The 4M Overturned Pyramid(MOP) Model Development to Characterize Accidents in Maritime Transportation System

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(海上輸送システムにおける海難分析のための MOP モデル開発)

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Summary

The number of ships has increased, on average, more than 1.5% per year. At the end of 2016, the number of ships around the world was 91,000 [UNCTAD, 2017]. The investigation institutions of European Union (EU) Member states form the European Maritime Safety Agency (EMSA) to keep track of all marine casualties and incidents every year. In order to do this, EMSA created the European Marine Casualty Information Platform (EMCIP) and now publishes an annual report of its findings. In 2014, EMSA received 3,025 accident and incident reports (reported occurrences) that involved 3,399 ships [EMSA, 2015]. This number was an increase from 2,767 reports in 2013, and the increase number is believed to be caused by improvements in reporting.

In Japan, in 2014, there were 688 accidents, and in 2015, 793 accident investigations were launched [JTSB, 2016]. The number of investigation reports increased just as it did at EMSA. Nowadays, accident investigation boards in each country have realized importance of collecting accident reports and are making improvements in collection. In line with these efforts to gather accident reports, analyzes is also being better developed. In this current research, the author develops a new model, the 4M Overturned Pyramid (MOP) Model, to characterize the various accidents. The characteristics found by this model are based on a list of causative factors and causative chains for each country, ship type, accident type, etc. depending on the needs of the inquiry.

MOP Model is developed by combining the Septigon model (society and culture, physical environment, practice, technology, individual, group, and organizational environment network) created by Grech et al. [Grech, Horberry, Koester, 2008] and the IM model proposed by Furusho [Furusho, 2013, 2000]. The IM model consists of 4M factors (man, machine, media, and management) that are connected by the individual element (I) as the core of the system. The MOP model is drawn as a three-dimensional relationship that appears as a three-sided inverted pyramid, where each

corner of the pyramid represents one 4M factor. Each corner (factor) is connected to and affects the other factors.

The man factor should always be at the bottom of the inverted pyramid because it is the intrinsic factor that significantly affects all other factors. Because the model is drawn three-dimensionally as a three-sided inverted pyramid, it has four corners representing the 4M factors, and six edges representing interaction between the two factors that are connected by the edges. The edges, which are called line relations, show that the system is the result of interactions among the 4M factors. Thus, to obtain a safe system, all corners and edges should be reliable and balanced.

The corners and edges in the model are representatives of stakeholders of Maritime Transportation System (MTS) that contain not only the construction of the ship, but also many stakeholders involved. This system called as Socio-Technical Environment (STE).
This dissertation provides a new model, MOP model, is developed to characterize several accidents from the chain of failure. The final outcome of this model is causative chains of collisions.

The aims of this study are to find characteristics of accidents using data from Japan, United States (US), Australia, and United Kingdom (UK) and expand 4M (Man, Machine, Media, Management) concept into 4M Overturned Pyramid (MOP) Model that characterizes accidents as a chain of failures. This study re-analyzes accident investigation reports that are published by Maritime Transportation Safety Agencies (MTSAs) from each country in 2008-2013.

This dissertation has 7 chapters and is arranged as explained below.

Chapter 1 – Introduction
This chapter provides background why author carries out this research in detail, objectives, methodology and a brief explanation how the dissertation is made. The chapter construction is also provided in this chapter to make reader easier understanding what is inside this book.

Chapter 2 – Maritime Transportation System and Accidents
This chapter presents a literature review about MTS and maritime accidents. Definition of several terms that are related to this study is also provided here to make

reader easier distinguish the different terms. Three main models of accidents are provided here including the definition of accident types.

Chapter 3 – 4M Overturned Pyramid (MOP) Model
This chapter outlines the original aspects of this research, the MOP model. Started from explanation how the MOP model is made up, the definition of the elements, the steps, to apply this model, to characterize accidents are also defined, and the development of the model year by year.

