues and ship architecture to human errors. The topics related to maritime accidents continue to expand into socioeconomic factors, and future research on maritime accidents has been suggested.

The second study is a statistical analysis of the determinants of a ship's lifespan using the Cox proportional hazards model. This analysis covers the effects of shipping market conditions, safety management factors, and maritime accidents factors on a vessel's lifespan. With respect to these three factors, in this study, vessel lifespan is analyzed from delivery to scrapping with data from 16,551 scrapped vessels. This study demonstrates a method to predict the life of merchant vessels, which can provide information to private businesses for decision-making related to ships and help to formulate public

policy on vessel safety and environmental requirements that may result in social welfare loss due to an early withdrawal of merchant ships.

Approximately 63% of the world's ship accidents are recurrent. Reducing the recurrence rate can contribute significantly to maritime safety. In this context, the aim of the third study is to find factors that affect both initial and recurrent ship accidents by analyzing the duration between the accidents. The Cox proportional hazards model and its extended models are applied to ship accident data from 1996 to 2015, and the results can be used to identify which ships have a high risk of recurrent accidents, on the basis of ship attributes, ship supply and market conditions, shipbuilding country, previous accident type, and ship type.

Publications arising from the thesis

Academic journal papers:

1. Luo, M., Shin, S.H. (2016), "Half-century Research Developments in Maritime Accidents: Future Directions", *Accident Analysis and Prevention* (SSCI). (In press, Available online 19 April 2016).

2. Luo, M., Shin, S.H., and Chang, Y.T. (2017), "Duration Analysis for Recurrent Ship Accidents", *Maritime Policy & Management* (SSCI), 44(5), 603-622.

Book chapter:

1. Luo, M., Shin, S.H. (Forthcoming), "Routledge Handbook of Transport in Asia", Maritime Accidents, Eds. Zhang, J., Feng, C.M. Routledge. (To be published on January, 2018).

Conference papers (presentation):

1. Luo, M. and Shin, S.H. (2015), "A Statistical Analysis on Recurring Accidents in Shipping", 2015 Global Port Research Alliance (GPRA) conference, The Hong Kong Polytechnic University, Hong Kong, 22, May, 2015.

2. Luo, M. and Shin, S.H. (2015), "A Half-Century Research on Maritime Accidents: The Future Directions", 2015 Asian Logistics Round Table (ALRT) conference, Soochow University, Taiwan, 31 August.

3. Luo, M., Shin, S.H. (2017), "Lifespan of World Merchant Fleet: An Empirical Analysis". 2017 International Forum on Shipping, Ports and Airports (IFSPA) conference, The Hong Kong Polytechnic University, Hong Kong, 22-25, May, 2017.

Working paper:

1. Luo, M., Shin, S.H. (2017), "Lifespan of World Merchant Fleet: An Empirical Analysis".

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1. Luo, M., Shin, S.H. (2016), "Half-century Research Developments in Maritime Accidents: Future Directions", *Accident Analysis and Prevention* (SSCI). (In press, Available online 19 April 2016).

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List of Abbreviations

GENERAL ABBREVIATIONS

DWT: Deadweight Tonnage

FOC: Flag of Convenience

FPSO: Floating Production, Storage, and Offloading

FVA: Formal Vulnerability Assessment

GT: Gross Tonnage

HNS: Hazardous and Noxious Substances

HOF: Human and Organizational Factors

IACS: International Association of Classification Societies

IMO: International Maritime Organization

IQSMS: Integrated Quality and Safety Management System

ISM: International Safety Management

ITF: International Transport workers' Federation

LIBOR: London Interbank Offered Rate

LNG: Liquefied Natural Gas

MSA: Maritime Safety Administration

OECD: Organisation for Economic Co-operation and Development

PSC: Port State Control

SMS: Safety Management Systems

SOLAS: Safety of Life at Sea

ULCV: Ultra Large Container Vessel

WSA: Work Situation Awareness

ABBREVIATIONS ABOUT DATA SOURCES

AIS: Automatic Identification System

AMSA: Australian Maritime Safety Authority

BS: Braemer Seascope

CDI: Chemical Distribution Institute

CSIN: Clarkson's Ship Intelligence Network

DNV: Det Norske Veritas

EQUASIS: Electronic/European Quality Shipping Information System

GIS: Geographic Information System

GISIS: Global Integrated Shipping Information System

ICOADS: International Comprehensive Ocean-Atmosphere Data Set

IMF: International Monetary Fund

ISL: Institute of Shipping Economics and Logistics

ITOPF: International Tanker Owners Pollution Federation

LMIU: Lloyd's Maritime Intelligence Unit

MAIB: Marine Accident Investigation Branch

MHIDAS: Major Hazard Incident Data Service

OCIMF: Oil Companies International Marine Forum

P&I Club: Protection and Indemnity Club

SIN: Ship Intelligence Network

VTS: Vessel Traffic Service

WCSC: Water Commerce Statistics Center

ABBREVIATIONS FOR METHODOLOGY

AHP: Analytic Hierarchy Process

ANN: Artificial Neural Networks

ANOVA: Analysis of Variance

ARMAX: Autoregressive Model (with explanatory variable and moving-average terms)

ARPA: Automatic Radar Plotting Aids

BDS: Business Dynamics Statistics

BN: Bayesian Network(s)

BRB: Belief Rule Base

BSC: Balanced Scorecard

CART: Classification And Regression Tree

CATS: Cost of Averting a Tonne of oil Spill

CBA: Cost-Benefit Analysis

CEA: Cost-Effectiveness Analysis

CFA: Confirmatory Factor Analysis

CFD: Computational Fluid Dynamics

CHAID: Chi-squared Automatic Interaction Detector

CPA: Closest Point of Approach

CREAM: Cognitive Reliability and Error Analysis Method

DCPA: Distance to the Closest Point of Approach

DEA: Data Envelopment Analysis

DFLM: Dynamic Fuzzy Logic Model

DST: Dempster-Shafer Theory

EDN: Event Decision Network

EFA: Exploratory Factor Analysis

EM: Expectation Maximization

ER: Evidential Reasoning

ETA: Event Tree Analysis

FAD: Fuzzy Axiomatic Design

FAHP: Fuzzy Analytic Hierarchy Process

FBNs: Fuzzy-Bayesian Networks

FCA: Formal Concept Analysis

FER: Fuzzy Evidential Reasoning

FFTA: Fuzzy Fault Tree Analysis

FMEA: Failure Modes and Effects Analysis

F-N diagram: Frequency-Number of fatalities diagram

FQSD: Fuzzy Quaternion Ship Domain

FSA: Formal Safety Assessment

FTA: Fault Tree Analysis

G-BRB: Generalized Belief Rule Base

GESAMP: Group of Experts on the Scientific Aspects of Marine Environmental Protection

GF-AHP: Generic Fuzzy Analytic Hierarchy Process

HFACS: Human Factors Analysis and Classification System

HFACS-CM: HFACS-Cognitive Mapping

HFACS-MSS: HFACS-Machinery Spaces on Ships

HOE: Human and Organizational Error

HRA: Human Reliability Analysis

JCA: Joint Correspondence Analysis

MAFAD: Multi-Attribute Fuzzy Axiomatic Design

MCMC: Markov Chain Monte Carlo

MDTC: Minimum Distance To Collision

MI: Multiple Imputation

MLE: Maximum Likelihood Estimation

MRRA: Model based on Relative Risk Assessment

PCA: Principal Component Analysis

PRA: Probabilistic Risk Assessments

QERA: Quantitative Ecological Risk Assessment

QMAS: Quality Management Assessment System

QRA: Quantified Risk Assessment

R-D diagram: Residual strength performance to the Damage index diagram

ROC: Receiver Operating Characteristic

SARF: Social Amplification of Risk Framework

SDSS: Spatial Decision Support System

SEM: Structural Equation Modeling

SHS: System of Hierarchical Scorecards

SMAS: Safety Management Assessment System

SPAR-H: Standardized Plant Analysis Risk-Human reliability analysis

SWOT: Strengths, Weaknesses, Opportunities and Threats

SYRAS: System Risk Analysis System

TCPA: Time to the Closest Point of Approach

TOPSIS: Technique for Order of Preference by Similarity to Ideal Solution

TQM: Total Quality Management

VCD: Variation of a Compass Direction

VSL: Value of Statistical Life

WBA: Why-Because Analysis

Note: RADTRAN (ANSI FORTRAN 77 computer code) is a risk assessment tool.

ABBREVIATIONS FOR STATISTICAL MODEL

AG model: Andersen & Gill model

Cox PH model: Cox Proportional Hazards model

HR: Hazard ratio

LR: Likelihood Ratio

PWP-CP model: Prentice, Williams & Peterson – Counting Process model

PWP-GT model: Prentice, Williams & Peterson – Gap Time model

WLW model: Wei, Lin & Weissfeld model

Chapter 1.

Introduction

On the morning of April 16, 2014, a passenger vessel named "Sewol" sank to the bottom of the sea in South Korea. In all, 304 passengers lost their lives, most of them high school students, in one of the worst maritime disasters in decades. This example clearly shows that a maritime accident, defined as an undesired event of a ship, often results in a loss of life, injury to persons on ship, and different types of property damage. Therefore, maritime accidents have been a focal issue in the maritime community since the very beginning of shipping. This thesis focuses on maritime accidents and discusses the results of three analyses conducted as part of the study. One of these three analyses focuses on the evolution of maritime accident research, and the other two examine important factors that affect the time between accidents involving a ship and the end of lifespan of a ship, respectively.

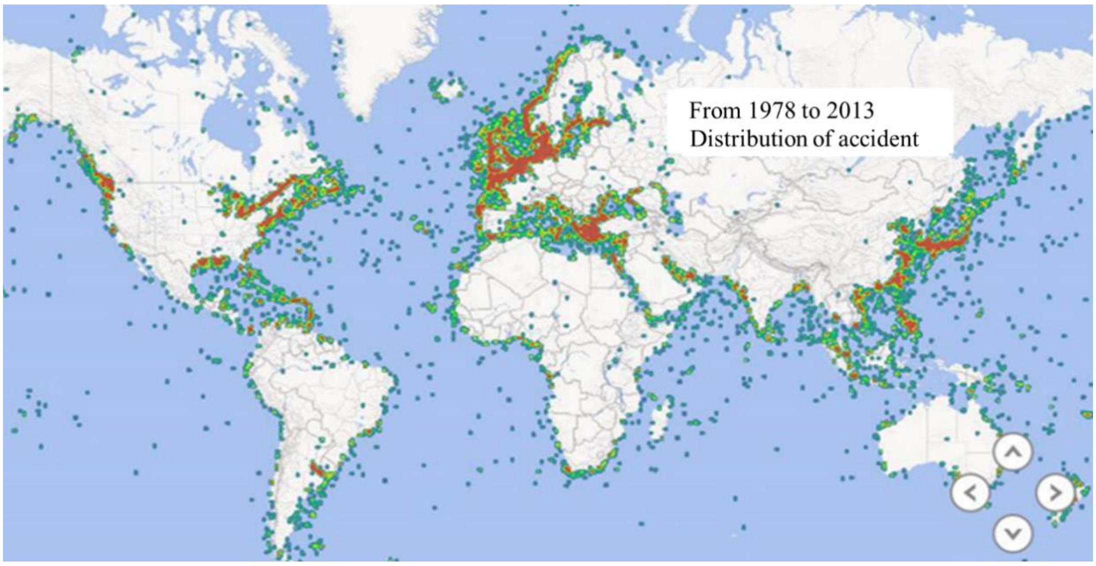
This chapter discusses the background of the thesis, the definition of maritime accidents, and the research scope. Research objectives and contributions are then provided, followed by an outline of the thesis.

1.1 Research background

Maritime transportation is a traditional industry with more than 3,000 years of history. The development of this industry can be characterized as the struggle of human beings to prevent maritime accidents so as to make lives at sea safer, protect the commodities and ships, and reduce the environmental pollution caused by oil spills.

Over the years, a considerable number of maritime accidents have occurred in oceans, coastal areas, inland waterways, lakes, and ports. Figure 1-1 shows the distribution of maritime accidents from 1978 to 2013. The red dots indicate regions that have a high density of accidents, including Europe, the Mediterranean, and East Asia.

Figure 1-1: Global distribution of maritime accidents (1978–2013).



Note: Author's own figure based on the Lloyds List casualty data

Owing to the advancements in ship-making technologies and better regulations to prevent maritime accidents, the frequency of ship accidents has been significantly reduced. As shown in Figure 1-2, the number of maritime accidents decreased from a high of 3,152 in 1979 to a low of 959 in 2001.

However, the number of maritime accidents increased again in 2002 and reached a second peak in 2008. The overall number of maritime accidents over the past 36 years is 63,991, an average of 1,777 per year. According to the *Guardian* [1], approximately 2,000 seafarers lose their lives at sea each year.

Therefore, a considerable amount of effort has been dedicated to the development of measures to improve maritime safety through a better understanding of the marine/coastal environment, improvement of the technology involved in shipbuilding and ship management, more advanced navigation technology, and better crew training. Moreover, international organizations such as the IMO [2] and many national MSAs have published extensive rules and regulations on the related safety standards along with various guidelines on the safe operation of ships (Baniela and Ríos, 2010). The development of these measures and regulations is largely based on new findings regarding the major causes of maritime accidents, through detailed analyses and research into the possible causes of such accidents.

[1] http://www.theguardian.com/world/2015/jan/10/shipping-disasters-we-never-hear-about

[2] For the purposes of clarity, all acronyms are given in full in the “List of Abbreviations” section.

Figure 1-2: Number of maritime accidents from 1978 to 2013.

Note: Author's own figure based on the Lloyds List casualty data

Based on this background, the aim of this thesis is three-fold: i) to investigate the research trends of maritime accidents, ii) to identify factors that influence the lifespan of a ship considering ship accidents, and iii) to find major factors that affect recurrent ship accidents.

1.2 Concept of maritime and ship accidents

1.2.1 Definition of maritime accidents and maritime risk in this thesis

Maritime accidents

Different terms have used in accident-related reports, databases, research articles, and other publications. A fairly typical example is the use of terms such as "casualty" and "incident" to mean "accident". The general concept of an "accident" as defined in an IMO report [3] is as follows:

[3] IMO (2002), Guidelines for Formal Safety Assessment (FSA) for Use in the IMO Rule-Making Process. London: International Maritime Organization.

"An unintended event involving fatality, injury, ship loss or damage, other property loss or damage, or environmental damage"

Furthermore, in many other instances, the term "casualty" is often used instead of "accident". Ship casualties in circulars MSC-MEPC.3/Circ.3 [4] of IMO are classified as "very serious casualties", "serious casualties", "less serious casualties", and "marine incidents". Lloyd's List Intelligence [5] provides the "Casualties Service" and "Lloyd's Casualty Week." They all use the word "casualty" to mean "maritime accidents".

However, these two terms are slightly different—the former is applicable to ships and/or the crew on the ships, while the latter also includes damage to offshore structures. In this thesis, the term "maritime accidents" is used instead of "casualties". This is consistent with the new expanded definition by MAIB, which applied the new definition of "accident" to their maritime accidents investigation and annual report as follows:

"Accident incorporates the old Hazardous Incidents (which are now known as marine Incidents). Accidents are now defined as being Marine Casualties or Marine Incidents, depending on the type of event(s) and the results of the event(s)."

(*MAIB Annual Report* 2013)

[4] Maritime Safety Committee - Marine Environment Protection Committee.3/Circular.3

[5] http://info.lloydslistintelligence.com/our-services/casualties (retrieved at June 25, 2015)

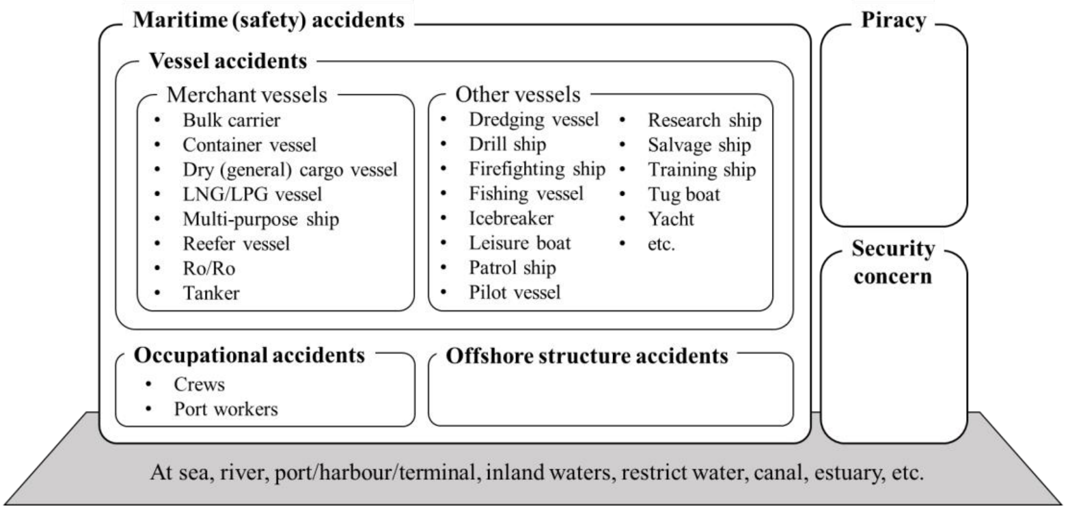
Maritime risk

Risk is generally referred to as the probability of an accident and the consequence of the harm or damage (Manuele, 2003; Li *et al.*, 2014; Kjellen and Albrechtsen, 2017). This thesis defines "maritime accident risk" as the likelihood and consequence of an accident during maritime and marine transportation along with the damages (i.e., loss of lives, property damage of ships and cargoes, and environmental pollution), as previous studies (Knudsen and Hassler, 2011; Fowler and Sørgård, 2000; Faghih-Roohi *et al.*, 2014) have used the term. In this context, "ship accident risk" is defined as the likelihood and consequence of ship (vessel) accidents, resulting in damage. Thus, this thesis covers maritime accident risk, not including security risk, piracy or robbery risk, system risk, and financial risk.

1.2.2 Scope of maritime accidents

According to Talley (2008), unwanted events in the maritime field can be classified into three categories: maritime safety accidents, maritime security, and piracy incidents. Among them, maritime accidents are discussed in this thesis (Figure 1-3). Furthermore, this thesis does not consider battleships or submarines in military service.

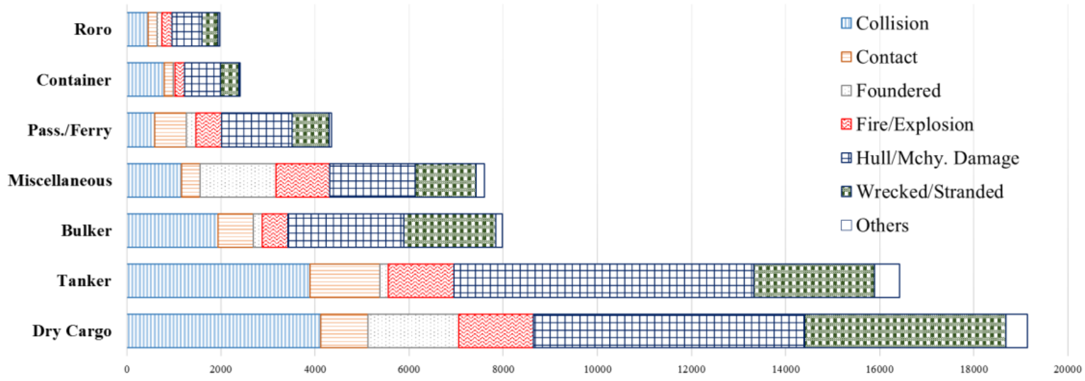
Figure 1-3: Unwanted events in the maritime field.



Note: Author's own figure based on the categorization by Talley (2008)

Maritime transportation is the main means of conveyance for goods and commodities in international trade, and studies on maritime accidents will continue to be a very important element in the shipping industry, requiring joint efforts from researchers, policy makers, and industry practitioners. The second and third aims of this study (Chapters 5 and 6) concentrate on merchant vessels, particularly bulkers, containers, general cargo (dry cargo) ships, and tankers. Therefore, the term "maritime accidents" is replaced by "ship (vessel) accidents" to achieve the aims of the study. Roll-on/roll-off vessels are not included, because the number of such vessels is very small.

Figure 1-4: Number of accidents by merchant vessels and their causes over time (1978–2013).



Note: Author's own figure based on the Lloyds List casualty data

1.3 Research objectives

In the past 50 years, research on maritime accidents has gone through a series of fundamental changes. Understanding the evolution of the research trend for maritime accidents can help the maritime community determine what has been done in the past and learn how to do better in the future to improve maritime safety and reduce or eliminate the risk to the lives and cargoes onboard the ship, the ship itself, and the marine environment. In this context, the first objective of the current study is as follows:

- to investigate how research in the area of maritime accidents has developed in the past and
- to identify the future directions for research on maritime accidents.

On the basis of the investigation of the research trend and the corresponding results of previous maritime accidents studies, the shipping market condition is recognized as an emerging factor in these accidents. Therefore, in this thesis, an empirical analysis was carried out to find the determinants of ship accidents, including the shipping market conditions. Based on the existing research trends and future directions, the following two studies were conducted to meet the second and third objectives.

The second objective of this thesis is to investigate the influence of ship accidents on the lifespan of a ship. Three hazard-based regression models are designed with or without the accidental loss and ship accidents. The analysis on the lifespan of a service vessel considers accident factors and the shipping market conditions.

The last objective of this thesis is to find the major factors involved in initial and recurrent ship accidents by focusing on the duration between accidents involving the same ship. Several vessel characteristics and market conditions are investigated to test whether and how they affect the timing of the recurrent accidents.

1.4 Contributions of thesis

A research trend study on maritime accidents makes two contributions. First, it summarizes the research publications over the past 50 years from different aspects and reveals the evolution of maritime accident research. Second, it indicates future research directions, including the involvement of new disciplines, emerging issues, new research methods, and data sources.

Second, the contribution of the longevity study for merchant ships is that it provides a method to predict the service time of a ship on the basis of ship-specific information, its operational and safety management record, and assumptions on the future economic conditions in the shipping market. This information is essential for the assessment of a ship's value. In addition to its practical contribution, this thesis demonstrates the possibility of applying durational analysis in ship lifespan analysis, which provides a new method to analyze the lifespan of ships in the global merchant fleet.

Finally, one important contribution of this thesis with respect to an analysis of recurrent ship accidents is that it provides a practical suggestion that port states need to design appropriate measures to reduce recurrent ship accidents. For example, Port State Control inspection teams need to focus their efforts more on the ships that have higher recurrent accident rates.

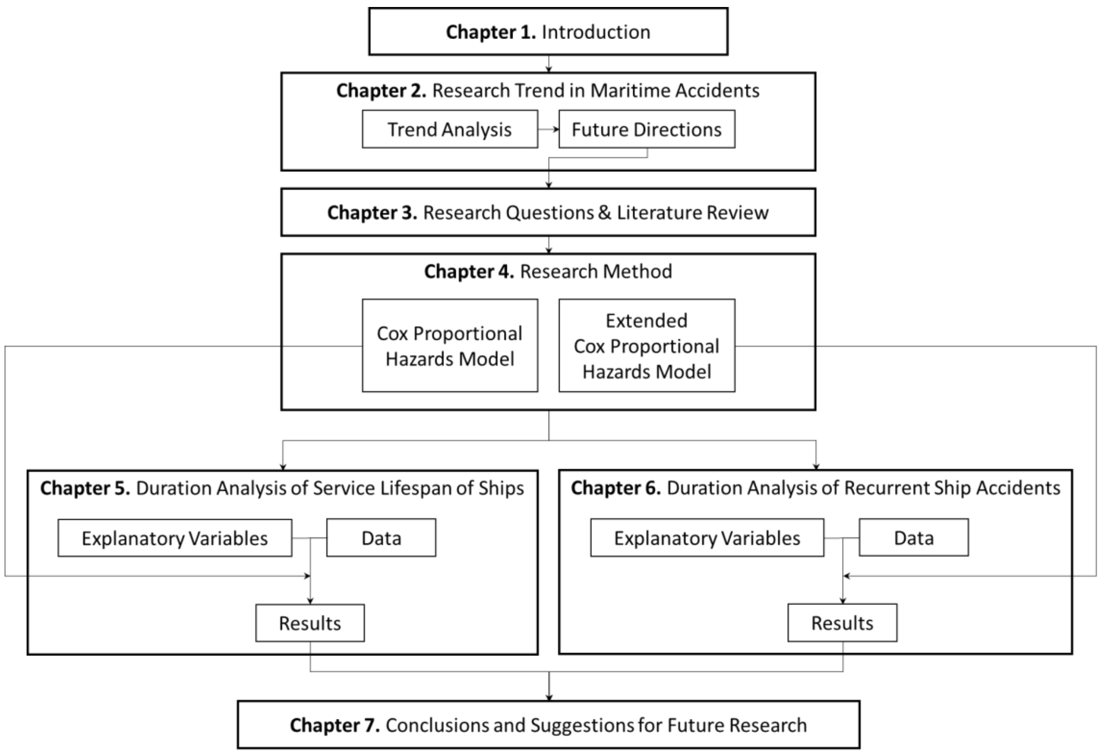
The result of this thesis can provide useful inputs for decision makers in both private businesses and public agencies of maritime safety administration. For the academic field, this thesis can provide a summary of the maritime research trend and fill the research gap by analyzing the effect of the shipping market conditions on ship accidents.

1.5 Structure of the thesis

This thesis consists of seven chapters, and the organization of this thesis is summarized and presented in Figure 1-5. A brief introduction of the background of this thesis, concept of maritime accidents, research objectives, and contributions is presented in Chapter 1.

Chapter 2 investigates the research trend for maritime accidents. Chapter 3 sets research questions and reviews the literature relevant to the research objectives and questions. Chapter 4 introduces the proposed methods and provides a detailed account of the study methods. Chapter 5 applies a hazard-based approach (Cox Proportional Hazards [PH] regression model) to find the determinants of the lifespan of vessels. A description of input variables, data, and the results is presented. Chapter 6 analyzes the determinants of recurrent ship accidents and the first-time ship accidents using durational models. Chapter 7 concludes this thesis and provides suggestions for future research.

Figure 1-5: Organization chart of the thesis.



References appear at the end of each chapter, and the appendix comprises the last part of this thesis.

References

Baniela, S. I., & Ríos, J. V. (2010). The Risk Homeostasis Theory. *The Journal of Navigation, 63*(4), 607–626.

Faghih-Roohi, S., Xie, M., & Ng, K. M. (2014). Accident risk assessment in marine transportation via Markov modelling and Markov Chain Monte Carlo simulation. *Ocean engineering*, *91*, 363-370.

Fowler, T. G., & Sørgård, E. (2000). Modeling ship transportation risk. *Risk Analysis*, *20*(2), 225-244.

Kjellen, U., & Albrechtsen, E. (2017). Prevention of Accidents and Unwanted Occurrences: Theory, Methods, and Tools in Safety Management. CRC Press.

Knudsen, O. F., & Hassler, B. (2011). IMO legislation and its implementation: Accident risk, vessel deficiencies and national administrative practices. *Marine Policy*, *35*(2), 201-207.

Li, K. X., Yin, J., Bang, H. S., Yang, Z., & Wang, J. (2014). Bayesian network with quantitative input for maritime risk analysis. *Transportmetrica A: Transport Science, 10*(2), 89-118.

Manuele, F.M. (2003). On the practice of safety. 2nd ed. Hoboken, NJ: Wiley.

Talley, W. K. (2008). *Maritime safety, security and piracy.* London: Informa.

Chapter 2.

Research Trend in Maritime Accidents

2.1 Introduction

This chapter collects maritime accident research papers published in various peer-reviewed journals written in English over the past half-century, and analyzes the evolution of these publications with respect to author location and field of study, the main topics, the dimensions of the analysis, the major causes of maritime accidents, the methodology, and the data sources. The main findings are that although research into maritime accidents has mainly focused on naval technology, human error has been identified as the main cause of maritime accidents, and many new methods have been developed to accommodate human behavior. In addition, this chapter reveals that the recent trends in maritime accident research have its multi-disciplinary nature using multiple data sources. The condition of the shipping market has recently emerged as a new causal factor of maritime accidents, which may lead to future development in this area.

Chapter 2 is arranged as follows. The method, data, and scope of this chapter are presented in the next section. This is followed by a description of the findings relating to the evolution of maritime accident research, in eight subsections. Finally, it summarizes the major findings and provides conclusions.

2.2 Method, data, and scope

This chapter collected papers on various aspects of maritime accidents from all of the academic journals written in English and categorized them according to aspects such as the location and affiliation of the author(s), the main concerns, major causes, dimensions, methods, and data sources. Examining the evolution of the research papers in this way enabled us to identify the trends in maritime accident research and directions for possible future research.