Chapter 4 – Accident in Several Countries Analyzed by MOP model
This chapter applies the MOP model to collision accidents in Japan, Australia, UK, and US. The detail step of the MOP model is explained here from the causative analysis until line relation analysis. It provides the outcome from each step of MOP model, causative factor and causative chain lists. However, the detail step how the list of causative factors found is written in Appendix B. The comparison results from corner analysis are provided in occurrence ratio so then the comparison is not done only by the number of failures for each causative factor but also considered the total number of all failures occurred in each 4M factor in the country. From here, reader can easily see the characteristic of the collision in a country.

Chapter 5 – Specific Topics
The previous chapter applies the MOP model to general purpose of characterizing the accidents. This chapter presents a deeper analysis utilizing MOP model for specific cases of time occurrence classification and improper look-out. The data is collision in Japan. The corner analysis and line relation analysis here are modified based on the need. The failures listed in causative factor list are divided based on time occurrences, day, night, and twilight. The more detail improper lookout occurred in Japan are also broken down in this chapter. The causative factors that are causing and caused by improper lookout are also showed here.

Chapter 6 - Summary of the Analysis and Discussion
It summarizes the analysis and discussion gotten from result in chapter 4 and chapter 5. This chapter provide the discussion of the most common causative factors that has outstanding number in each M factor as well as its causing factors. In total, there should be 4 point discussions because each point represents the most outstanding number of failures in each M factor. However, in man factor, there are two causative factors that have highest number of failures, thus there are 5 points discussed here. They are Careless from seaman in maintaining proper lookout (M101-02), Careless

from seaman in monitoring/identifying any accident risk (M101-03), Equipment failure: AIS/ radar could not show information (M201-01), Busy traffic (M301-01), Poor management from onshore in identifying/ monitoring/ communicating any risk accident (M405-01).

Chapter 7 - Conclusion
It concludes all the analysis and discussion with an explanation of the reliability of the MOP model for use in characterizing maritime accidents. The conclusion that is gotten are:

1. The dominant factor leading to collision is man factor (M1)

In general man factor is still act as the main CF of accident, it is supported by the result of analyzed accident report shown the biggest number of failure in MOP model`s CA is on man factor. And the most significant factors from man factor are “Careless seaman in maintaining proper lookout” and “Careless seaman in monitoring/identifying any accident risk”, both CF are classified as “Careless Seaman”. In Machine factor, the most common CF is “Equipment failure: AIS/radar could not show information”, in Media factor is “Busy Traffic”, while in Management factor, “Poor management from onshore in identifying/ monitoring/ communicating any accident risk”.

2. MOP model is one of choice to analyze accident because of its flexibility

As the simple approach, this model can be utilized by organization/company to get the tendency how their accident occurred and modified based on their needs. This flexibility will be the benefit because the researcher can utilize this method started by generating the data needed.

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Kobe, August 2017

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Chapter 1
Introduction

1.1 Background

The number of ships, oil tankers, bulk carriers, general cargo, container ships, and others, have been increasing steadily around the world since 2011. The number of ships has increased, on average, more than 1.5% per year. At the end of 2016, the number of ships around the world was 91,000 [1]. The investigation institutions of European Union (EU) Member states form the European Maritime Safety Agency (EMSA) to keep track of all marine casualties and incidents every year. In order to do this, EMSA created the European Marine Casualty Information Platform (EMCIP) and now publishes an annual report of its findings. In 2014, EMSA received 3,025 accident and incident reports (reported occurrences) that involved 3,399 ships [2]. This number was an increase from 2,767 reports in 2013, and the increase number is believed to be caused by improvements in reporting.

In Japan, in 2014, there were 688 accidents, and in 2015, 793 accident investigations were launched [3]. The number of investigation reports increased just as it did at EMSA. Nowadays, accident investigation boards in each country have realized importance of collecting accident reports and are making improvements in collection. In line with these efforts to gather accident reports, analyzes is also being better developed. In this current research, the author develops a new model, the 4M Overturned Pyramid (MOP) Model, to characterize the various accidents. The characteristics found by this model are based on a list of causative factors and causative chains for each country, ship type, accident type, etc. depending on the needs of the inquiry.