In total, 572 articles published from 1965 to 2014 were collected from 125 academic journals in business, economics, engineering, and medical science. The topics focus on maritime accidents, accident risk, and safety. Papers on maritime security, piracy, hijack, and financial risk were excluded. Technical reports, conference proceedings, book chapters, and regional journal papers in other languages were excluded.

The collected papers cover maritime accidents involving small fishing and leisure boats (O'Connor and O'Connor, 2005; Swett *et al*., 2011), Floating Production, Storage, and Offloading (FPSO) (Sii *et al*., 2005), merchant ships, fishing vessels, ferries and their passengers, cruise vessels, and offshore structures (excluding submarine and warship). Accident locations comprise rivers, ports/terminals, inland waterways, offshore restricted waters, and the open sea. The merchant vessels involved in accidents carry containers, dry bulk cargoes, oil and oil products, chemicals, or general cargoes. Accident and risk analysis for the transportation of HNS (Neuparth *et al*., 2011), dangerous goods (Ellis, 2010), and special nuclear materials (Bolat and Yongxing, 2013) were included.

Studies of management systems for accident prevention, mechanical analysis of the structural stability of ships, pollution from maritime accidents, and maritime regulations such as safety codes produced by national or international organizations were also included. Finally, papers dealing with databases of maritime accidents were collected as it is important for researchers to be able to find accident patterns and major factors involved in maritime accidents, so that appropriate policies may be developed to prevent future accidents (Hassel *et al*., 2011; Oltedal and McArthur, 2011; Psarros *et al*., 2010; Sii *et al*., 2003).

2.3 Trends in maritime accident research

2.3.1 Overall trends

Table 2-1 presents the number of published papers and journals grouped in 5-year intervals for the past 50 years, and gives the average number of papers published per year. Both the number of papers and the number of journals have increased, especially in recent years. Although the maritime sector has a long history of maritime accidents and loss of life, the marked increase in research publications only occurred in the past two decades. This phenomenon may be due to the increasing number of maritime accidents, the greater consequences of accidents in terms of the higher values of the ships and cargoes affected, and the resulting effects on the environment. In addition, the increased availability of different types of data and greater computational power allow researchers to do much more today than 20 years ago. These factors may explain the increasing output of this research area.

Of the 572 papers, 208 (36.3%) were published during the most recent 5-year period, and 64.8% were published during the past 10 years. Before 1995, the paper publication rate was about 1.73 papers per year, while in the past five years this rate has increased to 41.6 papers per year, or 1.6 papers biweekly. After 1995, the number of journals covering maritime accidents and issues of risk in the maritime domain also increased markedly.

Table 2-1: Number of papers and journals on maritime accident research from 1965 to 2014.

	1965-69	1970-74	1975-79	1980-84	1985-89	1990-94	1995-99	2000-04	2005-09	2010-14	**Total**
Number of papers	4	12	6	15	5	10	44	105	163	208	**572**
Average number of papers per year	0.8	2.4	1.2	3	1	2	8.8	21	32.6	41.6	**11.4**
Number of journals	1	3	2	7	5	9	28	41	55	53	**125**

Table 2-2 lists the top 20 journals publishing papers on maritime accidents and risk/safety. Of the 572 papers, 413 were published in these journals, accounting for 72.2% of the total number of papers. The *Journal of Navigation* is the most traditional journal, having published the highest number of papers in this area over the longest period than any other journal. From the top three journals, it can be seen that navigation, safety, and policy and management are the three most important areas. In addition to the specialized maritime journals that are the normal outlets for maritime accident research, many other academic journals publish research in this field. Recently, journals with a general focus on safety and risk analysis, such as *Safety Science*, *Reliability Engineering & System Safety*, *Accident Analysis & Prevention,* and *Risk Analysis,* have published articles on maritime accidents and safety/risks. Journals in the transportation field have published papers on water transportation accidents. All of these findings reflect an increasing awareness of the importance of research in maritime accidents in broader fields of study. Table 2-2 shows that engineering journals, such as *Marine Structures*, *Ocean Engineering*, *Marine Technology*, and *Ships and Offshore Structures*, have increased maritime accidents papers in number since 1995. This may be another trend in maritime accident research.

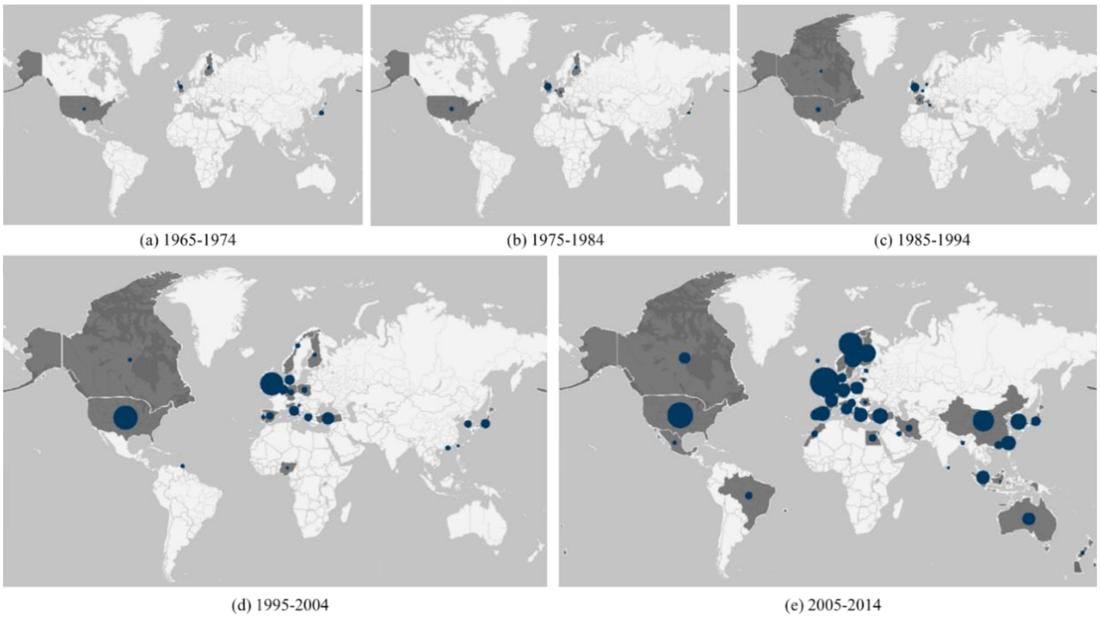
Table 2-2: Top 20 journals for maritime accident research from 1965 to 2014.

No.	Journals	1965 -74	1975 -84	1985 -94	1995 -04	2005 -14	Total number of papers
1	*Journal of Navigation*	*14*	14	1	12	20	61
2	*Safety Science*			1	12	44	57
3	*Maritime Policy & Management*		1	3	10	18	32
4	*Reliability Engineering & System Safety*				6	19	25
5	*WMU Journal of Maritime Affairs*				4	21	25
6	*Accident Analysis & Prevention*				1	22	23
7	*Marine Policy*				6	17	23
8	*TransNav Journal*					23	23
9	*Marine Structures*				9	10	19
10	*Risk Analysis*		1	1	6	11	19
11	*Ocean Engineering*				4	13	17
12	*Marine Technology*				7	7	14
13	*Journal of Hazardous Materials*		1	1	5	4	11
14	*Transportation Research Record*				2	9	11
15	*Ships and Offshore Structures*					10	10
16	*Disaster Prevention and Management: An International Journal*				6	3	9
17	*Marine Pollution Bulletin*					9	9
18	*Transportation Research Part D: Transport and Environment*				3	6	9
19	*Journal of Loss Prevention in the Process Industries*			1	3	4	8
20	*Journal of Safety Research*				3	5	8
Total		**14**	**17**	**8**	**99**	**275**	**413**

2.3.2 Evolution of the geographic location of maritime accident research

The popularity or capacity of research into maritime accidents in a particular country can be represented by the number of researchers in that country. Here this chapter uses the term 'researcher' rather than 'author', as one researcher can publish more than one paper in a year. Since the purpose is to identify the location of the researcher, if the research publish more than one paper, it also counted as one researcher at one location. In the collected publications, the researchers came from 43 countries based on the location of their institutions. Figure 2-1 presents the evolution of the number of researchers in each country in 10-year intervals over the past half-century.

Figure 2-1: Evolution of the popularity of maritime accident research in various countries over the past 50 years.



Note: The size of the circles indicates the number of researchers.

Before 1995, research into maritime accidents was only carried out in a few countries in Europe and North America, and the number of researchers was very low. From 1995 to 2004, more papers were generated in North America and Europe and some were generated in Asia. Over the past decade, many researchers from Europe carried out risk analysis on maritime accidents. In addition, research into maritime accidents expanded to China, Australia and South America.

Table 2-3 summarizes the evolution of the regional distribution of maritime accident research. North American and European researchers dominated this research area in the 1960s and 1970s. After 1995, African, South American and Asian researchers became new forces in the global research team. Of these, the number of Asian researchers grew especially rapidly. The number of Asian researchers has more than doubled from 57 during 2005–2009 to 124 during 2010–2014.

Table 2-3: Evolution of the number of researchers by region.

	1965-69	1970-74	1975-79	1980-84	1985-89	1990-94	1995-99	2000-04	2005-09	2010-14
Number of countries*	1	3	3	6	3	6	11	21	32	36
Number of researchers*	4	15	7	17	14	15	70	169	303	416
Africa	-	-	-	-	-	-	-	1 (0.6)	4 (1.3)	8 (1.9)
Asia	-	5 (33.3)	2 (28.6)	1 (5.9)	-	-	8 (11.4)	28 (16.6)	57 (18.8)	124 (29.8)
Europe	-	6 (40.0)	2 (28.6)	13 (76.5)	12 (85.7)	9 (60.0)	26 (37.1)	97 (57.4)	185 (61.1)	227 (54.6)
N. America	2 (50.0)	-	3 (42.9)	1 (5.9)	2 (14.3)	5 (33.3)	34 (48.6)	39 (23.1)	39 (12.9)	50 (12.0)
S. America	-	-	-	-	-	-	-	2 (1.2)	-	6 (1.4)
Oceania	-	-	-	-	-	-	-	-	18 (5.9)	1 (0.2)
Unknown	2 (50.0)	4 (26.7)	-	2 (11.8)	-	1 (6.7)	2 (2.9)	2 (1.2)	-	-

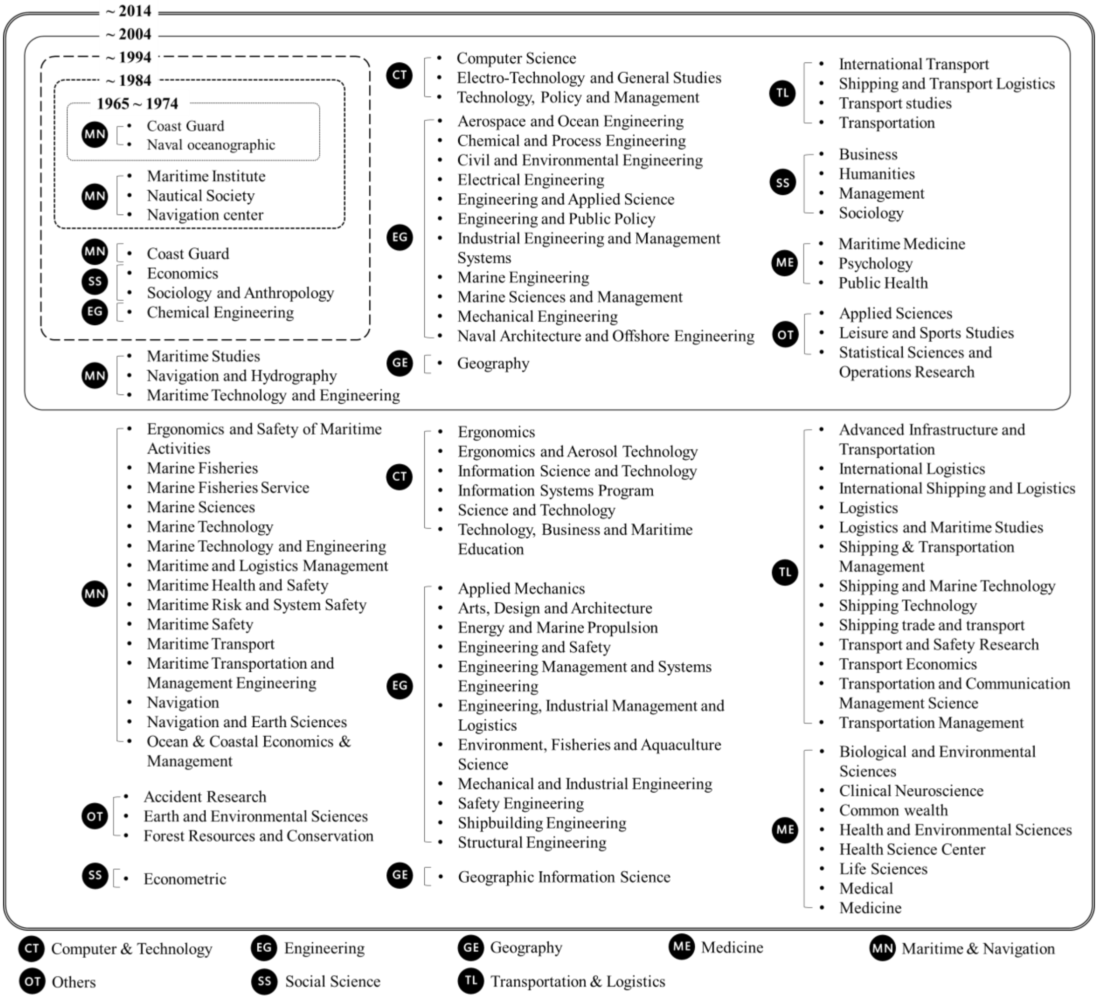
Note: The numbers in parentheses represent regional percentages.

Table 2-3 shows the spatial distribution of the researchers. The percentage of researchers in Asia has increased since 1995, while that for North America has declined over the same period. This indicates that although European institutions still have a leading position in this area, Asian researchers are catching up and are gaining importance over North American researchers in terms of publications. In other words, in the past five years, Asian researchers accounted for almost 30% of the world's researchers in terms of publication records. Furthermore, although research in this subject area has expanded to Africa, South America and Oceania, the number of researchers from these regions remains relatively small, indicating a direction for further development.

2.3.3 Evolution of the disciplines involved in maritime accident research

Maritime accidents are caused by various reason. Thus the study for maritime accidents requires researchers' collaboration from different backgrounds to study the possible causes. The affiliations of researchers can reflect their field of study. Accordingly, observing changes in affiliations can help understand changes in disciplines within maritime accident research. Figure 2-2 summarizes the evolution of authors' affiliations over time, in 10-year intervals.

Figure 2-2: Evolution of researchers' affiliations.



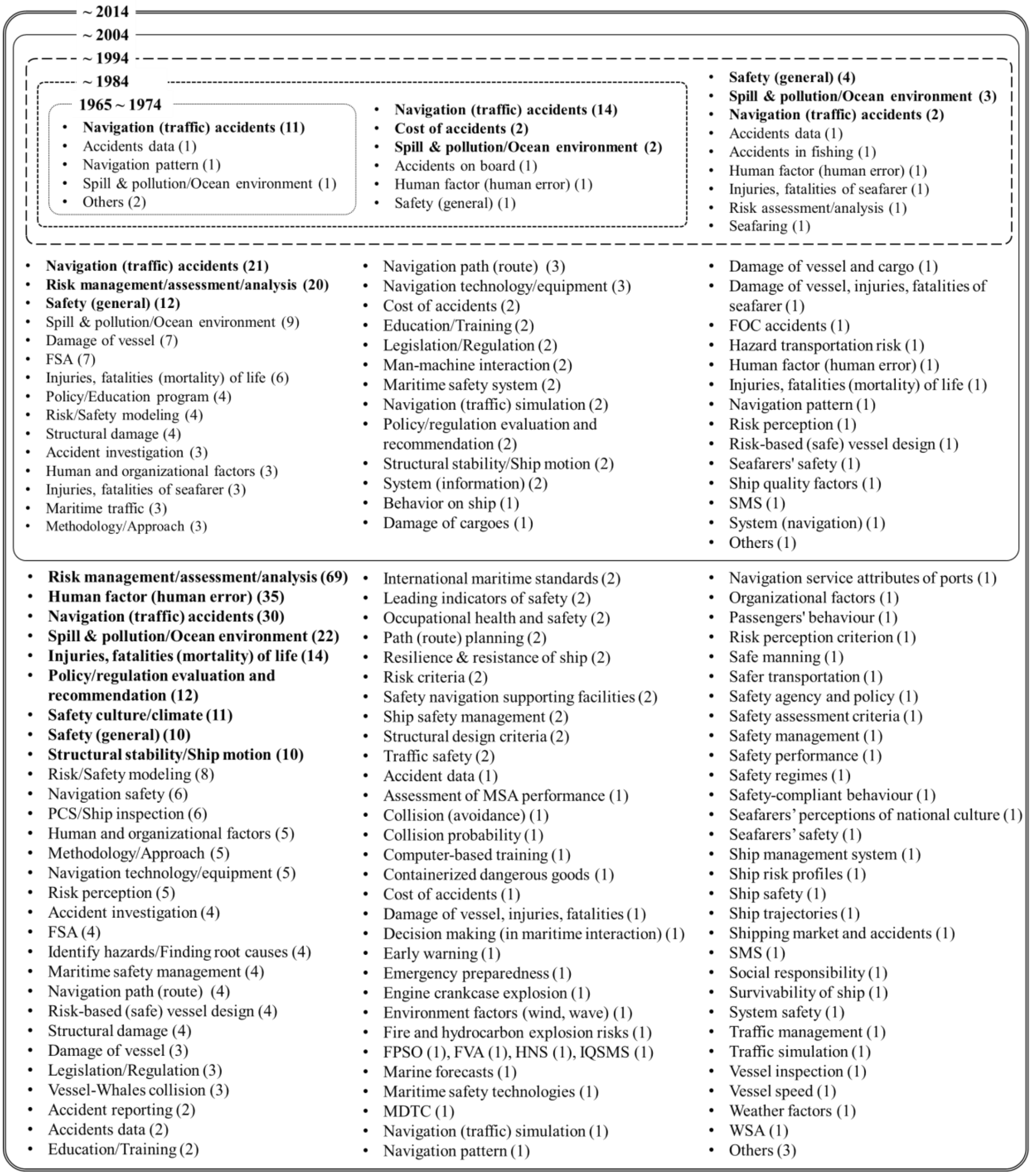
Over the first 20 years, authors of maritime accident research papers were mainly affiliated with maritime-related centers or institutes such as Coast Guard, maritime institutes, and navigation centers (MN in Figure 2-2). After 1985, authors from the social science (SS) and engineering (EG) fields began to study ship accidents from human behavior and ship structure perspectives. From 1995, many researchers from broader areas of engineering and social science joined the study of maritime accidents, and researchers from new fields of study, such as medicine (ME), computer and technology (CT), transportation and logistics (TL), and geography (GE), also contributed to the research in this area. In the most recent decade, the subject scope in each field of study have greatly expanded. This indicates that maritime accident research is becoming increasingly interdisciplinary and multidisciplinary, requiring cooperation between researchers having different backgrounds.

2.3.4 Evolution of the main focus of research

Maritime accidents result from a combination of complex conditions (Fukushima, 1976). Research in different periods involves different concerns, reflecting an improved understanding of the possible factors contributing to an accident, or multiple viewpoints on the complex accident environment. Understanding the changing patterns of the main focus of past research can help to identify new research directions that will fill gaps and improve maritime safety.

As shown in Figure 2-3, up until 1984 the investigation and analysis of navigation and traffic accidents were the most popular topics. Maritime safety and environmental issues related to spills and pollution gradually gained popularity from 1975 to 1994, probably due to increasing environmental awareness. From 1995 to 2004, systematic risk management methods (assessment and analysis) also emerged as a major area of maritime accident research. It has become the most popular topic since 2005, providing decision support and assisting with the formulation of proactive policies for safety management in ship operations.

Figure 2-3: Evolution of the main topics in maritime accident research, in 10-year intervals.



Note: The numbers in parentheses represent the numbers of papers.

In the past decade, the human factor has become increasingly important in maritime accidents, as it has been widely acknowledged to be a major cause of maritime accidents (Roberts *et al.*, 2014). In addition, environmental issues, such as the spillage of oil and hazardous materials, along with safety cultures and safety climates have also emerged as major concerns in maritime accident research.

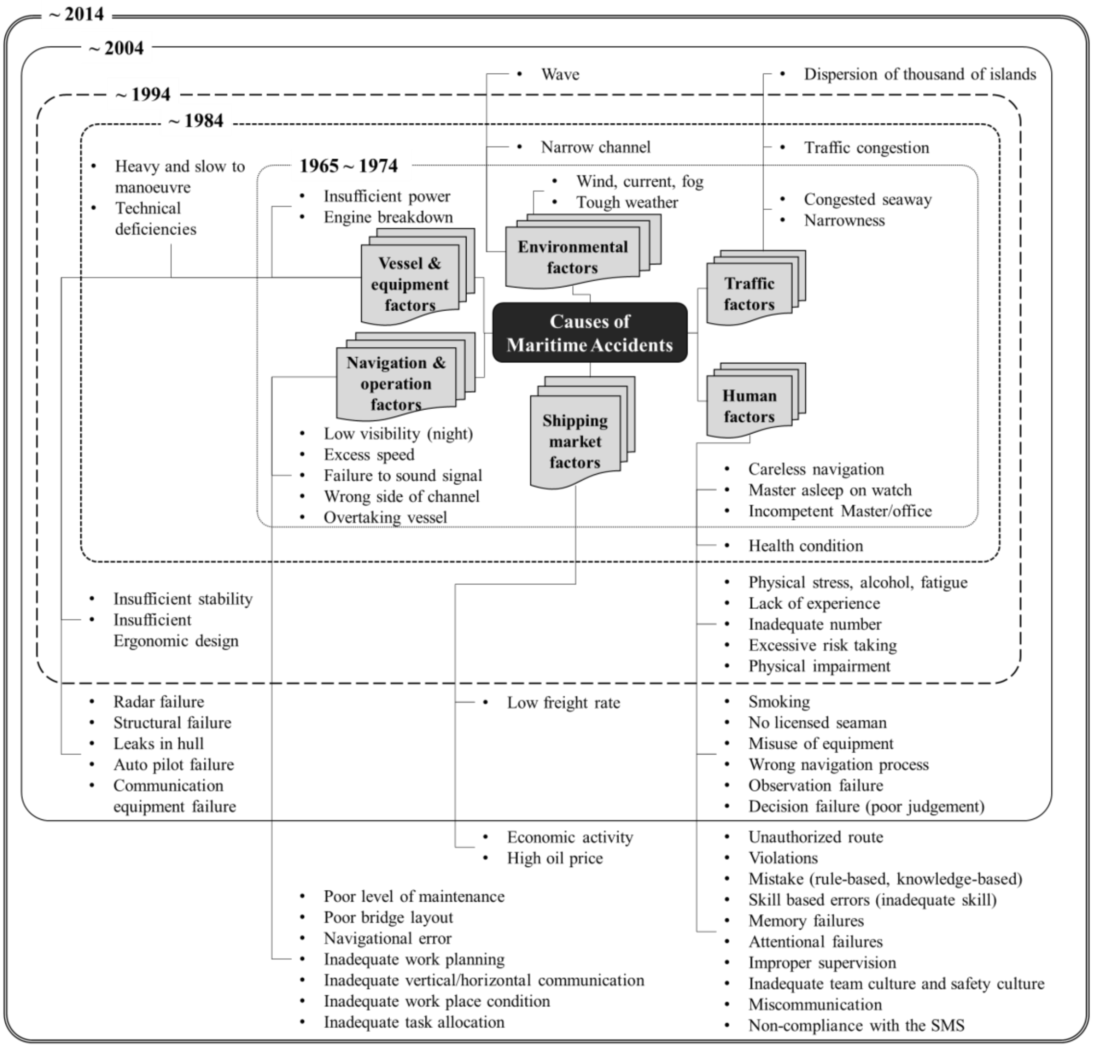
A noteworthy trend in maritime accidents research is work on the efficiency of policy and regulation in the prevention of accidents. Maritime safety administrations at both national and international levels have tried to apply regulations in the maritime industry. As previous studies point out, however, the shipping industry considers these safety provisions to be a necessary evil, due to the cost burden (Thai and Grewal, 2006), and a regulatory overload (Lappalainen *et al*., 2013). The appraisal of policy and regulation has emerged as a research topic.

In addition to major concerns, it is interesting to see that a much broader range of topics has been studied in the recent decade than in previous decades. This indicates that researchers are trying to analyze maritime accidents from many different angles. It also implies that future research in this area will be more multidisciplinary, requiring the collaboration of researchers from different fields of study.

2.3.5 Evolution of research into the major causes of maritime accidents

To facilitate discussion on the evolution of research into the major causes of maritime accidents, this chapter first examined how to categorize their major causes. Fukushima (1976) placed various conditions related to maritime accidents into five groups: natural conditions, route conditions, ship conditions, traffic conditions, and navigation conditions. Reilly (1984) summarized major causes of the maritime accidents into three etiological categories: human (navigator), ship structure, and environment (subdivided into human environment and physical environment). Goossens and Glansdorp (1998) grouped a list of 45 initiating events of maritime accidents into six categories: one mechanical failure and five human failure (human processing failure, strategic human failure, general human failure, human observation failure, and human decision implementation failure). In a SWOT analysis, Arslan and Er (2008) stated that maritime accidents resulted from three weaknesses (human-related factors, operational factors, and job-related factors). This chapter categorizes the past findings on the causes of maritime accidents into six groups: 1) vessel and equipment conditions; 2) environmental factors; 3) traffic factors; 4) navigation and operation; 5) shipping market conditions; and 6) human factors. The evolution of the major causes of maritime accidents found in the published papers over the past 50 years is shown in Figure 2-4.

Figure 2-4: Evolution of the major causes of maritime accidents.



• Other causes : Flammable cargo, unidentified causes (Acts of God)

Paper source: **1965~1974**: Cockcroft (1976); Couper (1968); Fricker (1965); Fujii and Yamanouc (1974); Kostilainen and Hyvärinen (1974); **Until 1984**: Fukushima (1976); Kostilainen and Tuovinen (1980); Until 1994: Forsyth (1991); Wagenaar and Groeneweg (1987); **Until 2004**: Antão and Soares (2010); Goossens and Glansdorp (1998); Knapp *et al.* (2011); Otto *et al.* (2002); Roberts and Marlow (2002); Toffoli *et al.* (2005); **Until 2014**: Akhtar and Utne (2015); Antão and Soares (2006, 2008); Arslan and Er (2008); Baniela and Ríos (2010); Barnett (2005); Uğurlu *et al.* (2013); Wang *et al.* (2013)

Figure 2-4 shows that research in all of the major causal categories except for shipping market conditions was published before 1995, reflecting the new direction in maritime accident research that takes into consideration the impact of market conditions. Such causal factors examined in the past publications include freight rate (Baniela and Ríos, 2010), economic activity (Heij and Knapp, 2014), and oil price

(Anderson and Talley, 1995; Glen, 2010).

The area of human error has been considered the most important factor in maritime accidents as new findings and new publications over the past 30 years. The complexity of human interactions with maritime operations has been recognized. Compared with human factors, the number of publications involving traffic and natural environmental conditions is relatively small, possibly because there is already better understanding and control of these factors in maritime accidents.

Major causes and preventive measures of maritime accidents from existing studies are summarized in Appendix A and Appendix B, respectively.

2.3.6 Evolution of the dimensions of the research

The 572 papers are categorized into 7 dimensions according to the different aspects (subjects) of the research, and Table 2-4 presents the development in the number of papers by dimension.

The general/overall analysis category involves exploratory or descriptive analysis of the general issues, policy assessment, problem description, and the explanation of preventive countermeasures. Such studies have been published throughout the half-century, and have mainly used the descriptive approach, case studies, or literature review.

Table 2-4: Trends in research dimension for maritime accident research.

Dimensions	1965-69	1970-74	1975-79	1980-84	1985-89	1990-94	1995-99	2000-04	2005-09	2010-14	**Total**
General/overall analysis	2	2	1	3	-	4	13	20	29	28	**102**
Navigation/traffic analysis	-	6	1	2	-	-	1	6	8	14	**38**
Accident data analysis	2	4	3	7	2	4	14	22	43	59	**160**
Risk analysis/ Safety assessment	-	-	1	3	2	1	12	38	63	84	**204**
Fatalities and occupational accident analysis	-	-	-	-	1	1	3	9	11	13	**38**
Mechanical analysis	-	-	-	-	-	-	1	9	9	6	**25**
Maritime database analysis	-	-	-	-	-	-	-	1	-	4	**5**
Total	4	12	6	15	5	10	44	105	163	208	**572**

The navigation/traffic area involves analyzing the effect of the navigation route and the traffic in ship's course on maritime accidents. Such research has usually been conducted using probabilistic/accident rate calculations (Fujii and Shiobara, 1971; Lighart, 1980; Ståhlberg *et al*., 2013), navigation pattern analysis (Bateman *et al*., 2007; Kemp, 1973; Silveira *et al*., 2013), or traffic analysis (Coldwell, 1981; Squire, 2003), and recently through analyzing AIS data and simulation (Goerlandt and Kujala, 2011; Goerlandt *et al*., 2012; Gucma and Przywarty, 2008).

Accident data analysis applies various statistical models to maritime accident data to find the casual factors of accidents. The methods used include descriptive statistics (Fricker, 1965; Jonse-Lee, 1990) and questionnaire surveys (Antonsen, 2009; Chang *et al*., 2014; Vinnem, 2011). Statistical reviews and econometric models were the most widely used in this dimension, with many published results using these methods. These three dimensions—general/overall analysis, navigation/traffic analysis, and accident data analysis—have a long history in maritime accident analysis to the present day.

Research on maritime risk and safety gained popularity from the mid-1990s. The most important method is the application of a Bayesian network (Eleye-Datubo *et al*., 2008; Faber *et al*., 2012; Hu *et al.*, 2008; Li *et al*., 2014; Martins and Maturana, 2013; Montewka *et al*., 2014; Trucco *et al.*, 2008), followed by AHP, FAHP, and FSA. Compared with research in other dimensions, the number of papers in this dimension is the highest since the 2000s.

Fatalities and occupational accidents analysis focuses on the death of or injuries to the crew aboard ships. Many fatalities and injuries can occur to seafarers on board ship (Hansen and Pedersen, 2001), and seafarers working aboard merchant ships have a high casualty rate (Li and Ng, 2002). With respect to methodology, most researchers used descriptive statistics, case studies, statistical reviews and surveys. In addition, econometric models were also used for analyzing seafarer accidents (Talley, 1999; Roberts *et al*., 2013).

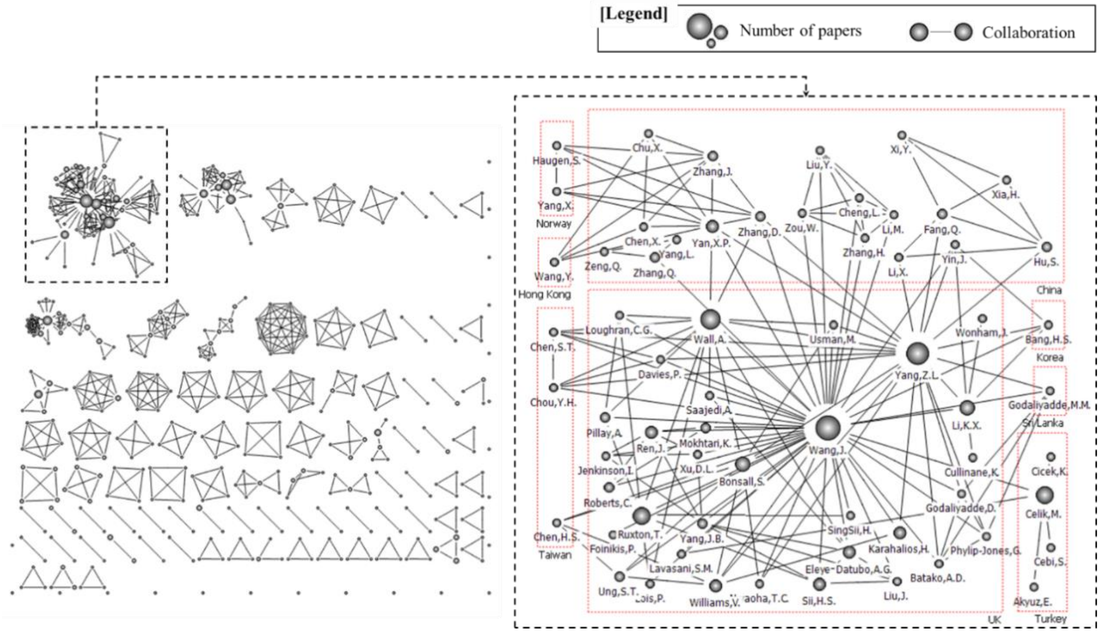
Most studies on mechanical analysis were conducted by engineers, analyzing vessel safety, seaworthiness, and ship stability. Probabilistic/accident rate calculation, modeling, and simulation were the most common methods. Laboratory experiments and results were also used in this sector (Korkut *et al*., 2004; 2005; Silber *et al*., 2010).

Studies on the importance and limitations of maritime data have indicated problems of under-reporting in maritime accident databases (Hassel *et al*., 2011; Psarros *et al*., 2010). The causal factors determined from such databases may suffer from problems of under-estimation, affecting their usefulness for formulating policies to reduce the probability of future accidents (Oltedal and McArthur, 2011).

Of the seven dimensions, risk analysis/safety assessment and accident data analysis have the highest numbers of published papers. Using social network analysis of the co-authorship of these papers and the corresponding geographic location of the authors' affiliations enables identification of the regional development of such research and the leaders in these research areas.

Figure 2-5 shows co-authorship and identification of the leader in the risk analysis/safety assessment dimension, which has 204 published papers over the past 50 years. Professor Jin Wang from Liverpool John Moores University is at the center of this research area. His co-authors are mostly located in the UK and China, and also in Korea and Turkey. The research methods include FSA, BN, ANN, AHP, FAHP, FBNs, FFTA, BSCs, ER, GIS, CREAM, and WBA. Most of the papers applying the above methods were published in the past five years (2010-2014), reflecting the trend toward risk analysis/safety assessment.

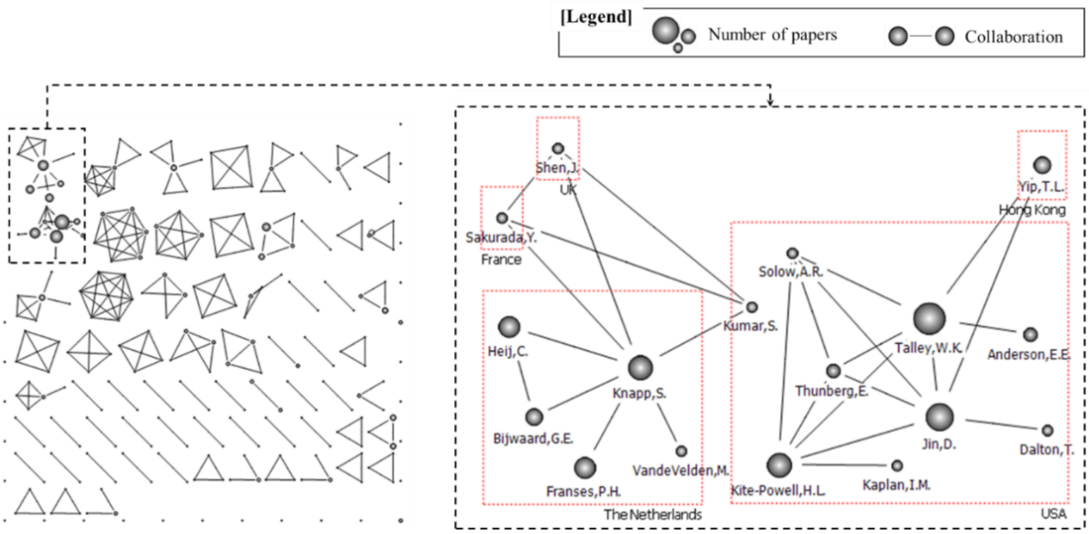
Figure 2-5: Collaboration network in risk analysis/safety assessment.



(a) Co-authorship in risk analysis/safety assessment (b) Connections of leading authors

The second largest dimension is accident data analysis, with a total of 160 papers. The collaboration network is shown in Figure 2-6. There are two main groups in this dimension, one led by Prof. Wayne K. Talley at Old Dominion University, USA, and the other by Dr. Sabine Knapp at Erasmus University, The Netherlands. Both groups have used various econometric models, such as Tobit and Probit, Poisson regression, negative binomial regression, ordered Probit and Logit, and duration analysis.

Figure 2-6: Collaboration network in accident data analysis.



(a) Co-authorship in accident analysis dimension

(b) Connections of the main two components

2.3.7 Trends in methodology

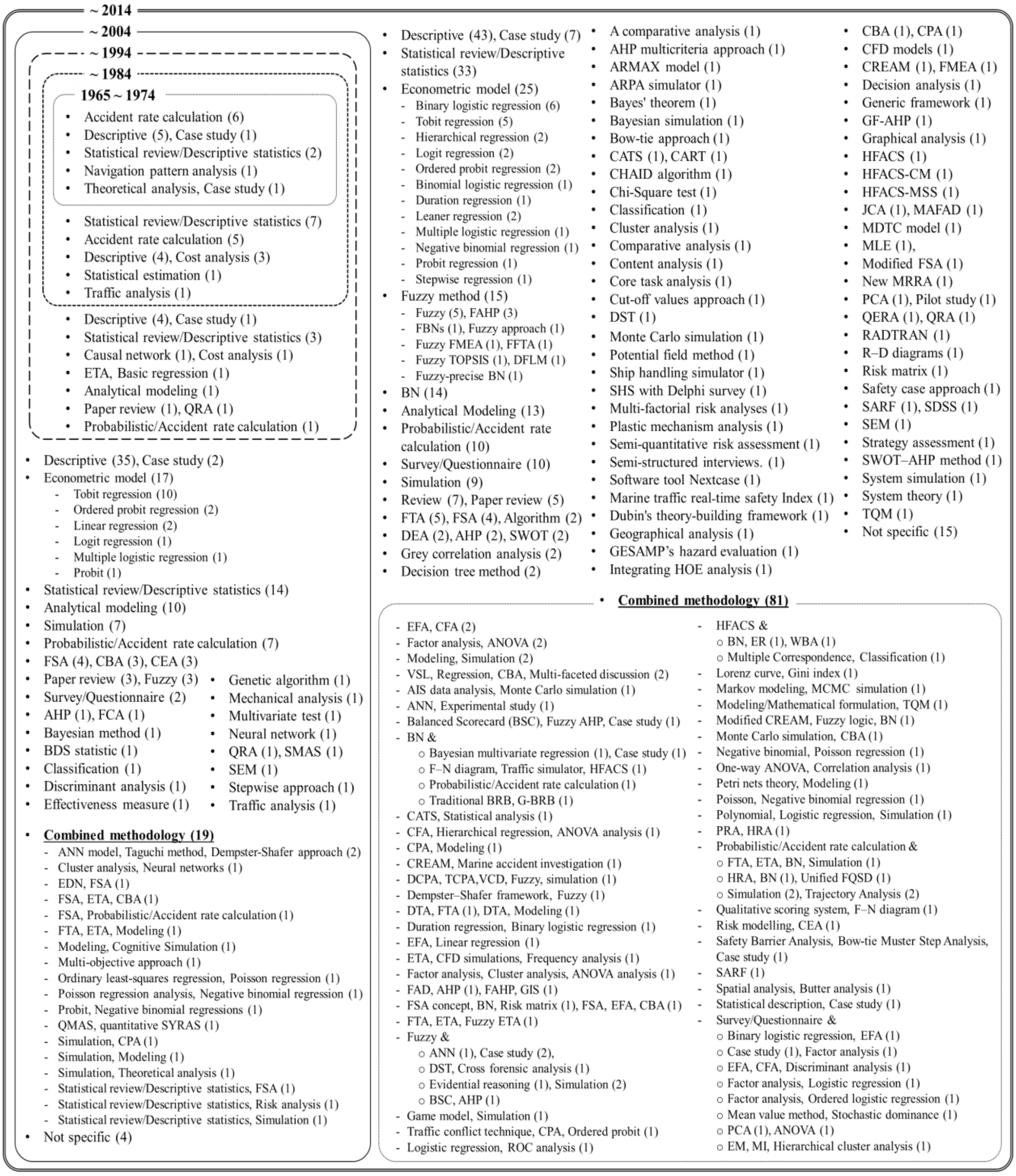
The early studies in maritime accident research usually adopted very basic methods such as statistical and descriptive reviews, case studies and probability calculations, while recent studies often used multi-disciplinary approaches, comprehensive risk analysis, and system-width viewpoints (Figure 2-7). After 1995, many studies adopted econometric methods to find causal factors (Anderson and Talley, 1995; Talley, 1996; Jin *et al*., 2001; Knapp and Franses, 2010; Talley *et al*., 2012). Econometric analysis has two major limitations: 1) under-reporting of maritime accident data, and 2) difficulty in taking into account human error or other qualitative information such as cultural factors (Roberts *et al*., 2013). In the past decade, many different approaches have been developed to address these problems. For example, HFACS, which has been used for accident analysis in other fields, was introduced to identify latent human errors (Celik and Cebi, 2009; Chauvin, 2011).

New methods that have appeared in maritime accident research also include CREAM (Akhtar and Utne, 2015), probabilistic risk assessment based simulation (Merrick *et al*., 2005), and many other modeling techniques (Tam and Bucknall, 2010; Goerlandt and Kujala, 2011; van Dorp and Merrick, 2011; Faghih-Roohi *et al*., 2014).

Recently, the most frequently used method for risk analysis and safety assessment was BN (Eleye-Datubo *et al*., 2006; Ren *et al*., 2008; Wang *et al*., 2013; Zhang *et al*., 2013; Wang and Zhang, 2014; Hänninen *et al*., 2014). It is a powerful tool for modeling repetitive patterns (Håvold, 2010), which can replace FTA as a classification method and take into account the joint effect of several events (Faber *et al*., 2012). Human fatigue, usually difficult to quantify, can be analyzed using BN methodology (Akhtar and Utne, 2014).

Another new trend in recent years is the use of combined methods and coupled analysis. Nwaoha *et al*. (2013) used a risk matrix together with an FER approach. Zhang *et al*. (2014) combined quantitative and qualitative data using BRB theory. Chang *et al*. (2014) used both qualitative and quantitative methods to analyze safety and security risks in container shipping. Some researchers analyzed survey and questionnaire data using not only factor analysis, cluster analysis, ANOVA, EFA and CFA, but also econometric models such as hierarchical regression and logistic regression. Ek *et al*. (2014) used EM and MI to estimate the missing value in a questionnaire. Fuzzy set analysis has also been used together with methods such as ETA (Mokhtari *et al*., 2011), and AHP (Perera *et al*., 2011).

Figure 2-7: Major methodology and models used in maritime accident research, in 10-year intervals.



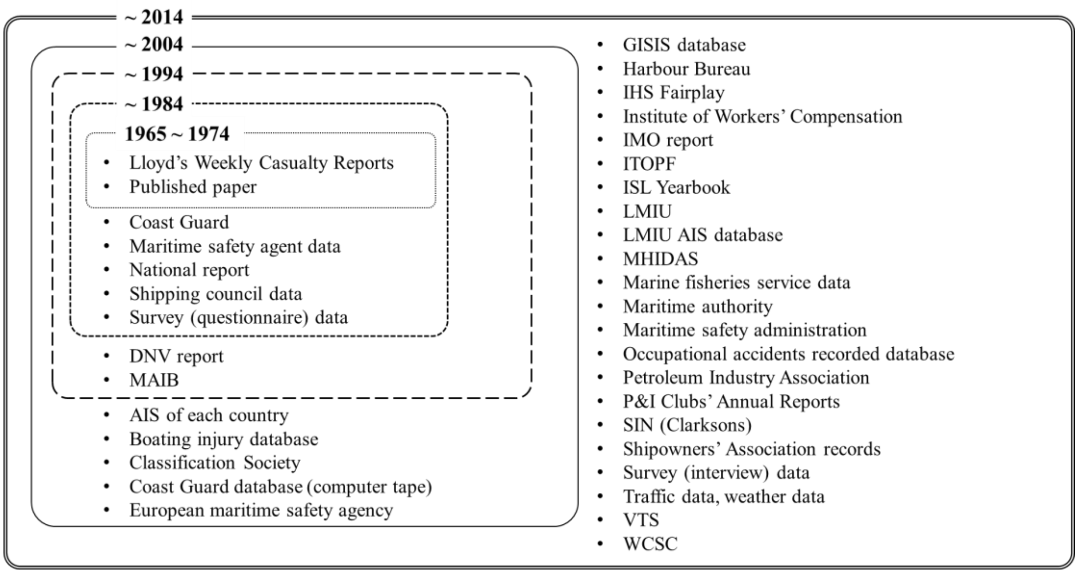
Note: Compiled by author.

Model extension has occurred alongside the introduction of new models to this research area. Yang *et al*. (2013) extended the CREAM approach by incorporating Bayesian reasoning in a fuzzy environment. Akyuz and Celik (2014) combined the HFACS approach with cognitive mapping (CM) to focus on human error in maritime accidents. The acronym HFACS-MA qualifies HFACS as applying to maritime accidents, and has been used to analyze human and organizational factors (Chen *et al.*, 2013); likewise HFACS-MSS for investigating deficiencies in machinery spaces on ships (Schröder-Hinrichs *et al.*, 2011).

2.3.8 Evolution of data sources

Maritime accident data play a crucial role in maritime accident research (Meek *et al.*, 1985; Dobler, 1994). The selection of data resources requires careful consideration due to important implications for the research results. Over the past 50 years the data sources used in the research published have also evolved, as shown in Figure 2-8.

Figure 2-8: Evolution of the data sources used in maritime accident research.



Note: Compiled by author.

From 1965 to 1974, the main sources of maritime accident data were Lloyd's reports and published papers. Coast Guard, maritime council, and government agency data were used in accident analysis after the mid-1970s. From 1985 to 1994, Det Norske Veritas reports related to maritime accidents were published, and the UK authorities published the accident-dedicated data from MAIB, which is still used currently. From 1995 to 2004, computer-based databases enabled rapid access to the data and easy computation, generating a large volume of papers on accident patterns and major causes according to ship type, place, and period. During the past decade, not only variables relating to maritime accidents and vessels (age, ship type, gross tonnage, FOC, classification societies), but also data on the marine environment, weather, and crews have been incorporated into analyses. Some very recent publications have even used data from GISIS and AIS. In this period more papers used multiple databases, due to increasing awareness of the complexity of maritime accidents and better data-processing capability. For example, Ronza *et al*. (2006) used climate data (average temperatures, humidity, wind roses and atmospheric stability) combined with traffic data; Qu *et al*. (2011) considered ships' speed data using the AIS database.

A recent trend in maritime accident research is the increasing number of studies using data from multiple sources. For example, Balmat *et al*. (2011) used data from Lloyd's Register, IMO, EQUASIS, and Paris MOU; Knapp *et al*. (2011) combined data from Lloyd's Register Fairplay, flag state inspections data, various PSC regimes, industry inspections from RightShip, OCIMF, CDI, and ISM audits from diverse flag states, LMIU, IMO, CSIN, and ICOADS. Heij and Knapp (2014) considered various variables from diverse datasets that included CSIN, the Institute of Supply Management, OECD, BS, IMF, AMSA, IMO, Lloyd's Register Fairplay, and LMIU.

As many studies indicate, maritime accident databases are vital for finding the root causes of maritime accidents and providing preventative measures. Although many different types of database have been developed, the lack of relevant data has been a problem for researchers. To overcome this problem, researchers used combined data or other less data-dependent approaches. For instance, econometric models are often unsuitable for dealing with qualitative data such as human error. Risk analysis models, such as the BN model, can act in a supplementary fashion by generating data samples according to assumed priori distribution of certain variables. This is one reason why BN models have recently been introduced into maritime accident studies.

2.4 Chapter conclusions

Huge effort has been expended in the maritime community on reducing or eliminating maritime accidents, due to the threats to the people aboard, the ships, the cargo, and the marine environment. This effort is reflected in the large collection of research papers that have been published in peer-reviewed journals. Understanding how the field has evolved can help future researchers, and thus better protect life and property at sea.

This chapter summarized the evolution of maritime accident research from broad perspectives over the past 50 years, using 572 peer-reviewed papers collected from 125 academic journals published in English. The number of papers published in the most recent decade increased rapidly compared with the previous period, due to the increasing role of maritime transportation in international trade, and recognition of the increasingly large potential damage resulting from maritime accidents. Europe and North America were the most active areas of maritime accident research before year 2000. Asia has now become increasingly active, due to its trade volume in sea transportation. Africa, South America and Oceania may be future growth areas.

Over the past half-century, maritime accident research has changed from being an exclusive area for naval architects to a big stage for many players from different disciplines. This reflects a shifting of the major concerns from ship structure problems to complex environmental conditions, including human error and shipping market conditions. This shift has also required the use of data from many different sources, and more advanced models and computer technologies.

The most popular dimensions in maritime accident research are risk analysis/safety assessment and accident data analysis. The focus of the former is on preventative measures, while that of the second is on learning from an accident. Analyzing accident data allows the knowledge base on the possible causes of maritime accidents to be enlarged, which can help in the development of better policies and more effective preventative measures to improve maritime safety.

Based on conclusions from this chapter, this thesis sets research questions and reviews the literature in Chapter 3. Using the method introduced in Chapter 4, the service lifespan and recurrent accidents of ship are analyzed in Chapter 5 and 6, using shipping market conditions which has emerged as an important factor affecting maritime accidents in Chapter 2. Finally, Chapter 7 provides the conclusions of this thesis and suggestions for future research.

References

Akhtar, M. J., & Utne, I. B. (2014). Human fatigue's effect on the risk of maritime groundings–A Bayesian Network modeling approach. *Safety Science, 62,* 427–440.

Akhtar, M. J., & Utne, I. B. (2015). Common patterns in aggregated accident analysis charts from human fatigue-related groundings and collisions at sea. *Maritime Policy & Management, 42*(2), 186-206.

Akyuz, E., & Celik, M. (2014). Utilisation of cognitive map in modelling human error in marine accident analysis and prevention. *Safety Science, 70,* 19–28.

Anderson, E. E., & Talley, W. K. (1995). The oil spill size of tanker and barge accidents: Determinants and policy implications. *Land Economics, 71*(2), 216–228.

Antão, P., & Soares, C. (2010). Analysis of the influence of waves in the occurrence of accidents in the Portuguese coast using Bayesian Belief Networks. *Journal of KONBiN, 13*(1), 105-116.

Antão, P., & Soares, C. G. (2006). Fault-tree models of accident scenarios of RoPax vessels. *International Journal of Automation and Computing, 3*(2), 107-116.

Antão, P., & Soares, C. G. (2008). Causal factors in accidents of high-speed craft and conventional ocean-going vessels. *Reliability Engineering & System Safety*, *93*(9), 1292-1304.

Antonsen, S. (2009). The relationship between culture and safety on offshore supply vessels. *Safety Science, 47*(8), 1118–1128.

Arslan, O., & Er, I. D. (2008). SWOT analysis for safer carriage of bulk liquid chemicals in tankers. *Journal of Hazardous Materials, 154*(1), 901–913.

Balmat, J.-F., Lafont, F., Maifret, R., & Pessel, N. (2011). A decision-making system to maritime risk assessment. *Ocean Engineering, 38*(1), 171–176.

Baniela, S. I., & Ríos, J. V. (2010). The Risk Homeostasis Theory. *The Journal of Navigation, 63*(4), 607–626.

Barnett, M. L. (2005). Searching for the root causes of maritime casualties. *WMU Journal of Maritime Affairs, 4*(2), 131-145.

Bateman, S., Ho, J., & Mathai, M. (2007). Shipping patterns in the Malacca and Singapore straits: an assessment of the risks to different types of vessel. *Contemporary Southeast Asia, 29*(2), 303–332.

Bolat, P., & Yongxing, J. (2013). Risk Assessment of Potential Catastrophic Accidents for Transportation of Special Nuclear Materials through Turkish Straits. *Energy Policy, 56*, 126–135.

Celik, M., & Cebi, S. (2009). Analytical HFACS for investigating human errors in shipping accidents. *Accident Analysis and Prevention, 41*(1), 66–75.

Chang, C.-H., Xu, J., & Song, D.-P. (2014). An analysis of safety and security risks in container shipping operations: A case study of Taiwan. *Safety Science*, *63*, 168–178.

Chauvin, C. (2011). Human Factors and Maritime Safety. *The Journal of Navigation, 64*(4), 625–632.

Chen, S.-T., Wall, A., Davies, P., Yang, Z., Wang, J., & Chou, Y.-H. (2013). A Human and Organisational Factors (HOFs) analysis method for marine casualties using HFACS-Maritime Accidents (HFACS-MA). *Safety Science, 60*, 105–114.

Cockcroft, A. (1976). Statistics of collisions at sea. *Journal of Navigation*, *29*(03), 215-231.

Coldwell, T. G. (1981). Marine Traffic Flow and Casualties on the Humber. *The Journal of Navigation, 34*(1), 38–52.

Couper, A. (1968). Marine Casualties in the Pacific Islands and their Economic Consequences. *Journal of Navigation, 21*(1), 19-23.

Dobler, J.-P. (1994). The requirement for the publication of detailed global marine casualties statistics. *Maritime Policy & Management, 21*(1), 45–60.

Ek, Å., Runefors, M., & Borell, J. (2014). Relationships between safety culture aspects–A work process to enable interpretation. *Marine Policy, 44,* 179–186.

Eleye-Datubo, A., Wall, A., Saajedi, A., & Wang, J. (2006). Enabling a Powerful Marine and Offshore Decision-Support Solution Through Bayesian Network Technique. *Risk Analysis, 26*(3), 695–721.

Eleye-Datubo, A., Wall, A., & Wang, J. (2008). Marine and Offshore Safety Assessment by Incorporative Risk Modeling in a Fuzzy- Bayesian Network of an Induced Mass Assignment Paradigm. *Risk Analysis, 28*(1), 95–112.

Ellis, J. (2010). Undeclared dangerous goods—Risk implications for maritime transport. *WMU Journal of Maritime Affairs, 9*(1), 5–27.

Faber, M. H., Straub, D., Heredia-Zavoni, E., & Montes-Iturrizaga, R. (2012). Risk assessment for structural design criteria of FPSO systems. Part I: Generic models and acceptance criteria. *Marine Structures, 28*(1), 120–133.

Faghih-Roohi, S., Xie, M., & Ng, K. M. (2014). Accident risk assessment in marine transportation via Markov modelling and Markov Chain Monte Carlo simulation. *Ocean Engineering, 91*, 363–370.

Forsyth, C. J. (1991). Factors affecting tanker safety. *Maritime Policy and Management, 18*(4), 313-319.

Fricker, F. (1965). Regional incidence of collision. *The Journal of Navigation, 18*(2), 163–179.

Fujii, Y., & Shiobara, R. (1971). The analysis of traffic accidents. *The Journal of Navigation, 24*(4), 534–543.

Fujii, Y., & Yamanouc.H. (1974). Some Factors Affecting Frequency of Accidents in Marine Traffic .4. Visual Range and Degree of Risk. *Journal of Navigation, 27*(2), 248-252.

Fukushima, H. (1976). Factors contributing to marine casualties. *The Journal of Navigation, 29*(2), 135–140.

Glen, D. (2010). Modelling the impact of double hull technology on oil spill numbers. *Maritime Policy & Management, 37*(5), 475–487.

Goerlandt, F., & Kujala, P. (2011). Traffic simulation based ship collision probability modeling. *Reliability Engineering and System Safety, 96*(1), 91–107.

Goerlandt, F., Ståhlberg, K., & Kujala, P. (2012). Influence of impact scenario models on collision risk analysis. *Ocean Engineering, 47*, 74–87.

Goossens, L. H., & Glansdorp, C. C. (1998). Operational benefits and risk reduction of marine accidents. *The Journal of Navigation, 51*(3), 368-381.

Gucma, L., & Przywarty, M. (2008). The Model of Oil Spills Due to Ships Collisions in Southern Baltic Area. *TransNav: International Journal on Marine Navigation and Safety of Sea Transportation, 2*(4), 415–419.

Hänninen, M., Banda, O. A., & Kujala, P. (2014). Bayesian network model of maritime safety management. *Expert Systems with Applications*, *41*(17), 7837–7846.

Hansen, H. L., & Pedersen, G. (2001). Poisoning at sea: Injuries caused by chemicals aboard danish merchant ships 1988-1996. *Clinical Toxicology*, *39*(1), 21–26.

Hassel, M., Asbjørnslett, B. E., & Hole, L. P. (2011). Underreporting of Maritime Accidents to Vessel Accident Databases. *Accident Analysis and Prevention, 43*(6), 2053–2063.