MOP Model is developed by combining the Septigon model (society and culture, physical environment, practice, technology, individual, group, and organizational environment network) created by Grech et al. [4] and the IM model proposed by Furusho [5] [6]. The IM model consists of 4M factors (man, machine, media, and management) that are connected by the individual element (I) as the core of the system. The MOP model is drawn as a three-dimensional relationship that appears as a three-sided inverted pyramid, where each corner of the pyramid represents one 4M factor. Each corner (factor) is connected to and affects the other factors. The man factor should always be at the bottom of the inverted pyramid because it is the intrinsic factor that significantly affects all other factors. Because the model is drawn three-dimensionally as a three-sided inverted pyramid, it has four corners representing the 4M factors, and six edges representing interaction between the two factors that are connected by the edges. The edges, which are called line relations, show that the system is the result of interactions among the 4M factors. Thus, to obtain a safe system, all corners and edges should be reliable and balanced.

The corners and edges in the model are representatives of stakeholders of Maritime Transportation System (MTS) that contain not only the construction of the ship, but also many stakeholders involved. This system called as Socio-Technical Environment (STE).

1.2 Objectives

- To find characteristics of accidents using data from Japan, United States (US), Australia, and United Kingdom (UK).
- Expand 4M (Man, Machine, Media, Management) concept into 4M Overturned Pyramid (MOP) Model that characterizes accidents as a chain

of failures

1.3 Methodology

These are the step conducting this work:

- Literature study and finding data (investigation reports)
- Listing all the causative factors of ship accidents from the accident reports
- Categorize the list into 4 M Factors
- Find the causative chain that connect the causative factors

1.4 Dissertation Structure

This dissertation has 7 chapters and is arranged as explained below.

Chapter 1 – Introduction

This chapter provides background why author carries out this research, objectives, methodology and a brief explanation how the dissertation is made. The chapter construction is also provided in this chapter to make reader easier understanding what is inside this book.

Chapter 2 – Maritime Transportation System and Accidents

This chapter presents a literature review about MTS and maritime accidents. There will be definition of several terms that are related to this study to make reader easier distinguish the different terms. Three main models of accidents are provided here including the definition of accident types.

Chapter 3 – 4M Overturned Pyramid (MOP) Model

This chapter outlines the original aspects of this research, the MOP model. Started from explanation how the MOP model is made up, the definition of the elements, the steps, to apply this model, to characterize accidents are also defined, and the development of the model year by year.

Chapter 4 – Accident in Several Countries Analyzed by MOP model

This chapter applies the MOP model to collision accidents in Japan, Australia, UK, and US. The detail step of the MOP model is explained here from the causative analysis until line relation analysis.

Chapter 5 – Specific Topics

The previous chapter applies the MOP model to general purpose of characterizing the accidents. This chapter presents a deeper analysis utilizing MOP model for specific cases of time occurrence classification and improper look-out. The data is collision in Japan.

Chapter 6 - Summary of the Analysis and Discussion

This chapter summarizes the analysis from chapter 4 and 5 and discusses the result by taking the relation among them.

Chapter 7 - Conclusion

This last chapter concludes with an explanation of the reliability of the MOP model for use in characterizing maritime accidents.