Håvold, J. I. (2010). Safety culture and safety management aboard tankers. *Reliability Engineering and System Safety, 95*(5), 511–519.

Heij, C., & Knapp, S. (2014). Dynamics in the Dry Bulk Market Economic Activity, Trade Flows, and Safety in Shipping. *Journal of Transport Economics and Policy (JTEP), 48*(3), 499–514.

Hu, S., Li, X., Fang, Q., & Yang, Z. (2008). Use of Bayesian method for assessing vessel traffic risks at sea. *International Journal of Information Technology & Decision Making, 7*(4), 627–638.

Jin, D., Kite-Powell, H., & Talley, W. K. (2001). The safety of commercial fishing: determinants of vessel total losses and injuries. *Journal of Safety Research, 32*(2), 209–228.

Jonse-Lee, M. (1990). The value of transport safety. *Oxford Review of Economic Policy, 6*(2), 39–60.

Kemp, J. (1973). Behaviour patterns in encounters between ships. *The Journal of Navigation, 26*(4), 417–423.

Knapp, S., & Franses, P. H. (2010). Comprehensive review of the maritime safety regimes: Present status and recommendations for improvements. *Transport reviews, 30*(2), 241–270.

Knapp, S., Kumar, S., Sakurada, Y., & Shen, J. (2011). Econometric analysis of the changing effects in wind strength and significant wave height on the probability of casualty in shipping. *Accident Analysis and Prevention, 43*(3), 1252–1266.

Korkut, E., Atlar, M., & Incecik, A. (2004). An experimental study of motion behaviour with an intact and damaged Ro-Ro ship model. *Ocean Engineering, 31*(3), 483–512.

Korkut, E., Atlar, M., & Incecik, A. (2005). An experimental study of global loads acting on an intact and damaged Ro–Ro ship model. *Ocean Engineering, 32*(11), 1370–1403.

Kostilainen, V., & Hyvärinen, M. (1974). Ship Casualties in the Baltic, Gulf of Finland and Gulf of Bothnia in 1971–2. *Journal of Navigation, 27*(02), 220-234.

Kostilainen, V., & Tuovinen, P. (1980). Casualties to Tankers in the Baltic 1960–1975. *Journal of Navigation, 33*(03), 379-388.

Lappalainen, J., Storgård, J., & Tapaninen, U. (2013). The effectiveness of maritime safety policy instruments from the Finnish maritime experts' point of view–case Gulf of Finland and prevention of an oil accident. *TransNav: International Journal on Marine Navigation and Safety of Sea Transportation, 7*(3), 353–362.

Li, K. X., & Ng, J. M. (2002). International Maritime Conventions: Seafarers' Safety and Human Rights. *Journal of Maritime Law and Commerce, 33*(3), 381–405.

Li, K. X., Yin, J., Bang, H. S., Yang, Z., & Wang, J. (2014). Bayesian network with quantitative input for maritime risk analysis. *Transportmetrica A: Transport Science, 10*(2), 89–118.

Lighart, V. H. (1980). Determination of probability of marine accidents with respect to gas carriers proceeding in Dutch coastal and inland waters. *Journal of Hazardous Materials, 3*(3), 233–247.

Martins, M. R., & Maturana, M. C. (2013). Application of Bayesian Belief networks to the human reliability analysis of an oil tanker operation focusing on collision accidents. *Reliability Engineering and System Safety, 110*, 89–109.

Meek, M., Brown, W., & Fulford, K. (1985). A shipbuilder's view of safety. *Maritime Policy & Management, 12*(4), 251–262.

Merrick, J. R., van Dorp, J. R., & Dinesh, V. (2005). Assessing Uncertainty in Simulation- Based Maritime Risk Assessment. *Risk Analysis, 25*(3), 731–743.

Mokhtari, K., Ren, J., Roberts, C., & Wang, J. (2011). Application of a generic bow-tie based risk analysis framework on risk management of sea ports and offshore terminals. *Journal of Hazardous Materials, 192*(2), 465–475.

Montewka, J., Ehlers, S., Goerlandt, F., Hinz, T., & Tabri, K. (2014). A framework for risk assessment for maritime transportation systems—A case study for open sea collisions involving RoPax vessels. *Reliability Engineering and System Safety, 124*, 142–157.

Neuparth, T., Moreira, S., Santos, M. M., & Reis-Henriques, M. A. (2011). Hazardous and Noxious Substances (HNS) in the Marine Environment: Prioritizing HNS that Pose Major Risk in a European Context. *Marine Pollution Bulletin, 62*(1), 21–28.

Nwaoha, T. C., Yang, Z., Wang, J., & Bonsall, S. (2013). Adoption of new advanced computational techniques to hazards ranking in LNG carrier operations. *Ocean Engineering, 72*, 31–44.

O'Connor, P. J., & O'Connor, N. (2005). Causes and Prevention of Boating Fatalities. *Accident Analysis and Prevention, 37*(4), 689–698.

Oltedal, H. A., & McArthur, D. P. (2011). Reporting practices in merchant shipping, and the identification of influencing factors. *Safety Science*, *49*(2), 331–338.

Otto, S., Pedersen, P. T., Samuelides, M., & Sames, P. C. (2002). Elements of risk analysis for collision and grounding of a RoRo passenger ferry. *Marine Structures*, *15*(4), 461-474.

Perera, L., Carvalho, J., & Soares, C. G. (2011). Fuzzy logic based decision making system for collision avoidance of ocean navigation under critical collision conditions. *Journal of Marine Science and Technology, 16*(1), 84–99.

Psarros, G., Skjong, R., & Eide, M. S. (2010). Under-reporting of maritime accidents. *Accident Analysis and Prevention, 42*(2), 619–625.

Qu, X., Meng, Q., & Suyi, L. (2011). Ship collision risk assessment for the Singapore Strait. *Accident Analysis and Prevention, 43*(6), 2030–2036.

Reily, M. S. (1984). The safety of UK fishing vessels 1961–80. *The Journal of Navigation, 37*(1), 60–82.

Ren, J., Jenkinson, I., Wang, J., Xu, D., & Yang, J. (2008). A methodology to model causal relationships on offshore safety assessment focusing on human and organizational factors. *Journal of Safety Research, 39*(1), 87–100.

Roberts, S. E., & Marlow, P. B. (2002). Casualties in dry bulk shipping (1963–1996). *Marine Policy, 26*(6), 437-450.

Roberts, S. E., Nielsen, D., Kotłowski, A., & Jaremin, B. (2014). Fatal accidents and injuries among merchant seafarers worldwide. *Occupational Medicine, 64*(4), 259–266.

Roberts, S. E., Pettit, S. J., & Marlow, P. B. (2013). Casualties and loss of life in bulk carriers from 1980 to 2010. *Marine Policy, 42*, 223–235.

Ronza, A., Carol, S., Espejo, V., Vílchez, J. A., & Arnaldos, J. (2006). A quantitative risk analysis approach to port hydrocarbon logistics. *Journal of Hazardous Materials, 128*(1), 10–24.

Schröder-Hinrichs, J. U., Baldauf, M., & Ghirxi, K. T. (2011). Accident investigation reporting deficiencies related to organizational factors in machinery space fires and explosions. *Accident Analysis and Prevention, 43*(3), 1187–1196.

Sii, H., Wang, J., & Ruxton, T. (2003). A statistical review of the risk associated with offshore support vessel/platform encounters in UK waters. *Journal of Risk Research, 6*(2), 163–177.

Sii, S. H., Wang, J., Eleye-Datubo, A. G., Yang, J. B., & Liu, J. (2005). Safety Assessment of FPSO Turret-Mooring System Using Approximate Reasoning and Evidential Reasoning. *Marine Technology, 42*(2), 88–102.

Silber, G. K., Slutsky, J., & Bettridge, S. (2010). Hydrodynamics of a ship/whale collision. *Journal of Experimental Marine Biology and Ecology, 391*(1), 10–19.

Silveira, P. A., Teixeira, A. P., & Soares, C. G. (2013). Use of AIS data to characterise marine traffic patterns and ship collision risk off the coast of Portugal. *The Journal of Navigation, 66*(6), 879–898.

Squire, C. D. (2003). The Hazards of Navigating The Dover Strait (Pas-de-Calais) Traffic Separation Scheme. *The Journal of Navigation, 56*(2), 195–210.

Ståhlberg, K., Goerlandt, F., Ehlers, S., & Kujala, P. (2013). Impact scenario models for probabilistic risk-based design for ship–ship collision. *Marine Structures, 33*, 238–264.

Swett, R. A., Sidman, C., Fik, T., Watkins, R., & Ouellette, P. (2011). Evaluating Boating Safety Risk in Intracoastal Waterways. *Coastal Management, 39*(6), 613–627.

Talley, W. K. (1996). Determinants of cargo damage risk and severity: The case of containership accidents. *Logistics and Transportation Review, 32*(4), 377–388.

Talley, W. K. (1999). The safety of sea transport: determinants of crew injuries. *Applied Economics, 31*(11), 1365–1372.

Talley, W. K., Yip, T. L., & Jin, D. (2012). Determinants of vessel-accident bunker spills. *Transportation Research Part D: Transport and Environment, 17*(8), 605–609.

Tam, C. K., & Bucknall, R. (2010). Path-planning algorithm for ships in close-range encounters. *Journal of Marine Science and Technology, 15*(4), 395–407.

Thai, V. V., & Grewal, D. (2006). The Maritime Safety Management System (MSMS): a survey of the international shipping community. *Maritime Economics & Logistics, 8*(3), 287–310.

Toffoli, A., Lefevre, J., Bitner-Gregersen, E., & Monbaliu, J. (2005). Towards the identification of warning criteria: analysis of a ship accident database. *Applied Ocean Research, 27*(6), 281-291.

Trucco, P., Cagno, E., Ruggeri, F., & Grande, O. (2008). A Bayesian Belief Network modelling of organisational factors in risk analysis: A case study in maritime transportation. *Reliability Engineering and System Safety, 93*(6), 823–834.

Uğurlu, Ö., Köse, E., Yildirim, U., & Yüksekyildiz, E. (2013). Marine accident analysis for collision and grounding in oil tanker using FTA method. *Maritime Policy & Management*(ahead-of-print), 1-23.

van Dorp, J. R., & Merrick, J. R. (2011). On a risk management analysis of oil spill risk using maritime transportation system simulation. *Annals of Operations Research, 187*(1), 249–277.

Vinnem, V. E. (2011). Evaluation of offshore emergency preparedness in view of rare accidents. *Safety Science, 49*(2), 178–191.

Wagenaar, W. A., & Groeneweg, J. (1987). Accidents at sea: Multiple causes and impossible consequences. *International Journal of Man-Machine Studies, 27*(5), 587-598.

Wang, J., & Zhang, Q. (2014). Model and Algorithm Design for Cargo Shipping Safety Based on Fuzzy-Precise Bayesian Network. *Journal of Networks, 9*(8), 2137–2144.

Wang, Y. F., Xie, M., Chin, K.-S., & Fu, X. J. (2013). Accident analysis model based on Bayesian Network and Evidential Reasoning approach. *Journal of Loss Prevention in the Process Industries, 26*(1), 10–21.

Yang, Z., Bonsall, S., Wall, A., Wang, J., & Usman, M. (2013). A modified CREAM to human reliability quantification in marine engineering. *Ocean Engineering, 58*, 293–303.

Zhang, D., Yan, X. P., Yang, Z. L., Wall, A., & Wang, J. (2013). Incorporation of formal safety assessment and Bayesian network in navigational risk estimation of the Yangtze River. *Reliability Engineering and System Safety, 118*, 93–105.

Zhang, J., Yan, X., Zhang, D., Haugen, H., & Yang, Y. (2014). Safety management performance assessment for Maritime Safety Administration (MSA) by using generalized belief rule base methodology. *Safety Science, 63*, 157–167.

Chapter 3.

Research Questions & Literature Review

Chapter 2 shows that shipping market conditions are an important factor in tandem with human error related to maritime accidents. Thus, in this chapter, a statistical analysis of the shipping market conditions and the factors responsible for maritime accidents is described. A comprehensive review of the 572 papers published over the past 50 years appears in Chapter 2. Furthermore, this chapter focuses on the application to ship accidents affecting the ships' lifespan and recurrent ship accidents.

3.1 Ship accidents and their longevity

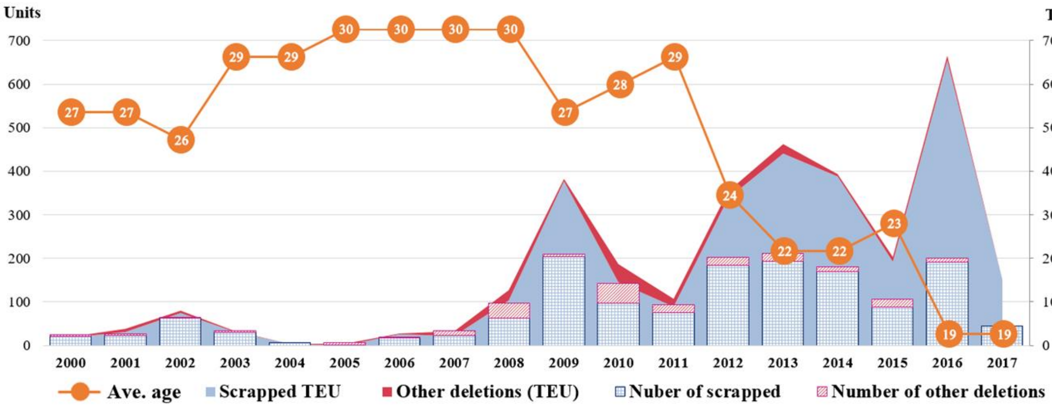
3.1.1 Research background and questions

Ships, like living beings, have a limited lifespan because their quality deteriorates when operating in a complex natural and socioeconomic environment after delivery or because of accidental losses. The lifespan of a ship, in addition to its structural and mechanical properties determined in the shipyard, is affected by numerous factors related to the social environment.

A review of the literature, presented in the next section, reveals that no study has addressed the determinants of a ship's lifespan other than from the engineering perspective. However, socioeconomic factors (i.e., shipping market conditions) play an important role in determining the lifespan of a ship. Using container shipping as an example, according to *Alphaliner Monthly Monitor*, on March 2017, a sharp distinction was observed upon the deletion of container ships from the global fleet before and after the global financial crisis of 2007-2008 (Figure 3-1). The youngest ship being scrapped in 2016 was only 7 years old[6]. Although each removal may have its own reasons, a fundamental cause is the ship's low profitability in the shipping market.

[6] http://www.joc.com/maritime-news/ships-shipbuilding/rickmers-maritime-scrap-youngest-container-ship-ever_20161212.html, accessed April 7, 2017.

Figure 3-1: Containership deletion from the global fleet between 2000 and March 2017.

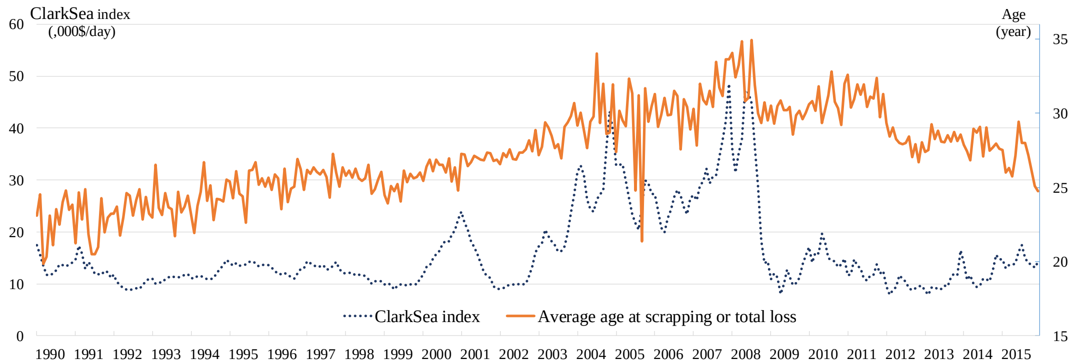


Note: Author's own figure based on the *Alphaliner Monthly* data

The increase in vessel demolition after the global financial crisis was observed not only in the container sector but also in other sectors.

Figure 3-2 presents the average ship age at deletion (scrapping and total loss) between 1990 and 2015 for the major merchant shipping sectors (containers, general cargo, bulkers, and tankers) and the corresponding market conditions (ClarkSea Index). In general, a booming market (before 2008) led to an increase in the global fleet size and an extension of ship life, but the bust (after 2008) resulted in a lower profitability that in turn led to a decrease in lifespan.

Figure 3-2: Trend of ClarkSea Index and average lifespan of global merchant vessels.



Note: Data from Clarkson Shipping Intelligence Network

Research questions

- What are the determinants of a ship's lifespan?
- How does a ship's lifespan change according to the economic environment?
- Does a ship accident affect the lifetime of the vessel?

Analysis of the determinants of a ship's lifespan is important for both private businesses with respect to their ship-related decision making and public agencies with respect to the determination of the safety and environmental requirements of the global merchant fleet. For example, to assess the value of a secondhand ship, information about the ship's possible future life is required. From the public agencies' perspective, any major safety or environmental policy that requires major recurrent changes to a ship must consider the effects of such a policy on the ship's lifespan. If a policy can result in a major reduction in a ship's lifespan, the current ship owners may resist it.

3.1.2 Literature review on the longevity of vessels study

The longevity of vessels is studied from the engineering or the social and environmental views. In engineering/structural studies, Ayyub *et al*. (1989) estimated the physical lifespan of a vessel on the basis of its structure by using the reliability concept and a cumulative probability distribution function. Ayyub and White (1990) assessed life expectancy on the basis of a probabilistic analysis with a case study on the ship's hull structure and the ship's life expectancy and durability. Ayyub *et al*. (2015) also assessed the structural life expectancy for marine vessels with time-dependent reliability functions considering factors that affect structural integrity including the hull strength, stiffened panels, fatigue, and fracture.

From social and environmental aspects, Mikelis (2008) provided statistics of ships scrapped between 1990 and 2006, including the average and the standard deviation of the scrapping age, the number of ships scrapped, and total and average GT. The study presented the cyclical nature of the scrapping market and proved that in most shipping sectors, the average age of the recycled vessel is high during a booming market.

Knapp *et al*. (2008) used binary logistic regression to estimate the probability of choosing the vessel scrapping country as a function of the ship's age, size, classification societies group, changes in ship ownership, and average earnings per day (one of the ClarkSea indices). The results show that higher earnings decrease the probability of demolition as owners earn more than the amount that they would receive by selling the ship to the scrapyard. These results also present that a ship's lifespan is subject to its profitability.

Bijwaard and Knapp (2009) analyzed the life cycle of ships, emphasizing the effect of safety inspections on the vessels' survival. They used survival curves to present the accident-free duration of each vessel type. Moreover, the study used a duration analysis to find the incident rates of ships. The study found a relationship between the economic variables of the shipping market and the end of the vessels' life because of ship accidents. Normal scrapping of a vessel is not considered in their study.

In the field of aviation, the lifespan of aircrafts also needs to be studied from the engineering aspects. Benavides (2010) used a survival analysis to study the corrosion of an aging aircraft, which can incorporate censored data—corrosion that did not result in failure. This study used a survival curve and a Cox PH model to identify the causes of failure, including environmental, geographic, and operational factors. However, the life expectancy of airplanes is typically determined by economic factors rather than technical limitations or deterioration causes. In this context, Jiang (2013) in her technical paper used the average scrapping age of airplanes and the survival curves of a major passenger aircraft to measure the economic life of an airplane by using the data of Boeing commercial airplanes.

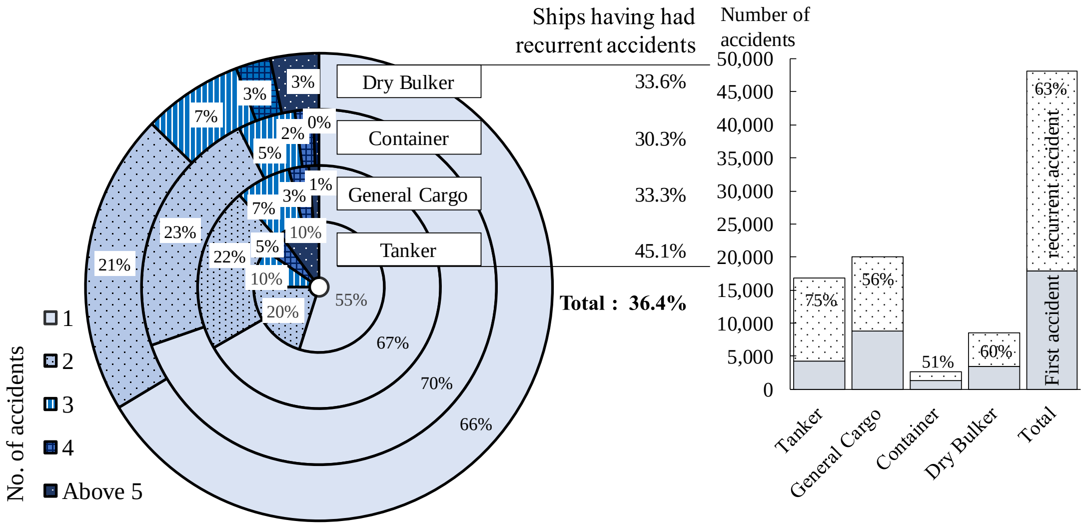
From this perspective, in this chapter, an in-depth study was performed on a ship's economic life to identify a directional relationship between the vessels' lifespan decrease caused by scrapping and the total loss and shipping market conditions with retrospective vessel data.

3.2 Recurrent ship accidents study

3.2.1 Research background and questions

Many ships have more than one accident. Among all ships that have had accidents (hereinafter referred to as "accident ships"), 36.4% have had more than one accident in their lifetime (see Figure 3-3). Figure 3-3(a) shows the percentage of accidents involving ships with recurrent accidents by ship type, on the basis of Lloyd's Register ship casualty data from 1978 to 2015. Furthermore, 45% of tanker ships experience more than one accident in their lifetime. The next in order are dry bulkers (33.6%), general cargo ships (33.3%), and container ships (30.3%). In terms of the recurrence of ship accidents, as shown in Figure 3-3(b), the percentages are higher. That is, 75% of the total accidents involving tanker ships are recurrent, followed by dry bulker ships (60%), general cargo ships (56%), and container ships (51%). These data revealed the remarkable fact that, overall, 63% of the global ship accidents were recurrent.

Figure 3-3: Distribution of recurrent ship accidents by ship type (1978-2015).



(a) Percentage of recurrent accident ships (b) Percentage of recurrent accidents

Note: Author’s own figure based on the Lloyds List casualty data

This high recurrence ratio highlights three important issues of maritime safety. First, many ship owners may not learn from previous accident experiences. Their priority tends to be to make the minimum necessary repairs so that they can return these ships to operation as soon as possible. However, if the root cause of an accident is not appropriately eliminated, the ships are likely to repeat the accident. Second, a ship owner’s measures to avoid the recurrence of ship accidents can improve maritime safety. Third, an understanding of the factors associated with the recurrence of ship accidents will help to devise future policies to help decrease the number of such accidents.

Research questions

- What are the determinants of ship accidents?
- How do the economic environment, vessel attributes, and factors related to the ship supply affect ship accidents?
- Do the shipping market conditions affect the incidence of ship accidents? If so, what types of accidents (first or recurrent ship accidents) pose a higher risk?

3.2.2 Literature review of the recurrent ship accident studies

Duration analysis is an appropriate method to analyze recurrent events that has been widely used in social sciences, engineering, and medical science. In contrast, only a few studies have applied a duration analysis to ship accident research, and these have focused mainly on ship inspection. Bijwaard and Knapp (2009) applied a duration analysis to the study of the effects of various ship inspections and shipping market cycles on a ship's lifespan. They found that good market conditions and ship inspections can generally decrease the incidence of ship accidents and prolong a ship's life. Moreover, the study identified the economic factors that contribute to the ship incident rate, such as new building price, secondhand price, and demolition price for certain types of vessels. Heij *et al*. (2011) estimated the contribution of ship inspections towards reducing ship accidents. Knapp *et al*. (2011) further computed the average probability of risk components, such as hull and machinery, loss of life, pollution, third-party liability and cargo damage; they also used a logistic model and estimated the upper and lower bounds of the total cost savings due to ship inspection.

Although these three previous studies used duration models, their main focus was on the effectiveness of inspections in improving ship safety. Despite the importance of maritime safety and the fact that a large proportion of ship accidents are recurrent, no studies have addressed the issue of recurrent accidents. This thesis aims to fill this gap in the literature.

References

Ayyub, B. M. (1989). Estimation of structural service life of ships. *Naval engineers journal, 101*(3), 156-166.

Ayyub, B. M., K. A. Stambaugh, T. A. McAllister, G. F. de Souza & D. Webb (2015). Structural Life Expectancy of Marine Vessels: Ultimate Strength, Corrosion, Fatigue, Fracture, and Systems. *ASCE-ASME Journal of Risk and Uncertainty in Engineering Systems, Part B: Mechanical Engineering, 1*(1), 011001.

Ayyub, B. M. & G. J. White (1990). Life expectancy assessment of marine structures. *Marine Structures, 3*(4), 301-317.

Benavides, S. (2010). Survival analysis of aging aircraft, The George Washington University.

Bijwaard, G. E., & Knapp, S. (2009). Analysis of ship life cycles—The impact of economic cycles and ship inspections. *Marine Policy, 33*(2), 350-369.

Heij, C., Bijwaard, G. E., & Knapp, S. (2011). Ship inspection strategies: Effects on maritime safety and environmental protection. *Transportation Research Part D: Transport and Environment, 16*(1), 42-48.

Jiang, H. (2013). "Key findings on airplane economic life." Boeing Commercial Analysis. Boeing.

Knapp, S., Bijwaard, G. E., & Heij, C. (2011). Estimated incident cost savings in shipping due to inspections. *Accident Analysis & Prevention, 43*(4), 1532-1539.

Knapp, S., S. N. Kumar & A. B. Remijn (2008). Econometric analysis of the ship demolition market. *Marine Policy, 32*(6), 1023-1036.

Mikelis, N. E. (2008). A statistical overview of ship recycling. *WMU Journal of Maritime Affairs, 7*(1), 227-239.

Chapter 4.

Research Method

Duration analysis, called Cox PH regression, is based on Survival Analysis, which was developed by John Graunt approximately 350 years ago in biostatistics and medical fields. Further, David Cox (1972) published his “proportional hazards model”, and his model allows us to solve the multivariate problem. Although Cox PH regression is called by different names in different fields of study, such as duration or transition analysis in economics, event history analysis in sociology, and failure time or lifetime analysis in engineering, these analyses are essentially synonymous (Allison, 2014). This analysis tool, based on survival analysis, investigates the important factors that affect the time to the occurrence of certain events.

This statistical method is a distribution-free and semiparametric model that does not require any assumption on the stochastic distribution of the error term. Therefore, the Cox PH model can provide reliable results regardless of whether the underlying assumption of the model is correct (Kleinbaum and Klein, 2006). Furthermore, Cox PH regression maximizes the likelihood ratio in estimating the parameter values, which does not require specifying the baseline hazard function—the natural tendency for certain events to happen. This study analyzes the important factors responsible for the ship accidents and ship destruction, and not the natural tendency for these events to happen. Therefore, the Cox PH model is the best tool for the analysis.

The core of all these analysis is to formulate the hazard rate, which is the conditional probability that a certain event will occur at a particular time t (Mills, 2011), and how the changes in the abovementioned important factors might affect the duration to the event.

To analyze recurrent events, a model that considers the order of events is needed. The AG model (Andersen and Gill, 1982), two types of PWP models (Prentice, Williams, and Peterson, 1981), and the WLW model (Wei, Lin, and Weissfeld, 1989) have been used in this thesis for the analysis of recurrent accidents. These four models are popular methods because they enable the analysis of all events for each individual and yield different results.

Thus, the Cox PH model and four of its extended models were applied to the first shipping accidents and recurrent ship accidents to determine the factors that affect both the initial and recurrent ship accidents with statistical advantages.

4.1 Cox PH model

This chapter applies the Cox PH model to the study of the determinants for the duration of a ship, considering vessel characteristics and shipping market conditions. Assume that the hazard for individual ship i to end its life at age t due to natural deterioration of the ship or other unknown factors is $h_0(t)$. Because of the ship-specific property $Z_i(t)$, which includes not only the ship attributes but also the different shipping environments, the actual hazard for the ship at that time ($h_i(t)$) can be expressed as follows:

$$h_i(t) = h_0(t)e^{\beta' Z_i(t)} \tag{4.1}$$

where β denotes a vector of the parameters to be estimated, which contains the contribution of each variable to the logarithm of the hazard ratio—the ratio of $h_i(t)$ to $h_0(t)$. A positive estimate indicates that an increase in the variable value will increase the hazard, thereby reducing the lifespan of the ship. Based on the Cox PH model, the likelihood for the estimated age for all the ships with respect to their destruction is the same as their observed age and can be expressed as follows:

$$PL(\beta) = \prod_{i=1}^{n} \left\{ \frac{e^{\beta' Z_i(t_i)}}{\sum_{j=1}^{n} Y_j(t_i) e^{\beta' Z_j(t_i)}} \right\}^{\delta_i} \tag{4.2}$$

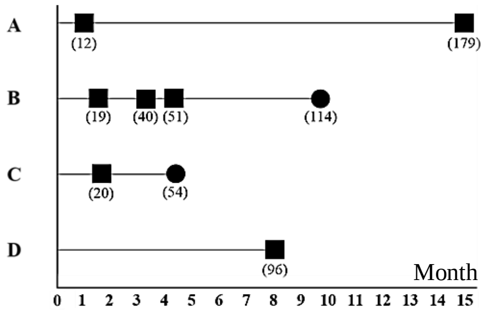
where t_i denotes the age of vessel i at the time of its destruction, and $Y_j(t_i) = I(t_j \geq t_i)$ is a dummy variable that indicates whether the lifetime of ship j is longer than that of ship i. This dummy variable allows us to exclude ships that have already been withdrawn from the fleet. It is called partial likelihood, because it excludes the likelihood for the ships that are still in operation. Such exclusion is necessary to make the regression feasible.

This model is called a semiparametric model because it does not require any assumption on the error distribution, and it has proven to be reliable by Kleinbaum and Klein (2006). This is an important reason why the duration analysis is used in this chapter.

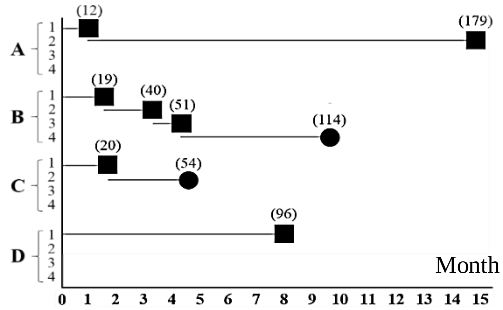
4.2 Extended Cox PH models

Based on the basic model, this chapter applies four extended Cox PH models to analyze recurrent accidents: the AG model (Andersen and Gill, 1982), two PWP models (the PWP-CP model and the PWP-GT model; Prentice, Williams, and Peterson 1981), and the WLW model (Wei, Lin, and Weissfeld, 1989). Figure 4-1 illustrates the durations between the first and second accidents of four ships. A black square indicates a recurrent accident, and a round square denotes that the ship is still in operation at the end of the sample period, which is also known as “censored” data. The duration in months to a recurrent accident is indicated in parentheses. These four models are introduced next.

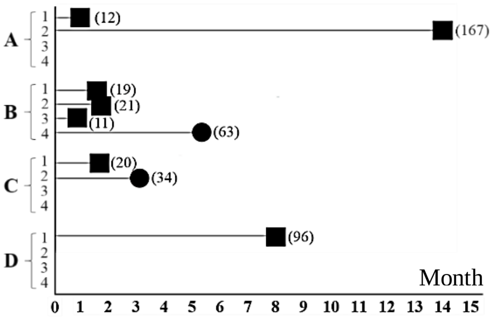
Figure 4-1: Illustration of four models for recurrent ship accident analysis.



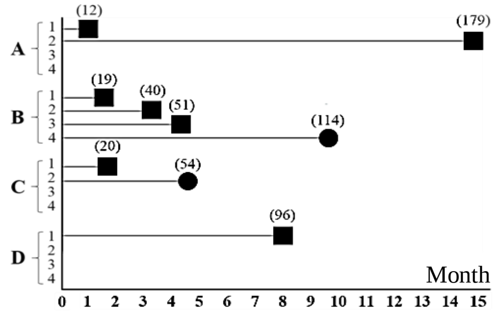
(a) AG



(b) PWP-CP



(c) PWP-GT



(d) WLW

Note: A, B, C, and C stand for individual ships.

4.2.1 AG model

The AG model is a basic model that assumes that the durations of recurrent accidents (i.e., the time from the first accident to later ones) are independent. This hazard function for the i^{th} ship to have the k^{th} accident at time t under this assumption can be expressed as follows:

$$h_{ik}(t) = h_0(t)e^{\beta' z_{ik}(t)} \tag{4.3}$$

where t denotes the number of months after the first accident. If the observed accident duration of the i^{th} ship to its k^{th} accident is t_{ik}, the partial likelihood function for all estimated ship accident durations to be equal to the observed accident time can be expressed as follows:

$$PL(\beta) = \prod_{i=1}^{n} \prod_{k=2}^{K_i} \left\{ \frac{e^{\beta' Z_i(t_{ik})}}{\sum_{j=1}^{n} Y_j(t_{ik}) e^{\beta' Z_j(t_{ik})}} \right\} \tag{4.4}$$

where K_i denotes the total number of accidents experienced by ship i, and $Y_j(t_{ik})$ is the dummy variable that indicates whether the j^{th} ship is in the risk set when the i^{th} ship is having its k^{th} accident. As long as the duration of the last accident of a ship is larger than t_{ik}, or the ship is censored, it is in the risk set of t_{ik}.

4.2.2 PWP model

In the PWP model, accidents are categorized by "strata"—the duration for ships having had the same number of accidents. The risk set of an accident therefore only includes ships in the same strata. The underlying assumption is that ship accidents under the same strata should show a similar pattern. In the hazard function, the base hazard is specific to strata k, which implies that different strata have different base hazard functions.

$$h_{ik}(t) = h_{0k}(t) e^{Z_{ik}(t)\beta} \tag{4.5}$$

PWP-CP model

The PWP-CP model is referred to as a "stratified AG model", because it incorporates strata. The duration is from the first accident to the recurrent one. The partial likelihood function is as follows:

$$PL(\beta) = \prod_{i=1}^{n} \prod_{k=2}^{K_i} \left\{ \frac{e^{Z_i(t_{ik})\beta}}{\sum_{j=1}^{n} Y_{jk}(t_{ik}) e^{Z_j(t_{ik})\beta}} \right\} \tag{4.6}$$

where $Y_{jk}(t_{ik}) = I(t_{j,k-1} < t_{ik} \leq t_{jk})$ is a dummy variable that indicates whether the j^{th} ship of strata k is in the risk set. If accidents in the same strata have already occurred within the duration t_{ik}, then $Y_{ik}(t_{ik}) = 0$; otherwise, 1. Therefore, the risk set only includes ships that are going to have the same k^{th} accident. Compared with the AG model, in this model, the dummy variable is indexed with jk, which includes only ships within the same strata.

PWP-GT model

This model differs from the PWP-CP model with respect to the duration in the hazard function. In the PWP-CP model, the duration is from the first accident. In this model, it is from the previous accident. The partial likelihood function takes exactly the same form as that in the PWP-CP model, except that the definition of t_{ik} is the number of months from the previous accident.

4.2.3 WLW model

Like the AG model, the duration in the hazard function of this model is counted from the first accident. Like the PWP model, the WLW model uses strata to determine the risk set, but unlike the PWP model, in which only ships in the same strata are included, the WLW model includes ships from all strata. The partial likelihood function for the WLW model is as follows:

$$PL(\beta) = \prod_{i=1}^{n} \prod_{k=2}^{K_i} \left\{ \frac{e^{Z_{ik}(t_{ik})\beta}}{\sum_{j=1}^{n} \sum_{k=2}^{K_j} Y_{jk}(t_{ik}) e^{Z_{jk}(t_{ik})\beta}} \right\} \tag{4.7}$$

where $Y_{jk}(t_{ik}) = I(t_{jk} \geq t_{ik})$ indicates that the accident time of the ship in the risk set should be later than that of the ship having the accident.

When choosing from these four models to analyze recurrent ship accidents, the major differences between them that must be considered include 1) how to deal with ships that have different numbers of accidents and how to form a risk set (in the PWP [both CP and GT] model, only accidents involving ships within the same strata are included in the risk set), and 2) how to define the duration (in the AG, PWP-CP, and WLW models, the duration is from the first accident, whereas in the PWP-GT model, the duration is from the previous accident).

4.3 Chapter conclusions

Cox PH regression has been widely used in engineering, social sciences, behavioral sciences, medicine, and economics. This regression provides reliable results regardless of the probability of selecting an unsuited parametric model (Kleinbaum and Klein, 2006). In a retrospective analysis, the most important research questions are about “when” and “how long.” However, logistic regression and other regression models cannot answer such time-related questions. The Cox PH model can input the “censored” data that the multiple regression cannot involve (Guo, 2010).

Furthermore, the Cox PH model can be extended to consider the order of events needed for analysis of recurrent events. The AG model, two types of PWP models, and the WLW model are four extended Cox PH models.

The AG model treats all recurrent accidents in the same manner, which makes the statistical analysis easier but does not account for the possible effects of a previous accident on the later accidents (Box-Steffensmeier and Zorn, 2002; Lim, 2008). The PWP model is appropriate if there are strong and consistent dependencies between the previous accident and the next accident (Lim, 2008). Researchers can either select an appropriate model or use both of them, depending on their needs. The WLW model includes all ship accidents from different strata in the risk set and takes the time of their first accident as the starting point of the accident duration. Therefore, the WLW model has the highest number of ships in the risk set, which improves the significance of the statistical result. The frequency of recurrence plays a major role in model selection, particularly when the sample size is small. The AG model should be selected if the recurrent event has a high frequency, whereas the PWP model may be a better choice for low-frequency events (Lim, Liu, and Melzer-Lange, 2007). This thesis uses the basic Cox PH model and its four extended models to analyze lifespan duration and ship accident time between accidents, respectively. In particular, because the extended Cox PH models can deal with repeated events such as recurrent accidents, these four models are appropriate for analysis of recurrent ship accidents. These extended Cox PH models have been developed over the past decade. Thus, the Cox PH approach and its extended models can handle censoring data and recurrent events efficiently, and this method is a suitable statistical method for analysis of ship accident data.

References

Allison, P. D. (2014). Quantitative Applications in the Social Sciences: Event history and survival analysis. Thousand Oaks, CA, United States, SAGE Publications, Inc.

Andersen, P. K., & Gill, R. D. (1982). Cox's regression model for counting processes: a large sample study. *The Annals of Statistics*, 1100-1120.

Box-Steffensmeier, J. M., & Zorn, C. (2002). Duration models for repeated events. *The Journal of Politics, 64*(4), 1069-1094.

Cox, D. R. (1972). Regression models and life tables (with discussion). *Journal of the Royal Statistical Society, 34*, 187-220.

Cox, D. R. & D. Oakes (1984). Analysis of survival data (Monographs on statistics and applied probability 21). London, UK, Chapman and Hall.

Kleinbaum, D. G. & M. Klein (2006). Survival analysis: a self-learning text, Springer Science & Business Media.

Lim, H. J. (2008). Statistical Methodologies for Analysis of Multivariate Failure Time Data in Injury Research. In A. de Smet (Ed.), *Transportation Accident Analysis and Prevention* (pp. 25-51). New York, USA: Nova Science Publishers, Inc.

Lim, H. J., Liu, J., & Melzer-Lange, M. (2007). Comparison of methods for analyzing recurrent events data: application to the emergency department visits of pediatric firearm victims. *Accident Analysis & Prevention, 39*(2), 290-299.

Mills, M. (2011). Introducing survival and event history analysis, Sage Publications.

Prentice, R. L., Williams, B. J., & Peterson, A. V. (1981). On the regression analysis of multivariate failure time data. *Biometrika, 68*(2), 373-379.

Guo, S. (2010). ‘Survival Analysis’, Oxford University Press

Wei, W. J., Lin, D. Y., & Weissfeld, L. (1989). Regression analysis of multivariate incomplete failure time data by modeling marginal distributions. *Journal of the American statistical association, 84*(408), 1065-1073.

Chapter 5.

Duration Analysis of Service Lifespan of Ships

5.1 Introduction

In this chapter, the service lifespan of global merchant vessels is analyzed from the following aspects on the basis of previous studies: i) economic conditions of the shipping market, ii) vessel-specific attributes, iii) operational attributes, and iv) safety management attributes. The lifespan of a ship (vessel) in this thesis is defined as the duration from the delivery of the ship to its withdrawal due to scrapping or total loss. This is different from the definition of “economic” and “structural” lifespan, which requires further study in engineering or economics.

Based on this definition, the deleted ships built between January 1960 and January 2016 are analyzed using the Cox PH model (Cox and Oakes, 1984). The global financial crisis is found to have changed the way that market profitability and capital cost affect the lifespan of a vessel, particularly the capital cost, which has an opposite effect when the total loss due to accidents is included.

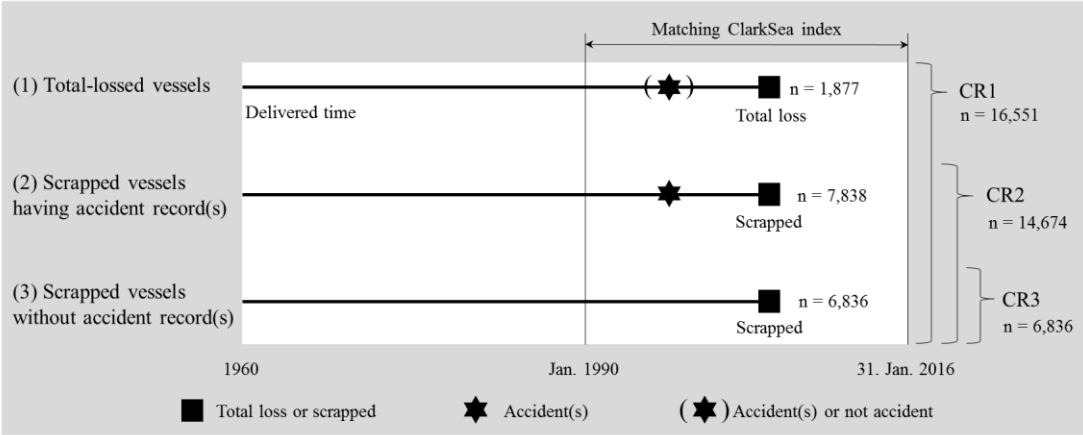
Chapter 5 is structured as follows. Section 5.2 explains the data used in the empirical analysis. Section 5.3 describes the variables that influence a vessel's lifespan and develops the relevant hypothesis. Section 5.4 presents the test results and the implications, and Section 5.5 summarizes and concludes the chapter.

5.2 Dataset

The main database for the analysis discussed in this chapter is the IHS vessel information database, which has data for 197,230 ships from 1868 to January 2016 and includes both deleted and current vessels. Vessels less than 500 GT are excluded because they are mainly fishing vessels and tugs deployed in coastwise trade (Fan *et al.*, 2014) and are exempt from ISM Code compliance (Tzannatos, 2010). They are not even required to install an AIS device according to the SOLAS Convention. Furthermore, vessels older than 55 years are excluded as outliers. A total of 97,421 vessels are included, which includes vessels built and delivered between January 1960 and January 2016 in shipyards around the world.

A ship's life can end because of total loss in an accident or its being scrapped normally. The ClarkSea index is only available from 1990, so only the ships that were destroyed after 1990 are considered in this analysis. In all, 16,551 vessels are selected, and three regression models (CR1, CR2, and CR3) are designed to analyze a ship's lifespan with or without accidental total loss and ship accidents (Figure 5-1).

Figure 5-1: Type and the number of vessels by model.



In CR1, all 16,551 vessels are selected for the region analysis to test the overall effects of different factors on their lifespan. The end-of-life events include scrapping and total loss caused by ship accidents. In CR2, only scrapped vessels (14,674) are selected, and the ships may or may not have had an accident during their lifetime. Finally, CR3 includes only vessels with no accidents in their lifetime. The descriptions of these three models and their purpose are given in Table 5-1.

Table 5-1: Three types of Cox regression by data construction.

Cox regression	Total loss	Scrapped vessels with accidents	Scrapped vessels without accidents	Purpose
CR 1	√	√	√	Testing overall impact of the included factors on the ship's service lifespan.
CR 2		√	√	Testing the impact of the variables on the scrapping age.
CR 3			√	Testing the impact of the scrapping age excluding the impact of ship accident.

5.3 Variables that influence vessels' lifespan

The lifespan of vessels is analyzed from four aspects: i) economic conditions of the shipping market, ii) vessel attributes, iii) operational attributes, and iv) safety management attributes. The variables for each aspect are shown below:

- Economic conditions of the shipping market: ClarkSea index (USD/day) and LIBOR;
- Vessel attributes: ship size, FOC, classification, building cohort period of the ship (from the 1960s to the 2010s in 10-year intervals), shipyard country, designed engine speed, and ship type;
- Operational attributes: changes in names, flags, and owners of the vessels; and
- Safety management attributes: accident and detention records of ships.

All variables except for two shipping market variables (ClarkSea Index and LIBOR) and vessel size are used as categorical variables, and one dummy variable is used to indicate a category. Missing values for each variable are classified into a group of unknowns. The distribution of the number of vessels in each data category, the number of observations, and the average vessel lifespan are summarized in Table 5-2. The justification of included variables is provided below, together with the possible hypothesis.

Table 5-2: Distribution of the number of ships, proportion, and average lifespan in three types of datasets.

			Data used in CR1			Data used in CR2			Data used in CR3		
			No. of Obs.	%	Avg. year*	No. of Obs.	%	Avg. year*	No. of Obs.	%	Avg. year*
Total			16,551	100.0	27.9	14,674	100.0	28.4	6,841	100.0	28.0
ii) Vessel attributes	FOC	Non-FOC	9,416	56.9	28.2	8,406	57.3	28.7	3,596	52.6	28.3
		FOC	6,971	42.1	27.3	6,119	41.7	27.8	3,099	45.3	27.6
		Unknown	164	1.0	30.1	149	1.0	30.1	146	2.1	30.1
	IACS	Non-IACS	2,203	13.3	29.4	1,886	12.9	30.3	924	13.5	29.2
		IACS	5,488	33.2	26.6	5,090	34.7	27.0	2,384	34.8	26.6
		Unknown	8,860	53.5	28.3	7,698	52.5	28.8	3,533	51.6	28.7
	Built of year	1960s	2,743	16.6	33.2	2,410	16.4	33.1	1,390	20.3	32.5
		1970s	7,602	45.9	28.5	6,800	46.3	28.9	2,822	41.3	28.7
		1980s	4,623	27.9	26.8	4,123	28.1	27.5	1,803	26.4	27.4
		1990s	1,450	8.8	19.5	1,298	8.8	20.1	789	11.5	19.9
		2000s	121	0.7	8.3	42	0.3	12.3	36	0.5	12.0
		2010s	12	0.1	2.7	1	0.0	5.8	1	0.0	5.8
	Shipyard country	Miscellaneous	2,345	14.2	26.9	2,039	13.9	27.5	1,110	16.2	27.5
		Europe	6,266	37.9	29.3	5,552	37.8	29.6	2,329	34.0	29.3
		North America	354	2.1	33.4	342	2.3	33.4	109	1.6	36.4
		Japan	6,270	37.9	27.4	5,575	38.0	27.9	2,644	38.6	27.7
		Korea(South)	825	5.0	24.2	758	5.2	24.7	361	5.3	24.0
		China	491	3.0	22.2	408	2.8	24.1	288	4.2	24.3
	Designed engine speed	Slow	9,312	56.3	26.7	8,830	60.2	26.9	4,209	61.5	26.6
		Medium	4,142	25.0	29.3	3,249	22.1	30.8	1,391	20.3	30.1
		High	349	2.1	28.0	228	1.6	30.8	105	1.5	27.8
		Unknown	2,748	16.6	29.9	2,367	16.1	30.3	1,136	16.6	30.6
	Vessel type	Bulker	4,587	27.7	27.4	4,266	29.1	27.7	2,078	30.4	27.2
		Container	1,410	8.5	24.9	1,352	9.2	25.2	736	10.8	24.6
		General cargo	6,529	39.4	29.2	5,255	35.8	30.3	2,822	41.2	29.8
		Tanker	4,025	24.3	27.3	3,801	25.9	27.5	1,205	17.6	27.4
iii) Operational attributes	Vessel name	No change	2,383	14.4	25.2	2,089	14.2	26.4	1,363	19.9	26.4
		Changed	14,168	85.6	28.3	12,585	85.8	28.7	5,478	80.1	28.4
	Vessel flag	No change	6,595	39.8	27.3	5,886	40.1	28.0	2,385	34.9	27.5
		Changed	9,790	59.2	28.2	8,637	58.9	28.6	4,309	63.0	28.2
		Unknown	166	1.0	30.0	151	1.0	30.0	147	2.1	30.0
	Vessel owner	No change	640	3.9	23.1	518	3.5	24.6	335	4.9	24.4
		Changed	2,809	17.0	25.2	2,457	16.7	25.9	1,249	18.3	25.5
		Unknown	13,102	79.2	28.7	11,699	79.7	29.1	5,257	76.8	28.8
iv) Safety management attributes	Accident	No accident	6,846	41.4	28.0	6,841	46.6	28.0	6,841	100.0	28.0
		Once (severe)	3,823	23.1	26.9	2,528	17.2	28.9	-	-	-
		Once (no severe)	1,501	9.1	28.0	1,500	10.2	28.0	-	-	-
		Recurrent accident	4,381	26.5	28.5	3,805	25.9	28.8	-	-	-
	Detention	No	8,741	52.8	26.8	7,651	52.1	27.4	3,772	55.1	27.3
		Once	2,597	15.7	27.3	2,358	16.1	27.6	1,118	16.3	27.3
		More than once	5,031	30.4	30.2	4,533	30.9	30.4	1,857	27.1	30.0
		Unknown	182	1.1	23.0	132	0.9	24.8	94	1.4	25.0

* Average service lifespan of vessels.

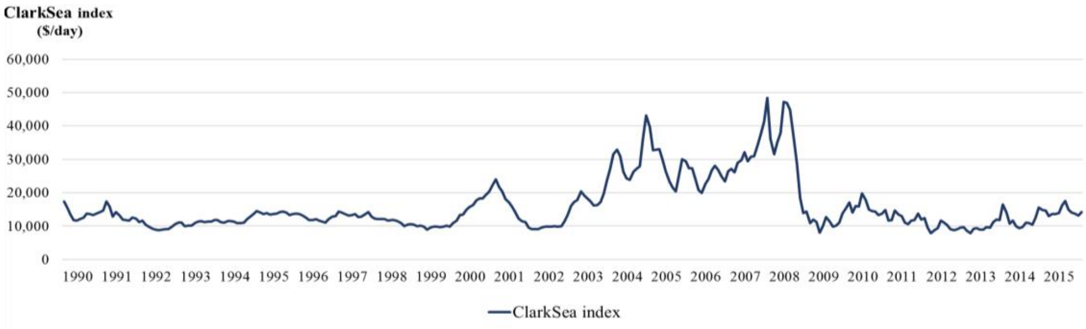
5.2.1 Economic condition of the shipping market

Two variables are included to reflect the shipping market conditions at the end of a ship's life due to total loss or scrapping: the ClarkSea index and LIBOR. The former indicates the earning capacity of the ship, and the latter represents the change in a ship's capital cost.

ClarkSea

ClarkSea Index (USD/day) is published by Clarkson's Research Limited as a proxy shipping market indicator. Figure 5-2 presents the change in the index from 1990 to 2015. This index has been widely used in previous studies to indicate profitability in the shipping industry (Grammenos *et al*., 2007), as an industry-specific factor in ship credit analysis (Kavussanos and Tsouknidis, 2014), and to calculate the operating cash flow of a shipping company (Drobetz *et al*., 2016). With respect to the relationship between ClarkSea index and ship scrapping, Stopford (2009) stated that relatively few ships are scrapped in a booming market, and Farthing and Brownrigg (1997) found more ship demolitions when the profitability of shipping companies was low. From the above, it can be postulated that the lifespan of a ship may be positively related with the ClarkSea index.

Figure 5-2: ClarkSea index.



Note: Author’s own figure based on Clarkson data

<u>LIBOR</u>

LIBOR refers to the interest rate when one bank borrows money from another. It is also the basis for the ship mortgage rate (Verny and Grigentin, 2009). It has been used as an explanatory variable for analysis of the price of secondhand vessels (Tsolakis *et al*., 2003; Merikas *et al*., 2008): the higher the interest rate, the higher the capital cost and the lower the liquidity of most ship owners. Because both can reduce the capability of a ship owner to replace his existing ship with a new one, it is postulated that an increase in LIBOR can increase the lifespan of a vessel. The monthly LIBOR data were obtained from Datastream International (as of January 4, 2017) as the average of the previous 3-month LIBOR rates.

To examine the different effects of these two shipping market conditions (i.e., ClarkSea index and LIBOR) before and after the 2008 global financial crisis, a dummy variable, D2008, is introduced to form an interactive variable with the two conditions.

5.2.2 Vessel-specific attributes

Vessel size

The vessel size can affect a ship's lifespan from four aspects. 1) A large ship usually requires a high capital cost. Therefore, it is more difficult to replace an aged ship with a new one. Therefore, the decision to scrap it may be more difficult than the decision to build a new ship. 2) Because of the relatively high capital cost, a ship owner may extend the ship's life by taking better care of the ship. 3) Large ships can enjoy economies of scale in case of their high demand. When the demand is low, however, it is difficult to enjoy such an advantage. In this case, it is possible that the owner may end its life earlier. 4) Some large ships (i.e., LNG vessels) are usually equipped with better technology and navigational devices that enable them to avoid dangerous weather conditions and thus shipping accidents. However, it can also be argued that larger ships may be more inclined to meet with accidents because of their poor maneuverability (Li *et al*., 2014). Therefore, in this analysis, the logarithm of the gross tonnage is used as an indicator of ship size to test the effect of vessel size on the lifespan of the ship.

FOC vessel

Being registered in FOC countries can affect a ship's lifespan from two aspects: accidents and scrapping. Previous studies have found that such vessels are more likely to meet with accidents (Luo *et al*., 2013; Fan *et al*., 2014) and are usually relatively substandard (Li and Wonham, 1999). Knapp, Kumar, and Remijn (2008) also found that a flag can be an important indicator of the probability of being scrapped. Therefore, this analysis tests whether FOC also leads to a shorter ship lifespan. In all, 34 countries are on the FOC list according to the ITF website.

Classification society

Ship classification is an important measure to ensure the standard and seaworthiness of a ship. The IACS members are said to have a high standard for the vessels that bear their certificate. Therefore, some researchers have argued that ships classified by IACS should have a longer life (Paik, Kim, and Lee, 1998). Furthermore, many studies have used this variable to examine its effect on the probability of a ship accident (Knapp, Bijwaard, and Heij, 2011; Luo and Shin, 2017). Because a vessel's classification can change during its lifespan, this study considers the classification when the ship is at the end of its lifetime. It is postulated that IACS-classified ships last longer.

Building cohort period

A building cohort period refers to the decade from 1960 to 2010 when the ship was built. The hypothesis is that the recent technological progress in shipyards may enable the ships built recently to last longer. However, the opposite result is also possible because in this analysis, only vessels that met with at least one accident are considered. Therefore, in the data selected, the newly built vessels have a relatively short lifespan.

Shipyard country

The performance and technology of shipyards are often country specific because of their shipbuilding history (Floriano, Lamb, and Souza, 2009). Therefore, we can reasonably assume that ships built in different countries may have different levels of quality, which may affect their lifespan. All shipbuilding countries are categorized into six groups: Europe, North America, Japan, Korea (South), China, and miscellaneous countries. The Europe group includes the following countries: Austria, Belgium, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Italy, the Netherlands, Norway, Poland, Portugal, Russia, Spain, Sweden, Turkey, and United Kingdom. Ships built in a country with a longer shipbuilding history, such as Japan and the European and North American countries, are expected to have a longer lifetime.

Engine speed

A vessel's engine speed may have an indirect effect on its lifespan. Endresen *et al*. (2003) found that high-speed engines consume more fuel and have high operating costs. High-speed engines are also related to greater emissions (Deniz and Durmuşoğlu, 2008). These vessels are not optimal to keep in an active working fleet because of their high fuel costs and environmental considerations. Therefore, it is postulated that a vessel with a high engine speed may have a relatively short lifespan.

Ship types

To check for an intrinsic effect of different ship types on the vessel lifespan, this analysis considered four dummy variables, namely, bulker, container, general cargo, and tanker, to indicate four ship categories. According to the statistics presented in Table 5-3, the scrapping age for these four categories is as follows: general cargo vessels > (bulker/tanker) > container vessels. Therefore, the type-specific effect is expected to follow the same order. Gas tankers and ULCV are excluded because of their small sample size; small ships (smaller than a handysize vessel or a feeder containership) are also excluded.