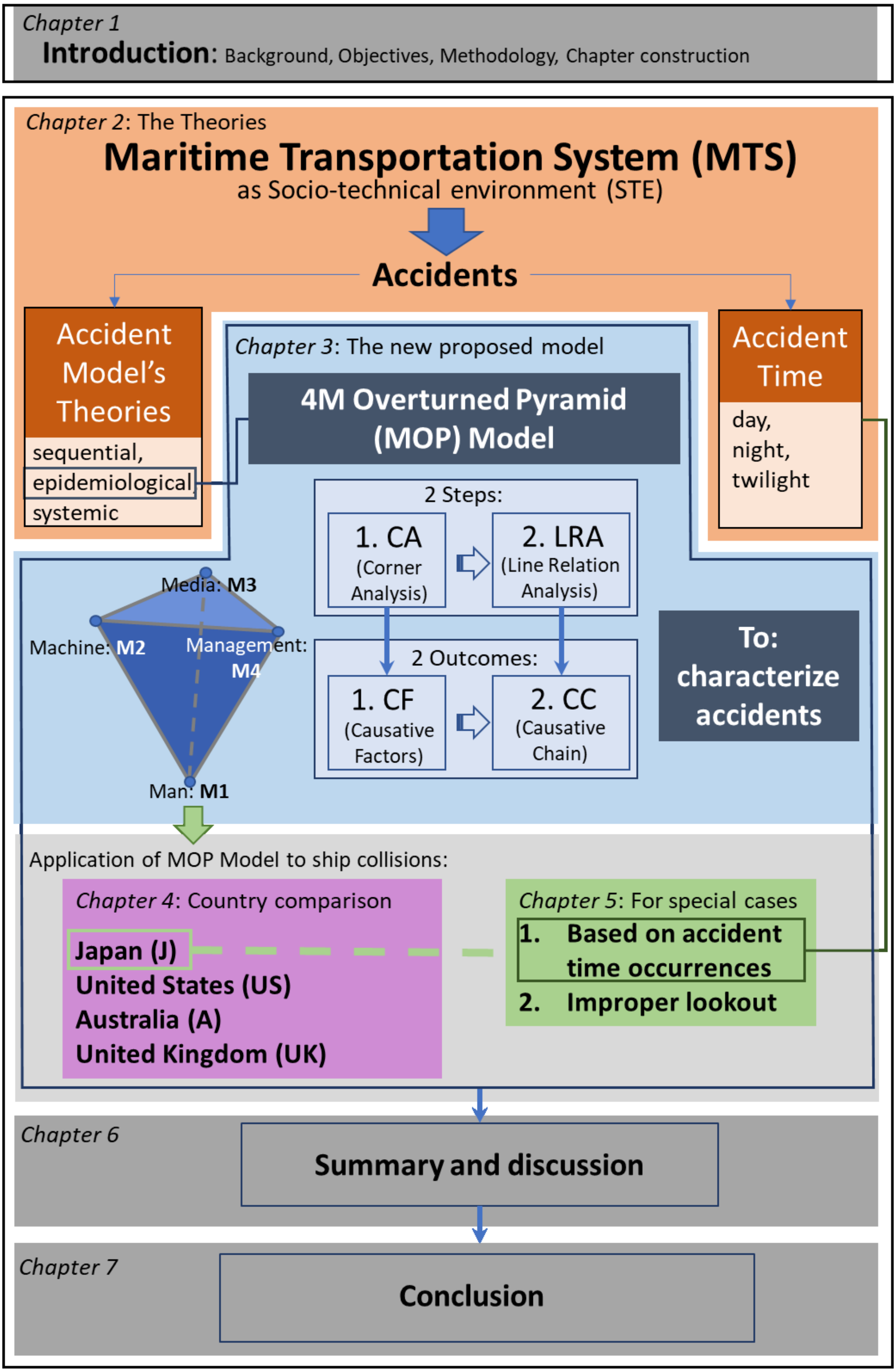


Fig. 1.1 Dissertation structure

Chapter 2
Maritime Transportation System (MTS) and Accidents

2.1 Term Definitions

There are several terms that are often used in literatures related to this study. The author defines those terms appropriate to this study. Table 2.1 provides the terms and definitions.

When there is an accident, it is important to analyze the accident to find the main cause. While there are many different kinds of accidents, we can collect the main causes and find the most common main causes among those accidents. If we can isolate the most common causal factors, this will help in reducing accidents. Kristiansen describes a number of accident analysis models, and has looked at various ways of approaching accident analysis [7]. He says that the basis of safety concerns should be firm knowledge about why accidents happen. We need to know what safe operation entails. A key source of such knowledge can be learned from accidents, incidents and near-accidents/ non-conformance. We make a distinction between the following events:

- An accident is an event that leads to damage, environmental consequences, with injuries or fatalities and economic loss.

- An incident is an event that is controlled before it leads to an accident.
- Non-conformance is a deviation from accepted technical or operational tolerances.