Table 5-3: Service lifespan for different ship types (years).

	Bulker	Container	General cargo	Tanker
CR1	27.4	24.9	29.2	27.3
CR2	27.7	25.2	30.3	27.5
CR3	27.2	24.6	29.8	27.4

5.2.3 Operational attributes

Changing name/flag/owner of vessels

The name, ownership, and flag of many vessels change during their lifetime for various reasons (Timmermann and McConville, 1996). Bijwaard and Knapp (2009) used two types of changing record variables for an analysis of ship accidents: ownership change and flag change. They found that such changes may indicate the underlined safety hazard, which may reduce the lifespan of the ship, leading to either total loss due to an accident or earlier scrapping. This thesis considers all these changes in Chapter 5 and postulates that vessels that have a record of flag, name, and ownership changes may have a relatively short lifespan.

5.2.4 Safety management attributes

Accident records

Many ships can have one or more accidents in their lifetime (Luo and Shin, 2017). Ship accidents affect the vessel's seaworthiness (Talley, 1999; 2002) if the vessel is not adequately repaired. Therefore, vessels with previous accidents are normally treated as unsafe and may have a relatively short lifetime. Therefore, the hypothesis is that vessels with an accident record, particularly severe accidents, are more likely to have a shorter lifespan.

Detention records

Foreign ships are subjected to a PSC inspection on maritime safety standards by coastal states. Vessels will be detained if they have serious defects and require immediate repair. Detained vessels are regarded as substandard ships (Li and Zheng, 2008). Ship owners and management companies avoid detention because of the additional expenses and the possibility of future inspections (Heij *et al*., 2011). However, ship owners must repair the ship and address the defects before the detained ship can set sail again. Therefore, the hypothesis is that having a detention record may extend the lifetime of the ship.

The average lifespan in the dataset for CR1 is lower than that of CR2 and CR3, because CR1 includes total losses. An interesting observation is that the average scrapping age in the dataset for CR3 is shorter than that for CR2, which contains vessels with accident records. A possible explanation for this observation is that ships with previous accident(s) have been repaired to a better condition, which may extend their lifetime.

5.4 Results

This section presents the regression results from three Cox PH regression models and for different ship types. Table 5-4 provides the regression results for the estimated coefficients and their significance level and the significance of each equation for the three models. The LR statistics of the three models clearly indicates an overall high goodness-of-fit, and the likelihood ratio of all models is significant. The explanatory power, as indicated by the R^2 statistic, is greater than 70% for all the three models.

A positive coefficient of a variable indicates that an increase in the variable value or being in that category will increase the hazard or probability for the vessel's life to be ended earlier. Therefore, positive coefficients imply a short lifespan, whereas negative ones indicate a long lifespan. Next, we will look at the results of each variable.

Table 5-4: Results of the three models for all vessels.

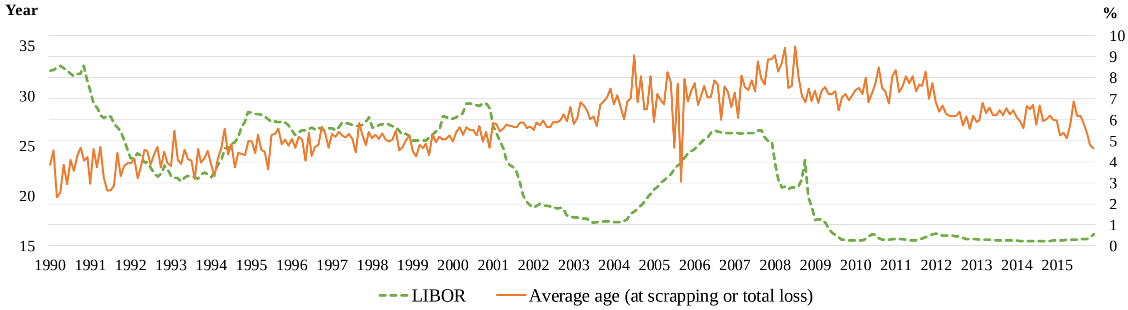
Covariate			CR 1	CR 2	CR 3
Economic condition attributes	ClarkSea (1,000 $/Day)		-0.052 ***	-0.056 ***	-0.058 ***
	LIBOR		0.255 ***	0.249 ***	0.256 ***
	ClarkSea × D2008		-0.103 ***	-0.109 ***	-0.102 ***
	LIBOR × D2008		-0.136 ***	0.092 **	0.028
Vessel attributes	Vessel size (*ln* GT)		0.297 ***	0.364 ***	0.324 ***
	FOCs (†Non-FOCs)	FOCs	0.059 ***	0.057 **	0.092 ***
		Unknown	-0.150	-0.260	-1.241
	IACS (†Non-IACS)	IACS	0.181 ***	0.218 ***	0.207 ***
		Unknown	0.204 ***	0.244 ***	0.251 ***
	Built of year (†1960s)	1970s	1.660 ***	1.578 ***	1.521 ***
		1980s	3.217 ***	3.036 ***	3.066 ***
		After 1990s	6.013 ***	6.051 ***	6.100 ***
	Shipyard country (†Miscellaneous)	Europe	-0.214 ***	-0.249 ***	-0.174 ***
		North America	-0.986 ***	-1.156 ***	-1.374 ***
		Japan	-0.123 ***	-0.198 ***	-0.118 **
		Korea (South)	-0.026	-0.096 **	-0.061
		China	0.072	-0.036	-0.048
	Designed engine speed (†Slow)	Medium	0.131 ***	0.100 ***	0.106 **
		High	0.178 **	0.364 ***	0.592 ***
		Unknown	-0.123 ***	-0.153 ***	-0.177 ***
	Vessel type (†Bulker)	Container	0.268 ***	0.341 ***	0.401 ***
		General cargo	0.236 ***	0.226 ***	0.259 ***
		Tanker	0.205 ***	0.275 ***	0.262 ***
Operational attributes	Vessel name (†No change)	Changed	-0.165 ***	-0.112 ***	-0.145 ***
	Vessel flag (†No change)	Changed	-0.028	-0.051 **	-0.046
		Unknown	0.017	0.194	1.206
	Vessel owner (†Not change)	Changed	-0.200 ***	-0.255 ***	-0.251 ***
		Unknown	-0.174 ***	-0.206 ***	-0.191 **
Safety management attributes	Accident record (†No accident)	Accident once (severe)	0.087 ***	-0.064 **	
		Accident once (non-severe)	0.040	-0.042	
		Recurrent accident	0.031	-0.026	
	Detention Record (†No detention)	Detained once	-0.154 ***	-0.115 ***	-0.134 ***
		Detained above once	-0.306 ***	-0.252 ***	-0.263 ***
		Unknown	1.333 ***	1.234 ***	0.910 ***
	Number of observations		16,551	14,674	6,841
	Likelihood Ratio		20148***	17985***	8570***
	Generalized (Cox-snell) R^2		0.704	0.706	0.714

Notes: † Benchmark class; ***$P \leq 0.01$, **$P \leq 0.05$, *$P \leq 0.1$
CR3 has no accidents record

The coefficients of ClarkSea and ClarkSea×Dummy_2008 are negative and significant, indicating that a booming shipping market extends a ship's life and a sluggish market shortens it. This finding is consistent with that of Knapp, Kumar, and Remijn (2008). Note that after the global financial crisis (in 2008), the coefficients are more negative, indicating that the change in the earning power during the considered period has an even bigger effect on a ship's lifespan than that before 2008.

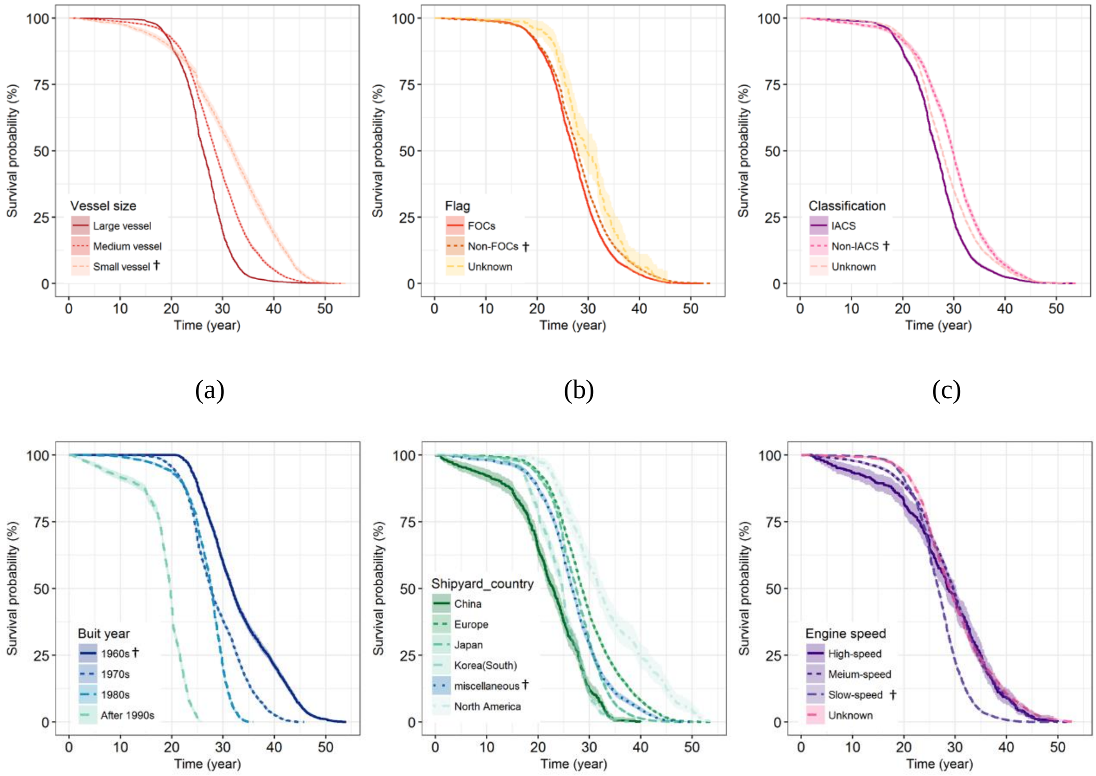
The effect of capital cost (LIBOR) has different signs before and after the global financial crisis for CR1, but not for CR2. Figure 5-3 presents the changes in LIBOR and the average lifespan for the period 1990 to 2015, which are volatile and showed an increasing trend before the global financial crisis. However, LIBOR is not volatile and showed a decreasing trend during the same period. Therefore, before the global financial crisis, the estimated coefficient is positive and significant, which implies that a high LIBOR can result in a short ship lifespan. A possible explanation for this correlation is that a high capital cost may reduce the capacity of the ship owner to invest in shipbuilding. Thus, ship owners would maintain their existing fleet or sell their vessels for scrap to secure financial power, which can result in the short lifetime. However, the coefficient of LIBOR×Dummy_2008 is negative and significant for CR1, indicating that a lower capital cost can result in a shorter ship lifespan. Because CR1 includes the total losses due to ship accidents, a possible explanation is that a low capital cost shortens the lifespan by increasing the accidental losses. In the case of CR2, the estimated coefficients are both positive, although they are considerably smaller after the global financial crisis. This finding reflects that ship owners had lower capital power after the crisis than before. In the case of CR3, no significant effect on the lifespan of a ship was observed before and after the global financial crisis.

Figure 5-3: Historical trend of LIBOR and average age of vessels.



With respect to the vessel-specific attributes, the survival probabilities of continuous variable vessel size and the other five categorical variables (FOC, IACS, building cohort period, shipyard country, and engine speed) are plotted in Figure 5-4. The estimated ship size is positive and significant, indicating that larger ships have a shorter lifespan. As shown in Figure 5-4(a), the survival curve of the largest vessel is the lowest. This result is similar to that of earlier research (Mikelis, 2008) that smaller ships have a longer lifespan. This finding is also consistent with the expectation on the ship size when the shipping market is sluggish.

Figure 5-4: Survival curve of vessel-specific characteristics (case of CR 1).



(a) (b) (c)

(d) (e) (f)

Note: † BM: Benchmark class

The estimated coefficient of FOC is positive and significant, indicating that ships registered in FOC countries have shorter lifespans. This result is the same as the result that revealed that the average lifespan of a non-FOC vessel is slightly higher than that of an FOC vessel (Table 5-2).

Unexpectedly, the estimated coefficient of IACS is positive and significant, indicating that ships classified by IACS members have a shorter lifespan. The statistics presented in Table 5-2 also show that the average lifespan for IACS vessels is 3 years shorter than that of the non-IACS vessels. A possible explanation of this finding is that when a ship cannot meet the classification criteria of IACS members, many shipping companies may consider scrapping it rather than getting a certificate from non-IACS members, because it is considered unsafe to run a substandard ship.

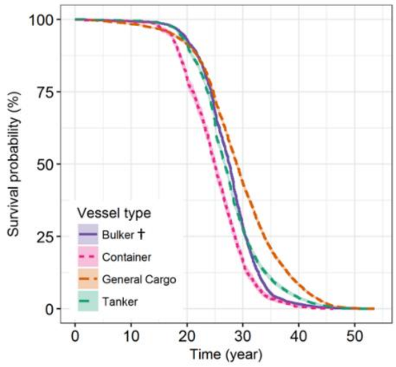
The regressed coefficients of the building cohort period are all positive and significant, and their values are larger for the newly built vessels. This finding is against the expectation that newer vessels may last longer because of the better shipbuilding technology available today. This result can also be attributed to the sample data problem: in this study, ships scrapped after 1990 were considered because of the unavailability of the ClarkSea index before 1990, and ships scrapped after 2000 are included in the "After 1990s" category because of the relatively few observations. This consideration resulted in the finding that scrapped vessels built in the 1990s have a shorter lifespan.

With respect to the shipyard country, the estimates for Japan and the North American and European countries are all negative and significant, whereas those for South Korea and China are not significant. This result is consistent with the expectation that countries with better technology and a longer shipbuilding history may build ships with a longer lifespan.

With respect to the designed engine speed, ships with slow-speed engines have a longer lifespan than those with medium- and high-speed engines. This finding agrees with the expectation that ships with high-speed engines may be replaced earlier because of their high fuel consumption rate and emission.

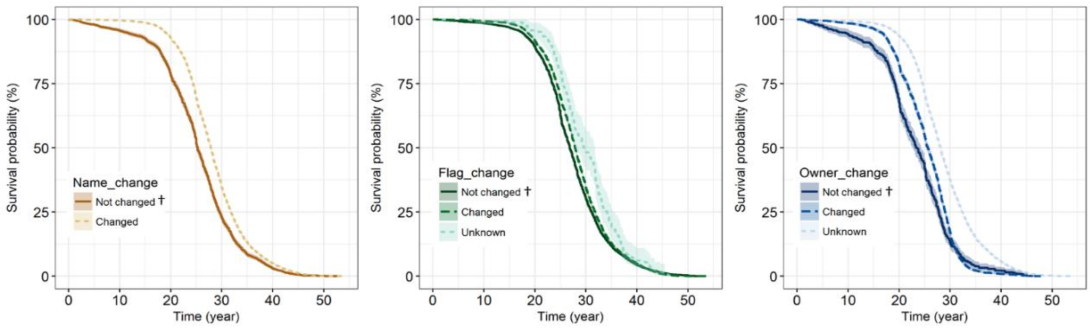
The estimated coefficients of the ship types are all positive and significant. Compared with bulkers, containers, general cargoes, and tankers have relatively short lifespans. Container vessels have the shortest lifespan, which is consistent with the expectation. The survival probability curves for these four different ship types are shown in Figure 5-5.

Figure 5-5: Survival curve by ship type.



Note: † Benchmark class

Figure 5-6: Survival curve of operational predictor variables (case of CR 1).



(a) (b) (c)

Note: † Benchmark class

The estimated coefficients of vessel name, flag, and ownership changes are negative and significant. This result is consistent with the survival probability (Figure 5-6) for different categories. Vessels that had name/owner changes have a longer duration, whereas flag changes had no significant effect except in the case of CR2. This was unexpected. However, the data (Figure 5-7) reveal that most of the name/flag/ownership changes were related to the relatively old vessels. Because the analysis discussed in this chapter considers the end-of-life vessels after 1990, vessels with operational attribute changes were found to have longer lifespans than the newer vessels.

Figure 5-7: Distribution of name, flag, and ownership changes by ship delivery year.

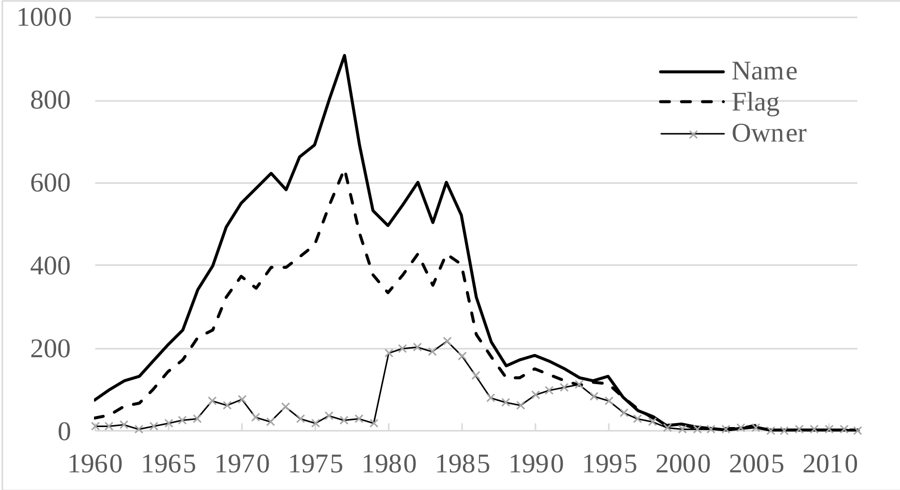
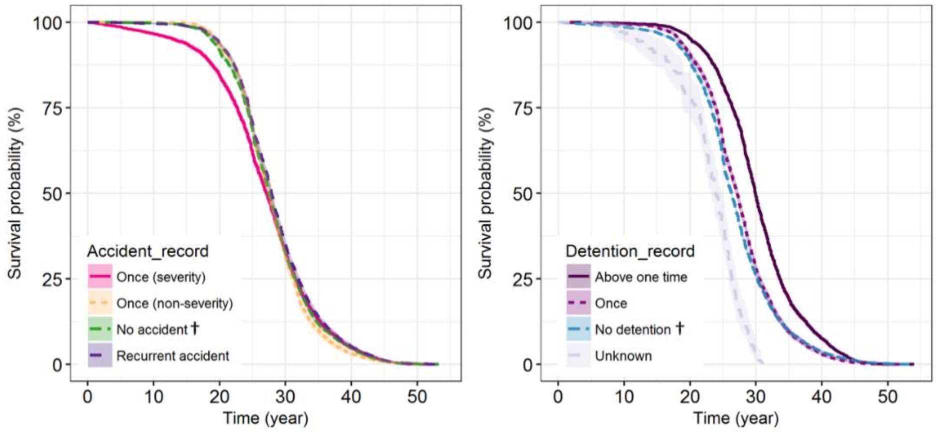


Figure 5-8: Survival curve of safety management variables (case of CR 1).



(a) (b)

Note: † BM: Benchmark class

With respect to the safety management attributes, as shown in Figure 5-8, in the case of CR1, vessels that met with a severe accident had a relatively short lifetime, whereas in the case of CR2, involvement in a severe accident led to a longer lifetime. The results related to the safety management attributes in the case of CR1 are reasonable, because most severe accidents can result in total loss; further, accident-related losses are included in the dataset. For the latter (in the case of CR2), because total losses due to ship accidents are not included, the result indicates that the effort required to repair the ship after the accident makes the ship last longer.

The estimated coefficients of ships with a detention record of once or more than once are all negative and significant, indicating the positive effect of ship detention on improving the safety standard and showing that this extended the ship's life.

5.5 Chapter conclusions

In this chapter, the lifespan of global merchant ships built since 1960 and destroyed after 1990 is analyzed using the Cox PH model. The analysis considers four aspects: i) economic conditions of the shipping market, ii) vessel-specific attributes, iii) operational attributes, and iv) safety management attributes. The major findings are summarized below:

- A booming market extended ship lifespan, and low profitability shortened the lifespan, particularly after the global financial crisis.
- In general, an increase in the financial cost (capital cost) shortened ship lifespan before the global financial crisis (year 2008). Thereafter, a lower financing rate shortened ship lifespan mainly because of the total loss incurred due to an accident. Excluding total loss, an increase in the financial cost had less of an effect on shortening the lifespan.
- In general, larger ships, ships flying an FOC flag, IACS-classified ships, and ships with high/medium engine speeds, have relatively short lifespans. Ships

built in Europe, North America, and Japan serve longer than those built elsewhere.

- Vessels with a record of name/flag/owner changes usually have longer lifespans.
- Severe accidents can reduce the overall lifespan of a ship. However, the repairs carried out after a severe accident can extend the ship's life.
- Having a detention record can extend the life of a ship.

The results presented in this chapter can provide useful inputs for decision makers in both private businesses and public agencies with respect to maritime safety administration. For private business, the potential life of a ship is very important information for making many decisions related to the ship, such as a secondhand transaction, continuous investment in the ships' maintenance and repair, insurance, chartering contract, and scrapping.

References

Ayyub, B. M. (1989). Estimation of structural service life of ships. *Naval engineers journal*, *101*(3), 156-166.

Ayyub, B. M., K. A. Stambaugh, T. A. McAllister, G. F. de Souza & D. Webb (2015). Structural Life Expectancy of Marine Vessels: Ultimate Strength, Corrosion, Fatigue, Fracture, and Systems. *ASCE-ASME Journal of Risk and Uncertainty in Engineering Systems, Part B: Mechanical Engineering*, *1*(1), 011001.

Ayyub, B. M. & G. J. White (1990). Life expectancy assessment of marine structures. *Marine Structures*, *3*(4), 301-317.

Benavides, S. (2010). Survival analysis of aging aircraft, The George Washington University.

Bijwaard, G. E. & S. Knapp (2009). Analysis of ship life cycles—The impact of economic cycles and ship inspections. *Marine Policy*, *33*(2), 350-369.

Cox, D. R. & D. Oakes (1984). Analysis of survival data (Monographs on statistics and applied probability 21). London, UK, Chapman and Hall.

Deniz, C. & Y. Durmuşoğlu (2008). Estimating shipping emissions in the region of the Sea of Marmara, Turkey. *Science of the Total Environment*, *390*(1), 255-261.

Drobetz, W., R. Haller & I. Meier (2016). Cash flow sensitivities during normal and crisis times: Evidence from shipping. *Transportation Research Part A: Policy and Practice*, *90*, 26-49.

Endresen, Ø ., Sørgård, E., Sundet, J.K., Dalsøren, S.B., Isaksen, I.S.A., Berglen, T.F., Gravir, G., 2003. Emission from international sea transportation and environmental impact. *Journal of Geophysical Research*, *108* (D17), 45-60.

Fan, L., M. Luo & J. Yin (2014). Flag choice and Port State Control inspections-Emprical evidence using a simultaneous model. *Transport Policy*, *35*, 350-357.

Farthing, B. & M. Brownrigg (1997). Farthing on international shipping, Informa Pub.

Grammenos, C. T., A. H. Alizadeh & N. C. Papapostolou (2007). Factors affecting the dynamics of yield premia on shipping seasoned high yield bonds. *Transportation Research Part E: Logistics and Transportation Review*, *43*(5), 549-564.

Heij, C., G. E. Bijwaard & S. Knapp (2011). Ship inspection strategies: Effects on maritime safety and environmental protection. *Transportation research part D: transport and environment*, *16*(1), 42-48.

Jiang, H. (2013). Key findings on airplane economic life. Boeing Commercial Analysis. Boeing.

Floriano, P. Jr., T. Lamb & C. Souza (2009). Shipbuilding performance benchmarking. *International Journal of Business Performance Management*, *11*(3), 216-235.

Kavussanos, M. G. & D. A. Tsouknidis (2014). The determinants of credit spreads changes in global shipping bonds. *Transportation Research Part E: Logistics and Transportation Review, 70,* 55-75.

Knapp, S., G. Bijwaard & C. Heij (2011). Estimated incident cost savings in shipping due to inspections. *Accident Analysis & Prevention*, *43*(4), 1532-1539.

Knapp, S., S. N. Kumar & A. B. Remijn (2008). Econometric analysis of the ship demolition market. *Marine Policy*, *32*(6), 1023-1036.

Li, K. & J. Wonham (1999). Who is safe and who is at risk: a study of 20-year-record on accident total loss in different flags. *Maritime Policy & Management*, *26*(2), 137-144.

Li, K. X., J. Yin & L. Fan (2014). Ship safety index. *Transportation research part A: Policy and Practice*, *66*, 75-87.

Li, K. X. & H. Zheng (2008). Enforcement of law by the Port State Control (PSC). *Maritime Policy & Management*, *35*(1), 61-71.

Luo, M., L. Fan & K. Li (2013). Flag choice behaviour in the world merchant fleet. *Transportmetrica A: Transport Science*, *9*(5), 429-450.

Luo, M., S.H. Shin & Y.T. Chang (2017). Duration Analysis for Recurrent Ship Accidents. *Maritime Policy & Management, 44*(5), 603-622.

Merikas, A. G., A. A. Merika & G. Koutroubousis (2008). Modelling the investment decision of the entrepreneur in the tanker sector: choosing between a second-hand vessel and a newly built one. *Maritime Policy & Management*, *35*(5), 433-447.

Mikelis, N. E. (2008). A statistical overview of ship recycling. *WMU Journal of Maritime Affairs*, *7*(1), 227-239.

Paik, J. K., S. K. Kim & S. K. Lee (1998). Probabilistic corrosion rate estimation model for longitudinal strength members of bulk carriers. Ocean Engineering, *25*(10), 837-860.

Stopford, M. (2009). MaritimeEeconomics 3e, Routledge.

Talley, W. K. (2002). Non-seaworthy risks of bulk ship accidents. *International Journal of Transport Economics/Rivista internazionale di economia dei trasporti*, 3-15.

Talley, W. K. (1999). Determinants of ship accident seaworthiness. *International Journal of Maritime Economics, 1*(2), 1-14.

Timmermann, K. & J. McConville (1996). An analysis of the quality redistribution of dry Capesize tonnage. *Maritime Policy & Management*, *23*(1), 45-53.

Tsolakis, S., C. Cridland & H. Haralambides (2003). Econometric modelling of second-hand ship prices. *Maritime Economics & Logistics*, *5*(4), 347-377.

Tzannatos, E. (2010). Human element and accidents in Greek shipping. *Journal of Navigation*, *63*(1), 119-127.

Verny, J. & C. Grigentin (2009). Container shipping on the northern sea route. *International Journal of Production Economics*, *122*(1), 107-117.

Chapter 6.

Duration Analysis of Recurrent Ship Accidents

6.1 Introduction

Numerous studies have analyzed the major factors involved in ship accidents, as surveyed in detail by Luo and Shin (2016). However, no studies in the literature have targeted recurrent accidents, in spite of their high proportion among all accidents. To fill this gap, this thesis examines the major factors involved in recurrent accidents, by focusing on the duration between accidents occurring to the same ship. More specifically, it examines when the first accident occurs, and how soon recurrent accidents ensue after the previous ones. In addition, several vessel characteristics and market conditions are investigated to test if and how they affect the timing of recurrent accidents. For instance, this thesis examines whether the age, size, registry type and detention record of ships in any way affect the timing of recurrent accidents. Moreover, it assesses whether bunker price, world fleet size (ship demand and supply condition) and charter rate, newbuilding price as well as shipbuilding country, affect accidents or not. These factors were identified in existing studies as being related to ship accidents, and this chapter tries to check what bearing they have on recurrent accidents.

The chapter is structured as follows: Section 6.2 describes major factors that influence recurrent accidents and the relevant hypothesis. Section 6.3 explains the data used in the empirical analysis. Section 6.4 presents the results and discusses, and Section 6.5 concludes the chapter.

6.2 Variables influencing recurrent ship accidents

This section describes the potential factors grounded in the literature with regard to first and recurrent ship accidents, and develops the relevant hypotheses for empirical test. These major factors can be classified as ship level factors (vessel attribute factors, others) and industry level factors (ship supply factors, shipping market factors).

6.2.1 Ship level factors - vessel attributes

The nature of a vessel, such as ship age, ship size, shipbuilding country, and ship registry may affect the duration to an accident. Therefore, this chapter tests the impacts of these variables on the duration before both the first and recurrent accidents. Various studies that will be presented in this sub-chapter have already used ship level factors with regard to ship safety, ship inspection and ship accidents. These previous studies provide the basis for building following hypotheses.

Ship age

Ship age has been identified as having a significant positive relationship to the probability of ship accidents (Talley 1995b; Talley, 2001; Roberts and Marlow, 2002; Knapp and Franses, 2007; Tzannatos, 2010). Li, Yin and Fan (2014), however, argued that vessel age can also be negatively correlated with ship accidents causing mechanical failures, as vessels that have been served for a long time are usually of high quality and have been well maintained.

In this chapter, ship age is conducted at three different accidents: *Ship age at first accident* (Age1), *at the previous accident* (AgeP), and *at the recurrent accident* (AgeR). After a new ship has its first accident, it is natural to expect that the ship owner will invest more to repair the ship. Therefore, a smaller Age1 may be followed by a longer duration before a recurrent accident. Likewise, for any accident happening at an early age, the ship owner would likely behave in the same way. Therefore, AgeP should have the same sign as Age1. On the other hand, AgeR should have a negative relationship with recurrent accidents, as a large AgeR means that the recurrent accident has occurred after a long time and so it is a lower risk. Since ship age is used as the duration to the first accident, it is not included in the analysis of the first accident.

Ship size

Ship size is used in the basic Cox PH model and extended four models. Li, Yin, and Fan (2014) found that large ships tend to have more accidents, due to their poor maneuverability. However, Talley (1999) found that larger ships shows lower accident rate after an accident because of better maintenance through repairing of ship. Therefore, the hypothesis is that ship size has an impact on the duration to a ship accident, but the sign of its impact needs to be determined from observed accident data.

FOC vessel

Ships registered in FOC countries[7] have been considered as 'risky' vessels because of various flexibilities allowed under these flag states (Luo, Fan, and Li, 2013; Fan, Luo and Yin, 2014), such as the ability to avoid strict regulations, escape national taxation, hide true identities, and cut costs on manning, as well as save on many other items (Metaxas, 1981; Thuong, 1987; Bergantino and Marlow, 1998). These may increase the probability of ship accidents, although Li, Yin, and Fan (2014) found that vessels flying a national flag are safer. Therefore, the hypothesis is that FOC ships may have a shorter duration to ship accidents.

Detention

The detention record of a ship has been used by Bijwaard and Knapp (2009) and Heij, Bijwaard, and Knapp (2011) in studying the major factors in ships' life cycle, maritime safety and environmental protection. Normally, a detention record is supposed to make the ship safer, as it forces ship owners to repair the problems the

[7] The 34 countries that have been declared FOCs by the ITF (International Transport Worker's Federation) are as follows: Antigua and Barbuda, Bahamas, Barbados, Belize, Bermuda (UK), Bolivia, Burma, Cambodia, Cayman Islands, Comoros, Cyprus, Equatorial Guinea, Faroe Islands (FAS), French International Ship Register (FIS), German International Ship Register (GIS), Georgia, Gibraltar (UK), Honduras, Jamaica, Lebanon, Liberia, Malta, Marshall Islands (USA), Mauritius, Moldova, Mongolia, Netherlands Antilles, North Korea, Panama, Sao Tome and Príncipe, St Vincent, Sri Lanka, Tonga, and Vanuatu.

ship has. However, they found that past detention contributes to increasing the incident rate of dry bulker and passenger vessels. The hypothesis is that ship detention affects the duration to a ship accident, but its sign will be determined by statistical analysis.

Shipbuilding country

As shown in Chapter 5, the ships building in different countries may have different quality, which may also affect their accidents risk. In this chapter, all the shipbuilding countries are categorized into five groups: Europe, Japan, Korea (South), China, and miscellaneous country. The accidents record of North America vessels are included in the miscellaneous country due to their small size of data. An assumption is that each country has different shipbuilding technologies, which may affect the quality of the ship and affect the duration to an accident. Especially, Japan, Korea (South), and China are the top 3 shipbuilding countries in the world. Normally, it is expected that Japan and Korea may build better ships. Therefore, the hypothesis is that better built ships have longer duration to ship accidents.

6.2.2 Ship level factors - other factors of ship level

Type of accidents

This is used in the analyses of both the first and recurrent accidents, but for different purposes. For the former, it is used to test which accident type will happen soonest after delivery of the ships. In the latter, it is used to test the possible impact of a previous accident on the duration to a recurrent accident. Ship accidents are categorized into three groups:

- Navigational accident: Collision, contact, wrecked, and foundered;
- Structural failures: Hull and machine damage;
- Miscellaneous: Fire and explosion, missing, war loss and hostilities.

Two dummy variables are introduced to identify accident types, and the last category is used as a benchmarking category.

Ship type

The duration to recurrent ship accidents may change by ship type. To test this, 3 dummy variables are used to indicate 4 types of merchant ships: bulker (drybulk carrier), container ship, general cargo ship, and tanker (except for gas tanker). As shown in Chapter 5, Gas tankers, ULCV, and small size ships (smaller than a Handysize vessel or Feeder containership) are excluded with the same reasons in Chapter 5.

6.2.3 Industry level factors - ship supply factors

External conditions, such as bunker price and the size of the global shipping fleet can affect the supply of shipping services, which in turn can have an impact on the duration to recurrent ship accidents.

Bunker price

Fuel in a part of cost, the main part of a ship voyage cost, is very sensitive to bunker price. A high bunker price may have decrease a ship accident. High bunker price may motivate slow steaming (Notteboom and Vernimmen, 2009), which may reduce the accident rate (Qu, Meng, and Suyi, 2011). On the other hand, the ship operators may cut ship repair and maintenance costs, which may increase the possibility of a ship accident. Therefore, this chapter postulate that a higher bunker price can affect the duration to ship accidents.

Fleet size

The number of ships in the world fleet is an indicator of aggregated market supply. Overcapacity in ship supply can have a negative impact on the earnings (Luo, Fan, and Liu, 2009; Kou and Luo, 2016) and reduce the resources used for ship maintenance. Therefore, it is postulated that an increase in the world fleet reduces the duration to ship accidents.

6.2.4 Industry level factors - shipping market factors

Similar to the ship supply factors, the shipping market conditions can affect the behavior and earnings of ship owners, which can in turn affect the duration to ship accidents.

Time charter rate

Bulut and Yoshida (2015) found that a high freight rate reduces ship accidents, possibly because ship owners have better financial profitability to invest for ship safety measures. On the other hand, Baniela and Ríos (2010) and Heij and Knapp (2014) found that a high freight rate increases ship accidents because ship operators or shipping companies would increase the speed of the ship when the freight rate is higher. Other reason for the relationship between high freight shipping rate and high probability of ship accidents can be explained as follows; if the shipping market changes for the better, ship owners are motivated to increase their ship's operational schedule. Then high frequency of shipping schedule may cause high probability of the accidents due to the lack of time for safety maintenance. Bijwaard and Knapp (2009) found that higher earnings reduce the accidents of drybulk ships, but increase the accidents of container ships. Thus, this chapter postulates that time charter rate can affect the duration to ship accidents, but the nature of its impact needs to be identified by statistical analysis.

Newbuilding price

Like bunker price, newbuilding price may also have different impacts on the first accident and recurrent accidents. A high newbuilding price increases market value of second hand ships, which motivates ship owners to invest more on the ships' maintenance. This may reduce the possibility of accidents of old ships. On the other hand, a higher newbuilding price usually corresponds to high demand in the freight market (Luo, Fan, and Liu, 2009). Facing high demand, ships tend to sail at high-speed, which may increase the probability of ship accidents. Therefore, the hypothesis is that newbuilding price affects the duration between ship accidents and the next accidents; however, it is unclear whether it has a positive or negative effect on ship accidents. Changes in ship supply and shipping markets may take some time before having a visible impact on ship accidents. To reflect this time-lag effect, the regression analysis in this chapter uses the average of the previous 3-month and 6-

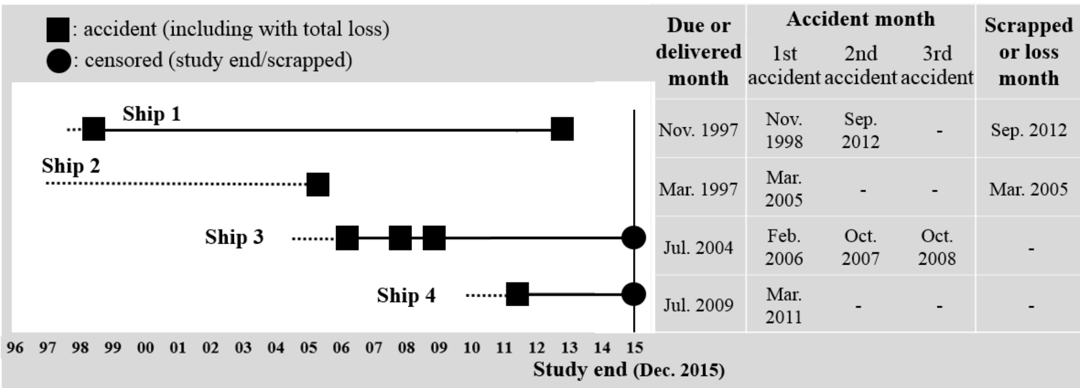
month values of the four variables (bunker price, fleet size, time charter rate, and new building price) respectively.

6.3 Dataset

The data used in this chapter is from two sources. One source is the worldwide casualty records maintained by IHS Lloyd's Register, and the other is shipping market information from CSIN.

Cox's general model and Cox's extended models allow to deal with recurrent issue which has time-varying and censored data in maritime casualty records. Global shipping database of Clarkson and worldwide casualty dataset managed by Lloyd's Register were utilized in this analysis with monthly data format in the period 1996 to 2015.

Figure 6-1: Timeline and accident records of real sample ships.

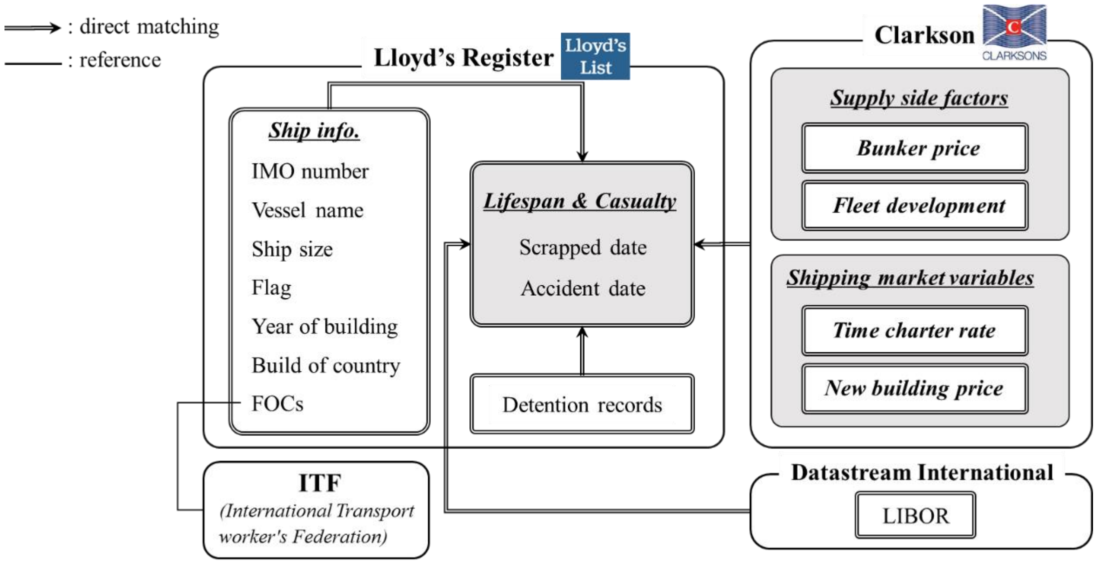


Note: Dotted lines stands for the duration of the first accident from delivery time
Bold lines stands for the duration of the recurrent accident from previous accident time

The vessel accident database includes all ship accidents from January 1978 to December 2015, and contains both vessel and accident information (Figure 6-4).

Ship registration information is obtained from the ITF, and the detention records are available from the Memorandum of Understandings (MoU) of regional Port State Control offices (Figure 6-2).

Figure 6-2: Combined dataset through matching each data.



As the shipping market data is available only from 1996, for the analysis of the first accidents, only those ships that had their first accidents later than January 1996 are selected; for the recurrent ship accident analysis, only ships that had their second accident later than that date are included.

Table 6-1 summarizes the number of accident ships by ship type and size for those that had their first accident since January 1996. It includes the number of ships that had only one accident, and those that had more than one accident. The recurrence ratio in the table is lower than that from 1978 to 2015, because many ships that had their first accident before 1996 are excluded. From the table, it is clear that, except for general cargo ships, smaller ships usually have a larger recurrence ratio.

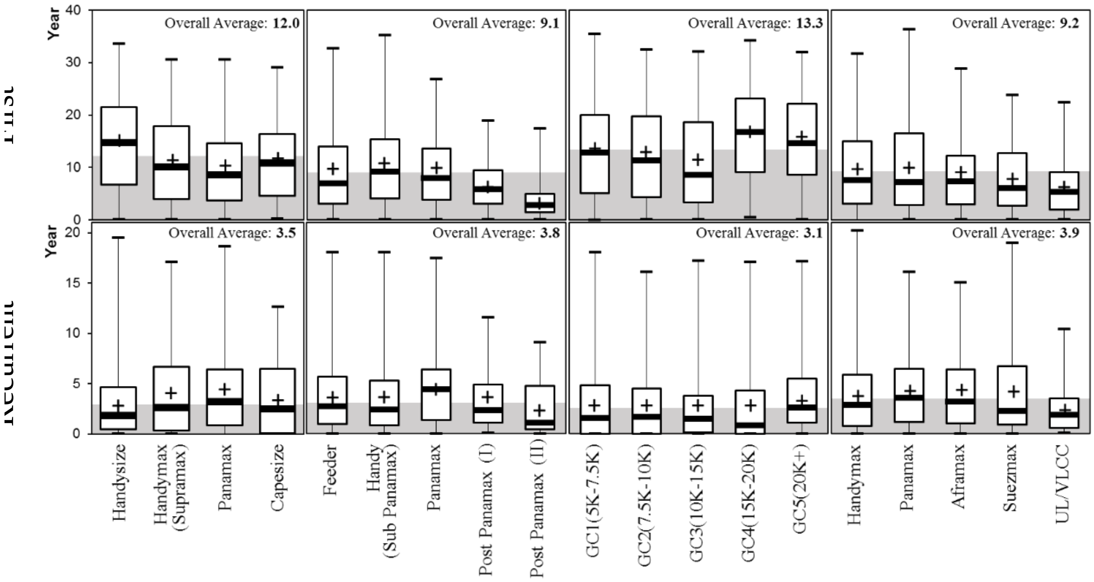
Table 6-1: Number of accident ships by vessel type and size.

Type of ship (Size unit)	Subtype	Size range	No. of ships		
			Only one accident (a)	≥2 (b)	Recurrent ratio (%) b/(a+b)
Dry Bulker (Deadweight Tonnage, DWT)	Handysize	10,000-39,999	607	320	34.5
	Handymax (Supramax)	40,000-64,999	377	273	42.0
	Panamax	65,000-99,999	377	112	22.9
	Capesize	100,000+	220	54	19.7
Container (TEU)	Feeder Containership	100-1,000	267	119	30.8
	Handy/Sub Panamax	1,000-2,999	395	150	27.5
	Panamax	3,000-4,999	200	50	20.0
	Post panamax(I)	5,000-7,999	113	26	18.7
	Post panamax(II)	8,000-11,999	70	8	10.3
General Cargo (DWT)	GC1	5,000-7,499	439	188	30.0
	GC2	7,500-9,999	252	104	29.2
	GC3	10,000-14,999	169	73	30.2
	GC4	15,000-19,999	110	48	30.4
	GC5	20,000+	191	56	22.7
Tanker (DWT)	Handysize	10,000-59,999	685	209	23.4
	Panamax	60,000-79,999	94	19	16.8
	Aframax	80,000-119,999	183	44	19.4
	Suezmax	120,000-199,999	72	18	20.0
	UL/VLCC	200,000+	59	8	11.9

Figure 6-3 displays the average duration for first accidents (the grey area) and recurrent ship accidents, as well as the age distribution for each ship type and size category. Generally, the duration for recurrent accidents (the time from one accident to the next) is shorter than that to the first accident (from delivery to the first accident).

In the analysis, the unit of ship size is the logarithm of DWT. Table 6-2 provides a statistical summary on the registration and detention, shipbuilding country, and accident types. Smaller ships are more likely to be registered in FOC countries across all ship types, and they also have more detention records. Japan, Korea and China are the three major shipbuilding countries. Navigational accidents and structural failures are the two major accident types. All other accident types are grouped together as a reference type.

Figure 6-3: Distribution of duration of first and recurrent ship accidents by ship type and size.



(a) Dry Bulker (b) Container (c) General Cargo (d) Tanker

Table 6-2: Summary of statistics of major variables.

		Dry bulker					Container*			
		Handysize	Handymax/ Supramax	Panamax	Capesize	Feeder	Handy/ Sub Panamax	Panamax	Post Panamax (I)	Post Panamax (II)
FOC		295	99	83	50	77	119	34	20	6
Detention		332	92	73	37	29	45	14	5	0
Build of country	Europe	78	11	16	6	88	111	14	0	2
	Japan	252	95	84	28	11	25	10	4	1
	Korea(South)	18	17	14	26	8	20	36	20	7
	China	90	15	21	6	48	17	0	4	0
	Other	249	39	40	14	24	36	5	1	0
Accident type**	Navigational accidents	373	118	111	45	106	117	38	20	7
	Structural failures	257	51	59	33	65	70	21	9	2
	Others	57	8	5	2	8	22	6	0	1

		General cargo					Tanker					Total
		GC1	GC2	GC3	GC4	GC5	Handysize	Panamax	Aframax	Suezmax	ULCC /VLCC	
FOC		187	108	76	44	38	134	13	28	8	4	**1,423**
Detention		210	121	77	43	30	60	2	3	2	1	**1,176**
Build of country	Europe	73	61	34	27	20	88	3	8	1	0	**641**
	Japan	121	43	17	13	36	61	7	22	1	3	**834**
	Korea(South)	28	4	2	2	12	44	5	16	16	7	**302**
	China	51	24	33	18	8	19	8	2	1	0	**365**
	Other	103	69	49	35	12	92	4	5	10	0	**787**
Accident type**	Navigational accidents	224	110	64	54	52	163	13	34	12	4	**1,665**
	Structural failures	127	77	54	32	29	97	14	18	14	6	**1,035**
	Others	25	14	17	9	7	44	0	1	3	0	**216**

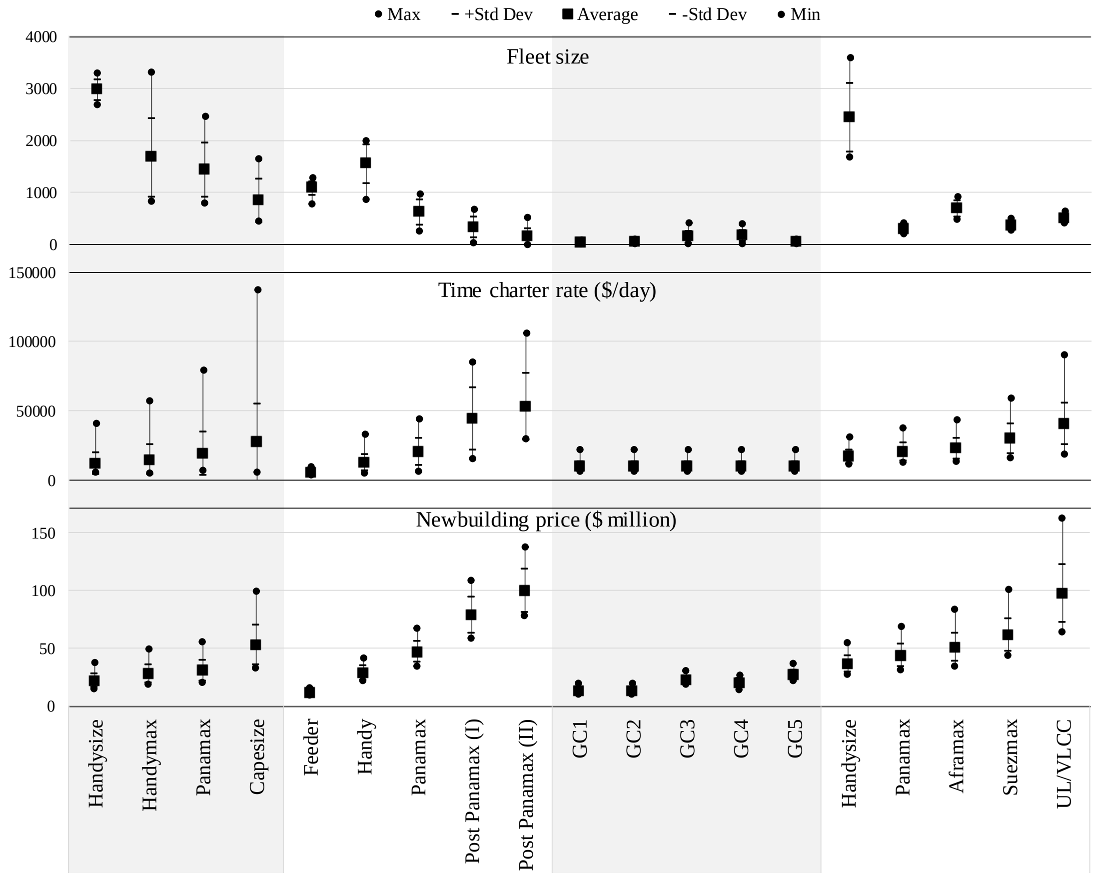
Note: Summarized according to the number of accidents with first accident happening after January 1, 1996

* Ultra Large Container Vessels are not included because of the small number of accidents

** **Navigational accidents**: collision, contact, wrecked, and foundered; **Structural failures**: hull damage, machine damage; **Others**: fire, explosion, and miscellaneous (missing, war loss/hostilities, wrecked, stranded)

Like many existing studies (e.g., Notteboom and Vernimme, 2009; Pedrielli, Lee, and Ng, 2014), the 380 cst bunker price in Singapore is used to represent the bunker price, and the unit is US$/metric tonne. The other market variables, such as time charter rate, newbuilding price and fleet size, use data for the ship type and size category that is as close as possible to the accident ship. In the event that some data is not available, the closest substitutes are used to extrapolate the data series. Figure 6-4 provides a statistical summary of the market variables used in the analysis.

Figure 6-4: Summary of market variables used in the analysis.



(a) Dry bulker (b) Container (c) General cargo (d) Tanker

Note: 1) Clarkson provides the time charter rate after January 2006, and the newbuilding price after December 2000 for Post Panamax (I). Since Post Panamax vessels did not have many accidents prior to 2006, these observations are deleted. For Post Panamax (II), both the time charter rate and newbuilding price start from November 2006. Therefore, all accidents prior to this date are deleted.

2) For the time charter rate of General Cargo, Clarkson only provides data for GC5 (20-25,000 dwt). All other categories therefore use the same time charter rate.

3) For the newbuilding price of General Cargo, Clarkson only provides data for GC2 size (semi-containerized vessel 400 TEU).

6.4 Results

A statistical package (SAS) was used both for the Cox PH model to analyze the first accident, and for the four extended Cox PH models to analyze the recurrent ship accidents. The regression results are presented next.

6.4.1 Result for the first accidents

Table 6-3 reports two sets of results from the Cox PH model for first accidents, each with the average of different time periods for bunker price, fleet size, time charter rate and newbuilding price. The results are similar, indicating that there is no significant difference. The marginal impact of the variables on HR is omitted, as it is just an exponential of the estimated coefficient.

Table 6-3: Regression results for the first accident.

		Parameter Estimate	
		3 month average	6 month average
Ship size		0.126 *	0.124 *
FOC registry		0.076 ***	0.077 ***
Detention		-0.165 ***	-0.164 ***
Shipbuilding Country (BM†: Other countries)	Europe	0.163 ***	0.164 ***
	Japan	0.088 **	0.090 **
	Korea	0.472 ***	0.472 ***
	China	1.370 ***	1.373 ***
Type of accident (BM: Others‡)	Navigational accidents	0.261 ***	0.258 ***
	Structural failures	0.203 ***	0.201 ***
Type of vessel (BM: Tanker)	Dry bulker	-0.238 ***	-0.236 ***
	Container	0.083 *	0.083 *
	General cargo	-0.506 ***	-0.512 ***
Bunker price		-0.001 ***	-0.001 ***
Fleet size		-0.087 *	-0.092 *
Time charter rate ($/Day)		-0.002	-0.003
Newbuilding price ($ Million)		0.007 ***	0.007 ***
Likelihood Ratio		1637.690 ***	1634.110 ***
Number of observations		6758	6758
Generalized (Cox-snell) R^2		0.215	0.215

Note: †BM: Benchmark variable; ‡Others: Fire, explosion, and miscellaneous (missing, war loss/hostilities, wrecked, stranded); ***P ≤ 0.01, **P ≤ 0.05, *P ≤ 0.1

Vessel Attributes

Ship size has a positive and significant impact on the hazard of the first accident, indicating that larger vessels have a shorter duration to the first accident. This is consistent with Bijwaard and Knapp (2009), that larger cargo ships have a higher accident rate. This result can be understood by the distribution of the first accident across different ship sizes. As shown in Figure 6-3, large vessels have a mostly short duration to their first accident.

FOC ships have a positive significant impact on the risk of their first accident, i.e., they have a shorter duration to their first accident. This finding is consistent with the existing studies on flag choice behavior (Luo, Fan, and Li 2013; Fan, Luo, and Yin 2014) and how it affects maritime safety (Li and Wonham 1999; Li, Yin, and Fan 2014).

The impact of a ship detention record on the risk of her first accident is negative significant. As the detention record of a ship not only forces the ship to rectify deficiencies, but also gives plenty of warning on the maintenance and management of the ship, it is reasonable that the detention can improve the safety standards of the ship and thus extend the duration to its first accident.

Regarding shipbuilding countries, Europe[8] , Japan, South Korea, and China are positive significant. The test result shows that ships built in these countries (Europe, Japan, South Korea, and China) have a higher probability of accidents than those built elsewhere. Moreover, the parameter estimate shows that ships built in China have the highest likelihood to an accidents in the case of the first accidents, followed in order by Korea, Europe and Japan. In other words, from this test result, it is seen that ships built in China have the shortest duration prior to their first accident: ships built in Japan, Europe and Korea have a longer duration to the first accident than those from China, due to better shipbuilding technology.

Other variables in ship level factors

Among the dummy variables for accident types, navigational accidents and

[8] In this thesis, European countries include Austria, Belgium, Denmark, Finland, France, Germany, Germany (West), Greece, Iceland, Ireland, the Netherlands, Norway, Poland, Portugal, Turkey, United Kingdom

structural failures have positive significant impacts on the first accident. Compared with the reference type (miscellaneous accidents), these two accident types can first occur earlier.

The estimated coefficients on dry bulker and general cargo ships are negative significant, while the one on containerships is positive significant. Compared with the benchmark type (tanker), dry bulker and general cargo ships take a longer time to have their first accident, while container ships have a shorter duration to their first accident.

This result can also be explained by the statistics in Figure 6-3. The average time from a ship delivery to her first accident is the shortest for container ships (9.1 years), followed in order by tankers (9.2 years), dry bulkers (12.0 years), and general cargo ships (13.3 years).

Supply side factors

The coefficient on bunker price is negative significant, indicating that when the bunker price is high, it takes longer to the first accident. The vessel operators may practice slow steaming because the first accidents usually happen to newer ships, which are more competitive. They do not need to cut cost on safety measures, but. Therefore, it has a negative relationship with ship accidents.

Fleet size is also negative significant for the first accident. A possible explanation is that when the shipping market competition is fierce owing to oversupply, new ships may face more competitive than old ones. Therefore, they can afford more investment in shipping safety, and thus may have longer duration to the first accident.

Shipping market variables

The estimated coefficient for time charter rate is insignificant. On the other hand, the newbuilding price is positive significant. If new building price increases, then the ship owners or operators would meet their shipping demand with existing vessels. Therefore, they desire to reduce vessel’s turnaround time, which can cause ships to sail faster. Faster navigation may in turn lead to an earlier first accident. This is consistent with findings in Bijwaard and Knapp (2009) that the newbuilding price has a positive effect on the accident rate for tanker and other types of vessel.

Finally, the likelihood ratio of the Cox PH model is significant. The R2 is only about 20%, because the duration analysis and partial likelihood estimation usually have a low goodness of fit.

6.4.2 Results of recurrent accidents

Similar to the analysis of the first accidents, the analysis of recurrent accidents also used average values for supply side variables and market variables for different periods. However, in addition to the variables used for the first time accidents, three variables were used to represent the age at the first accident (Age1), the previous accident (AgeP) and the recurrent accident (AgeR). The results are in Table 6-4.

Table 6-4: Estimated coefficients of four Cox PH models for recurrent accidents.

Variables \ Model		Previous 3-month average				Previous 6-month average			
		AG	**PWP-CP**	**PWP-GT**	**WLW**	**AG**	**PWP-CP**	**PWP-GT**	**WLW**
AgeR		-0.053***	-0.067***	-0.067***	-0.064***	-0.053***	-0.067***	-0.067***	-0.064***
Age1		0.038***	0.062***	0.000	0.056***	0.038***	0.062***	0.000	0.057***
AgeP		0.014***	0.005**	0.067***	0.008***	0.014***	0.005**	0.067***	0.008***
Ship size		-0.473**	-0.535***	-0.560***	-0.479***	-0.431**	-0.488***	-0.512***	-0.441***
FOC registry		1.639***	1.356***	1.336***	1.396***	1.671***	1.383***	1.363***	1.410***
Detention		-0.287***	-0.391***	-0.365***	-0.483***	-0.272***	-0.381***	-0.353***	-0.476***
Ship building country (BM†: Other countries)	Europe	-0.044	-0.028	-0.043	-0.124***	-0.052	-0.031	-0.048	-0.125***
	Japan	-0.591***	-0.359***	-0.325***	-0.354***	-0.584***	-0.348***	-0.317***	-0.347***
	Korea	-0.136	0.013	-0.067	-0.224***	-0.135	0.017	-0.062	-0.225***
	China	-0.653***	-0.485***	-0.533***	-0.558***	-0.646***	-0.476***	-0.525***	-0.548***
Previous accident type (BM: Others)	Navigational accidents	-0.271***	-0.256***	-0.227**	-0.227***	-0.276***	-0.251***	-0.225**	-0.227***
	Structural failures	-0.240**	-0.353***	-0.412***	-0.251***	-0.233**	-0.349***	-0.408***	-0.250***
Type of Vessel (BM: Tanker)	Dry bulker	0.599***	0.658***	0.699***	0.399***	0.558***	0.614***	0.655***	0.375***
	Container	0.287***	0.490***	0.525***	0.266***	0.249***	0.447***	0.483***	0.246***
	General cargo	0.816***	1.428***	1.480***	1.287***	0.741***	1.372***	1.427***	1.268***
Bunker price		0.002***	0.001***	0.001***	0.001***	0.001***	0.001***	0.001***	0.001***
Fleet size		0.449***	0.681***	0.658***	0.695***	0.432***	0.676***	0.655***	0.702***
Time charter rate		0.045***	0.050***	0.046***	0.047***	0.045***	0.051***	0.047***	0.050***
Newbuilding price		-0.045***	-0.054***	-0.050***	-0.060***	-0.046***	-0.057***	-0.053***	-0.063***
Likelihood Ratio		4119***	5120***	4745***	76593.2***	4440***	4693***	4693***	70416***
Number of Observations		4443	4696	4696	70447	4088.21	5090.33	4715.13	76294.9
The Generalized (Cox-Snell) R^2		**0.604**	**0.664**	**0.636**	**0.663**	**0.662**	**0.602**	**0.630**	**0.603**

Note: †**BM**: Benchmark variable ‡**Others**: fire, explosion, and miscellaneous (missing, war loss/hostilities, wrecked, stranded)

***$P \leq 0.01$, **$P \leq 0.05$, *$P \leq 0.1$

Vessel attributes

The coefficient of AgeR is negative significant, indicating that for most of the older ships, a long time passed prior to recurrent ship accidents. Age1 and AgeP are positive significant, indicating that when an old ship has an accident, it will have subsequent recurrent accidents sooner. This may be because when a new ship has an accident, the ship owner has an incentive to repair it and maintain its condition, which may reduce the subsequent risk of recurrent ship accidents, whereas if the ship is already old, the owner may hesitate to repair it, which could result in recurrent accidents happening sooner.

In contrast to the results of the analysis of the first accidents, the estimated coefficients on ship size are negative significant, indicating that smaller vessels have a higher probability of recurrent ship accidents.

The estimated coefficients of FOC and detention are similar to those in the analysis of the first accidents. Thus, the risk of both the first and recurrent accidents is high when vessels are registered in FOC countries and no detention record. Of course, the ship that managed well has no detention record. At the same time, ships may have less probability through detention and repairing according to port states control's recommendation. Thus, the probability of recurrent accidents can be lower than vessels having no detention records.

For the dummy variables indicating the shipbuilding countries, Japan is negative significant for all models, which may be explained by its advanced shipbuilding technology. On the other hand, the coefficients for Europe and Korea are not statistically significant in recurrent accidents, except in the WLW model. China shows the lowest likelihood of recurrent accidents (-0.653), which is the opposite of the result obtained for first accidents. This may indicate that the ships built in Chinese shipyards have less recurrent probability than is thought.

Other variables in ship level factors

All the estimated coefficients on accident types are negative significant, indicating that compared with navigational accidents and structural failures, other accident types (fire, explosion, missing, war loss/hostilities, wrecked, and stranded) carry a higher risk of a recurrent accident.

For vessel type dummy variables, the estimated coefficients are all positive significant, indicating that dry bulker, container, and general cargo vessels present a higher risk than tanker vessels. This result is consistent with the distribution of recurrent ship accidents in tankers (Figure 6-3) where tankers have the lowest percentage of recurrent accidents. In addition, general cargo vessels have the highest risk of recurrent accidents, followed in order by dry bulker and containerships. This trend is also consistent with the distribution of the duration to recurrent ship accidents in Figure 6-3, where the average duration of the general cargo vessels is the shortest , followed in order by dry bulker, container and tanker.

Supply side factors

Estimated coefficients of the supply side factors are all positive significant. In contrast to that of the first accidents, the coefficient on bunker price is positive significant for recurrent accidents, indicating that a higher bunker price may increase the risks. One possible explanation is that, for older ships, a rise in bunker price forces the ship operators to cut down on ship maintenance, which may increase the risk of a recurrent accident.

As for fleet size, the sign of coefficient is positive significant, while it presents negative coefficient in the first accident analysis result. This confirms the postulation that shipping market can be overheated owing to the oversupply, which will increase the risk of recurrent ship accidents.

Shipping market variables

The coefficients of the shipping market variables are all significant. The time charter rate is positive, indicating that high earnings from shipping services can also induce more recurrent accidents. When the time charter rate is high, shipping traffic may increase. Ship owners would tend to increase the utilization rate and reduce maintenance time, all of which can increase the risk of recurrent ship accidents.

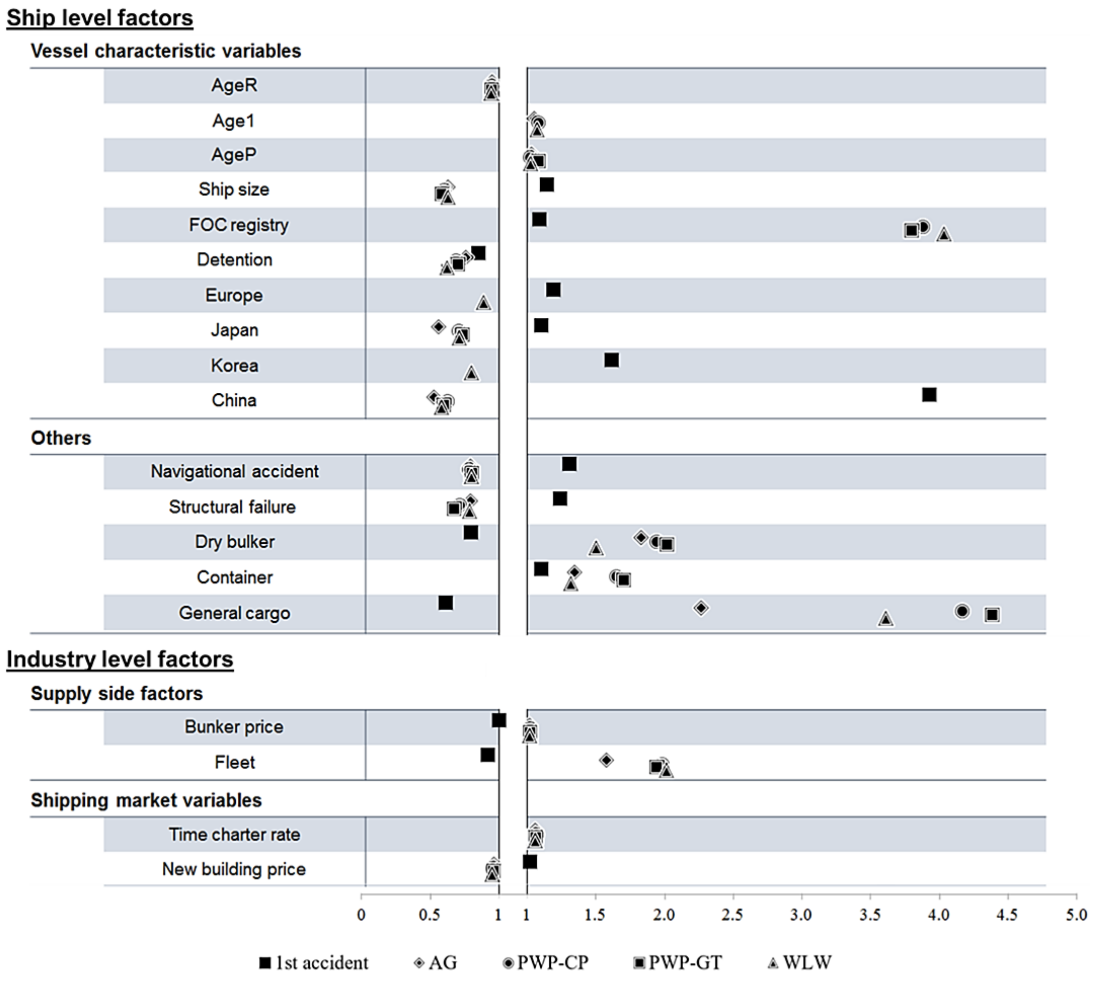
The newbuilding price is negative significant, indicating that it can reduce the risk of recurrent ship accidents. This confirms the expectation that a high newbuilding price can increase the market value of older and secondhand ships, thus motivating ship owners to manage their ships more in safety aspect, which may reduce the accident rate (Talley, 1995a; 1999b). Also, a low newbuilding price may trigger sub-standard ships by low profile ship owners. The sub-standard ships can be one of the reasons causing vessel accidents.

Finally, the whole model is significant based on the high likelihood ratio. The R2 is also high, indicating that the model has a high explanation power.

6.4.3 Comparison of the results between first accidents and recurrent accidents

To enable a comparison of the results between first and recurrent accidents, the HRs of all the significant variables were computed and plotted in Figure 6-5. For a positive/negative coefficient, HR>/<1 indicates that the factor will increase/reduce the risk of an accident.

Figure 6-5: Hazard Ratio of different factors (3 months' average).



From Figure 6-5, the results can be summarized as follows:

1. When an old ship has an accident, whether it is the first or not, the likelihood to an accidents of her recurrent accident is higher than that of new ships.
2. Smaller ships have higher recurrent accidents probability than larger ones, whereas larger ships have their first accidents earlier than smaller ones.
3. Registration in FOC countries indicates a higher risk for both the first and recurrent accidents, whilst a detention record can reduce the risk of both kinds of accidents.
4. Ships built in China have their first accidents sooner than ones built elsewhere, but last longer before having recurrent accidents.
5. As regards ship supply factors, a high bunker price and large fleet size can increase the risk of recurrent accidents, but reduce that of the first accidents.
6. As regards market variables, a high time charter rate increases the risk of recurrent accidents, but does not affect that of first ones; whereas a high newbuilding price increases the first accident risk, but reduces that of recurrent ones.
7. Regarding accident types, most of the earlier first accidents are navigational accidents or structural failures. However, if the previous accident is one of these two types, more time passes before a recurrent accident.
8. Regarding ship type, containerships have their first accidents earlier than tankers, dry bulkers and general cargo ships; in contrast, tankers carry the least risk of recurrent accidents, followed in order by containerships, dry bulkers and general cargo ships.

6.5 Chapter conclusions

Numerous studies have analyzed the causes of and important factors relating to ship accidents, using various methods (Luo and Shin, 2016). To reduce maritime accidents, it should be noted that a large proportion of ship accidents are recurrent. In spite of various extant studies on ship accidents, no studies have previously examined why such a high number of recurrent accidents occur. To fill this gap in the maritime literature, this chapter examined the major factors affecting recurrent ship accidents.

Using historical ship casualty data, the IHS ship database and global shipping market information, this chapter applied both the original and extended Cox PH models to identifying important factors relating to first accidents and recurrent accidents, respectively.

This chapter also discovered the relationship between shipping market conditions and ship accident behavior. It is seen from the industry level factor results that high bunker price and time charter rate can be an indicator of recurrent accidents, so through this chapter ship owners and operators can recognize the risk of recurrent accidents during peak markets, since the poor financial performance of shipping companies may affect the risk of ship accidents.

Moreover, ship owners and operators can also use these results in their fleet management decisions, especially for ships that have suffered accidents and sub-standard vessels that they may have.

References

Baniela, S. I., & Ríos, J. V. (2010). The risk homeostasis theory. *The Journal of Navigation, 63*(4), 607–626.

Bergantino, A., & Marlow, P. (1998). Factors influencing the choice of flag: empirical evidence. *Maritime Policy & Management, 25*(2), 157-174.

Bijwaard, G. E., & Knapp, S. (2009). Analysis of ship life cycles—The impact of economic cycles and ship inspections. *Marine Policy, 33*(2), 350-369.

Bulut, E., & Yoshida, S. (2015). Are marine accidents really accidents? Fallacy of random marine accidents in dry cargo fleet. *The Asian Journal of Shipping and Logistics, 31*(2), 217-229.

Fan, L., Luo, M., & Yin, J. (2014). Flag choice and Port State Control inspections-Emprical evidence using a simultaneous model. *Transport Policy, 35*(2014), 350-357.

Heij, C., & Knapp, S. (2014). Dynamics in the dry bulk market economic activity, trade flows, and safety in shipping. *Journal of Transport Economics and Policy (JTEP), 48*(3), 499–514.

Heij, C., Bijwaard, G. E., & Knapp, S. (2011). Ship inspection strategies: Effects on maritime safety and environmental protection. *Transportation Research Part D: Transport and Environment, 16*(1), 42-48.

Knapp, S., & Franses, P. H. (2007). Econometric analysis on the effect of port state control inspections on the probability of casualty: Can targeting of substandard ships for inspections be improved? *Marine Policy, 31*(4), 550-563.

Kou, Y., & Luo, M. (2016). Strategic capacity competition and overcapacity in shipping. *Maritime Policy & Management, 43*(4), 389-406.

Li, K. X., Yin, J., & Fan, L. (2014). Ship safety index. *Transportation Research Part A: Policy and Practice, 66*, 75-87.

Li, K., & Wonham, J. (1999). Who is safe and who is at risk: a study of 20-year-record on accident total loss in different flags. *Maritime Policy & Management, 26*(2), 137-144.

Luo, M., & Shin, S.-h. (2016). Half-century research developments in maritime accidents: Future directions. *Accident Analysis and Prevention,* (In Press).

Luo, M., Fan, L., & Li, K. X. (2013). Flag choice behavior in the world merchant fleet. *Transportmetrica A: Transport Science, 9*(5), 429-450.

Luo, M., Fan, L., & Liu, L. (2009). An econometric analysis for container shipping market. *Maritime Policy & Management, 36*(6), 507-523.

Metaxas, B. N. (1981). Flags of convenience. *Marine Policy, 5*(1), 52-66.

Notteboom, T. E., & Vernimmen, B. (2009). The effect of high fuel costs on liner service configuration in container shipping. *Journal of Transport Geography, 17*(5), 325-337.

Pedrielli, G., Lee, L., & Ng, S. (2014). Optimal Bunkering Contract in a Buyer-Seller Supply Chain under Price and Consumption Uncertainty. *Transportation Research Part E: Logistics and Transportation Review, 77*(March), 77-94.

Qu, X., Meng, Q., & Suyi, L. (2011). Ship collision risk assessment for the Singapore Strait. *Accident Analysis & Prevention, 43*(6), 2030– 2036.

Roberts, S. E., & Marlow, P. B. (2002). Casualties in dry bulk shipping (1963–1996). *Marine Policy, 26*(6), 437-450.

Talley, W. K. (1995a). Safety investments and operating conditions: Determinants of accident passenger-vessel damage cost. *Southern Economic Journal, 61*(3), 819-829.

Talley, W. K. (1995b). Vessel damage severity of tanker accidents. *Logistics and Transportation Review, 31*(3), 191-207.

Talley, W. K. (1999a). The safety of sea transport: determinants of crew injuries. *Applied Economics, 31*(11), 1365-1372.

Talley, W. K. (1999b). Determinants of ship accident seaworthiness. *Maritime Economics & Logistics, 1*(2), 1-14.

Talley, W. K. (2001). Determinants of the property damage costs of bulk barge accidents. *Maritime Policy & Management, 28*(2), 175-186.

Thuong, L. T. (1987). From flags of convenience to captive ship registries. *Transportation Journal, 27*(2), 22-34.

Tzannatos, E. (2010). Human element and accidents in Greek shipping. *The Journal of Navigation*, *63*(1), 119-127.

Chapter 7.

Conclusions and Suggestions for Future Research

7.1 Conclusions

Causal factors in maritime accidents in tandem with policies for preventing maritime accidents have been a steady concern, because of the possible loss of lives and the property damage of ships and cargoes, as well as environmental pollution caused by oil spills and gases emitted by ships. Despite better shipbuilding technologies and suggestions from numerous studies regarding maritime accidents, vessels plying in global waters and engaging in international trade are faced with the risk of accidents.

In this context, this thesis analyzes maritime accidents from three aspects: research trends and the effects on vessel lifespan of accidents and recurrent accidents. The first issue was analyzed by a comprehensive review of the literature on maritime accidents. The last two issues have been analyzed by means of hazard-based statistical models.

The first study summarized the evolution of maritime accident research from broad perspectives over the past 50 years, using 572 peer-reviewed papers collected from 125 academic journals published in English. As indicated in Chapter 2, human factors are a major cause of ship accidents, and the shipping market condition is an emerging factor. Furthermore, an analysis of the effect of the shipping market on human error, and how it affects the probability of ship accidents, is a very promising future research area, particularly from the perspective of the current market conditions.

Understanding the possible future life of a ship and its determinants are vital for the value assessment of the ship. In this context, the second study analyzed the lifespan of global merchant ships built since 1960 and ended its life from 1990 by using a Cox PH model. The analysis considered four aspects: economic conditions of the shipping market, vessel-specific attributes, operational attributes, and safety management attributes.

For public agencies responsible for maritime safety and environmental pollution management, understanding what type of ships usually last longer and what external factors may reduce their lifespans can help to formulate appropriate policies to maintain the standard of the global merchant fleet and simultaneously prevent accidental total loss or earlier scrapping of ships that can still provide services. When the cost to replace an existing ship is low, the high investment on safety management will be difficult to justify, and such ships will be scrapped earlier. All this can result in social welfare loss.

Despite various extant studies on ship accidents, no studies have previously examined the reasons for such a high number of recurrent accidents. To fill this gap in the maritime literature, this thesis intended to examine the major factors of recurrent ship accidents.

Using historical ship casualty data, the IHS ship database and global shipping market information, this thesis applied both the original and the extended Cox PH models to identifying important factors related to first accidents and recurrent accidents, respectively.

This thesis also discovered the relationship between shipping market conditions and ship accidents. The analysis of the industry-level factors revealed that high bunker prices and time charter rates indicate recurrent accidents. Moreover, the results showed that ship owners and operators can recognize the risk of recurrent accidents from the shipping market conditions.

Moreover, ship owners and operators can also use these results while making their fleet management decisions, particularly for ships that have suffered accidents. For example, when purchasing a secondhand vessel, the result of this thesis can help a stakeholder identify the risk and take a proactive measure to avoid the recurrent accidents of merchant vessels.

7.2 Suggestions for Future Research

Despite the efforts made to design this thesis to be a sound research record, there are several limitations to this thesis that should be acknowledged.

Human error, the most common factor of ship accidents (Tzannatos, 2010; Vinagre-Ríos and Iglesias-Baniela, 2013; Uğurlu *et al*., 2016), and seafarers' fatigue (Akhtar and Utne, 2015; BeşİkÇİ *et al*., 2016; Uğurlu *et al*., 2017; Alapetite and Kozine, 2017) are not included in this thesis, mainly because of the lack of data. Most ship accident databases only contain observable facts about accidents, such as ship conditions and environmental conditions, because information on human errors can only be revealed after a detailed accident investigation. Therefore, the effects of human errors and seafarers' fatigue on the probability of a ship accident are rarely studied using statistical analyses.

Because of the limited information on ship operation and the management of ship accidents, both the human factors involved and the effects of operational factors such as geographical information on the deployment location have not been included in this thesis. In practice, these two factors may also play a significant role in the recurrence of ship accidents. Research on their impact can only be carried out on the basis of detailed accident investigation data. Because the main aim of this thesis was to ascertain the statistical relationships based on all accidents that occurred since 1996, further separate research is required to investigate the effects of these additional factors. When it comes to the human error factor, the combined effect of multiple variables that have used in this thesis can be analyzed by means of the Bayesian approach (i.e., the Bayesian Networks model). Moreover, an analysis of accidents by different types of accidents may contribute to the knowledge required to prevent maritime and ship accidents.

Furthermore, on the basis of the studies of maritime safety regulations (Akyuz, Akgun, and Celik, 2016; Fenstad, 2016; Pantouvakis and Karakasnaki, 2016; Zheng *et al*., 2016; Fenstad, Dahl, and Kongsvik, 2016), the effects of these regulations on the recurrence of accidents can be a further research topic. The effect of risk assessment on cargoes and ports (Lam and Lassa, 2017), as well as the effect of security training and education on ship safety (Urciuoli, 2016) can also be a good topic for further research on maritime accidents and risk (safety) assessment.

References

Akhtar, M. & Utne, I.B. (2015). Common Patterns in Aggregated Accident Analysis Charts from Human Fatigue-related Goundings and Collisions at Sea. *Maritime Policy & Management*, *42*(2), pp.186-206.

Akyuz, E., Akgun, I. & Celik, M. (2016). A Fuzzy Failure Mode and Effects Approach to Analyse Concentrated Inspection Campaigns on board Ships. *Maritime Policy & Management*, *43*(7), pp.887-908.

Alapetite, A. & Kozine, I.,(2017). Safe manning of merchant ships: an approach and computer tool. *Maritime Policy & Management*, *44*(3), pp.1-13.

BeşİkÇİ, E.B., Tavacıoğlu, L. & Arslan, ö. (2016). The Subjective Measurement of Seafarers' Fatigue Levels and Mental Symptoms. *Maritime Policy & Management*, *43*(3), pp.329-343.

Fenstad, J., Dahl, Ø. & Kongsvik, T. (2016). Shipboard safety: exploring organizational and regulatory factors. *Maritime Policy & Management*, *43*(5), pp.552-68.

Lam, J.S.L. & Lassa, J.A. (2017). Risk assessment framework for exposure of cargo and ports to natural hazards and climate extremes. *Maritime Policy & Management*, *44*(1), pp.1-15.

Pantouvakis, A. & Karakasnaki, M. (2016). An Empirical Assessment of ISM Code Effectiveness on Performance: the Role of ISO Certification. *Maritime Policy & Management*, *43*(7), pp.874-886.

Tzannatos, E. (2010). Human element and accidents in Greek shipping. *The Journal of Navigation*, *63*(1), pp.119-27.

Uğurlu, Ö., Kum, S. & Aydoğdu, Y.V. (2017). Analysis of occupational accidents encountered by deck cadets in maritime transportation. *Maritime Policy & Management*, *44*(3), pp.304-322.

Uğurlu, Ö., Sercan, E. & Başar, E. (2016). The Analysis of Life Safety and Economic Loss in Marine Accidents Occurring in the Turkish Straits. *Maritime Policy & Management*, *43*(3), pp.356-370.

Urciuoli, L. (2016). Port security training and education in Europe—a framework and a roadmap to harmonization. *Maritime Policy & Management*, *43*(5), pp.580-596.

Vinagre-Ríos, J. & Iglesias-Baniela, S. (2013). The human element in shipping casualties as a process of risk homeostasis of the shipping business. *Journal of Navigation*, *66*(3), pp.385-397.

Zheng, Y., Talley, W.K., Jin, D. & Ng, M. (2016). Crew Injuries in Container Vessel Accidents. *Maritime Policy & Management*, *43*(5), pp.541-551.

Appendices

Appendix A. Major causes of maritime accidents from existing studies

Numerous studies have been conducted for finding root causes for maritime accidents, so as to minimize the occurrence of such events and provide specific directions for safer maritime transportation. Based on past studies, this section lists the causal factors of maritime accidents that THREAT maritime safety.

Traffic factors: traffic congestion, narrowness of seaway, dispersion of thousands of islands

Human factors: attention failures, careless navigation, decision failure (poor judgment), excessive risk taking, improper health condition for workers, improper supervisory, inadequate number, inadequate teamwork and safety culture, incompetence master/officers, lack of experiences, master asleep on watch, memory failures, miscommunication, mistake (rule-based, knowledge-based), misuse of equipment, no licensed seaman, non-compliance with the Safety Management System (SMS), observation failure, physical impairment, physical stress, alcohol, fatigue, skill-based errors (inadequate skill), smoking, unauthorized route, violations, wrong navigation process

Risk of vessel operation: excessive speed, failure to sound signal, inadequate task allocations, inadequate vertical/horizontal communications, inadequate work place conditions, inadequate work planning, low visibility (night), navigation errors, overtaking vessels, poor bridge layout, poor level of maintenance, wrong side of channel

Environmental factors: current, fog, tough weather, wave, wind

Aids and vessel structure factors: auto pilot failure, communication equipment failure, engine breakdown, heavy and slow to maneuver, insufficient ergonomic design, insufficient power, insufficient stability, leaks in hull, radar failure, structural failure, technical deficiencies

Transportation (shipping market) market factors: high oil price, low freight rate

Appendix B. Preventive measures of maritime accidents from existing studies

This section introduces the prevent measures for maritime accidents from the past studies. It can be categorized into 14 categories, and represented by the acronym MARITIME SAFETY:

<u>M</u>aritime navigation: speed limitation, traffic separation, timely traffic guidance and control, traffic management, traffic management system, integrated and one-man bridge interface, path planning, monitoring, Pilotage

<u>A</u>wareness of risk: risk awareness of stakeholders (ship captains, maritime pilots, VTS operators), subjective risk perception, awareness of accident prevention, precautionary risk planning, establishment of risk criteria, emphasizing to preventive measures (such as the Formal Safety Assessment framework), public awareness for maritime accidents

<u>R</u>egulation: efforts of regulatory government agencies, proper enforcement, the promotion and maintenance of adequate safety standards, safety regulation and policy, safety standard, liability law, more regulatory changes, compliance of regulation

<u>I</u>nformation: compiled accidents data, better database, combining data sources on inspections, data sharing/harmonization of inspection database

<u>T</u>echnology & Equipment: improved navigational aids, real-time simulation combined with a realistic environment, effective and simultaneous use of radar, maintenance of electronic equipment

Inter-communication: quicker communication between ships, bridge-to-bridge communications

Management & Operation: improving management structures, patrol activity by coast guard, engine room resource management (ERM), bridge resource management/bridge team management (BRM/BTM)

Education & Training: crew training, conducting safety program, high and common education standards for officers on watch, education language for avoiding miscommunication, adequate knowledge and procedures, medical training, effective training courses

Ship & Structure: ergonomics design, significant advancements in design technologies, risk-based ship design, vessel inspection, double hull, vessel design (for preventing maritime accidents), Port State Control and ship inspections

Adequate manning: resource (human) management, controlling human behavior, manning of ships by licensed operators, licensed crew allocation, proper rest, record keeping, sufficient nutrition and water supply, physical condition and sailing competence of the crew, safe manning, adequate resources for training, reviewing their working patterns and conditions

Forecasting: higher weather prediction

Economic (financial) supporting: supporting of government

Transformation: for development of safety culture (or safety climate)

Yelling (alerting) system: early warning system, alerting and advanced notice of an accident likelihood, integrated MIS (Management Information System), SMS (Safety Management System), vessel traffic management system, integrated VTS/AIS/GIS system, bridge system for safety.