Table 2.1 Terms and Definitions

Terms	Definitions
Peril	something that causes or may cause injury, loss, or destruction
Danger	an instance or cause of peril; menace
Harm	physical or mental injury
Error	a deviation from accuracy or correctness
Hazard	- possible events or conditions that may result in severity, i.e. cause significant harm [7] - potential to threaten human life, health, property or the environment [8]
Risk	- an evaluation of hazards in terms of severity and probability [7] - a combination of frequency and the severity of consequence [8]
Consequence	the outcome of an accident [8]
Safety	the degree of freedom from danger and harm. Safety is achieved by doing things right the first time and every time [7]
Reliability	the ability of a system or component to perform certain defined functions [7]
Safety Management	keeping an operation safe through systematic and safety-minded organization and management of both human and physical resources [7]
System Safety	the discipline that utilizes system engineering and management techniques to make systems safe throughout their life-cycle [7]
Risk Analysis	the process of calculating the risk for the identified hazards [7]
Risk Assessment	the process of using the results obtained in the risk analysis to improve the safety of a system through risk reduction [7]
Risk Management	a process to manage the risk in the system by considering new safety measures (or risk control measures) and assessing to what degree current risk management and regulations mitigate the system hazards [7]
Formal Safety Assessment (FSA)	a structured and systematic methodology, aimed at enhancing maritime safety, including protection of life, health, the marine environment and property, by using risk analysis and cost benefit assessment [8]
Human Error	a departure from acceptable or desirable practice on the part of an individual or a group of individuals that can result in unacceptable or undesirable results [8]
Human Reliability	the probability that a person: correctly performs some system-required activity in a required time period, performs no extraneous activity that can degrade the system [8]
Human Factors/ Ergonomics	study concerned with optimizing the relationship between people and their activities, by the systematic application of human sciences, integrated within the framework of system engineering, synonymous with ergonomics [9])
Human Element	a term synonymous with human factors (widely used in Asia) or ergonomics (widely used in Europe), set by IMO [8]
Human Sciences	Study of the structure and nature of human beings, their capabilities and limitations, and their behaviors both singly and in groups [9]

Those three events can also be determined by the different degrees of seriousness with respect to consequences as follows:

- Accident is an undesirable event that results in damage to humans, asset and/or the environment.

- Incident is an undesirable event that are detected, brought under control or neutralized before they result in accidental outcomes
- Non-conformance is a situation where the operation is outside certain criteria that define what is acceptable.

2.2 Maritime Transportation System (MTS)

Before analyzing maritime accidents, we have to know about the Maritime Transportation System (MTS). According to Kristiansen, the MTS includes actors, effects and deviations [7]. It should be pointed out that the performance, or rather lack of performance from the actors, will be reflected in different types of deviations or non-conformities and result in some effects. While Rothblum says that the MTS is a people system [10]. In this system people interact with technology, the environment, and organizational factors as shown in Fig. 2.1.

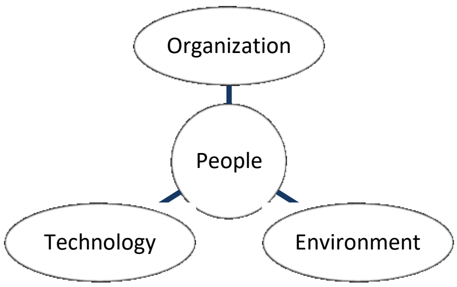


Fig. 2.1 Maritime Transportation System (revised [10])

Table 2.2 Maritime systems effects - people

	Effects from system	Effects on people
Technology (Machine)	- Anthropometry - Equipment layout - Information display - Maintenance	- Reach, strength, agility - Perception & comprehension - Decision-making - Safety and performance
Environment (Media)	- Temperature, noise - Sea state, vibration - Regulations - Economics	- Physical and mental performance - Fatigue - Risk-taking
Organization (Management)	- Work schedules - Crew complements - Training - Communication - Safety culture	- Fatigue - Knowledge and skills - Work practices - Teamwork - Risk-taking

First, the core of the system is people. In the MTS, this includes the ship's crew, pilots, dock workers, Vessel Traffic Service (VTS) operators, and others. The performance of these people depends on many traits, both innate and learned. The components of people are made up of their knowledge, skills, abilities, memories, motivations, and alertness. The interaction between people and other factors is shown in Table 2.2.

Since all the elements connect and affect each other, the system cannot be broken down into separate components. Mullai and Paulson describe the MTS as a very complex and large-scale socio-technical environment (STE) system comprising human and man-made entities that interact with each other and operate in a physical environment [11]. In the STE system, the system can be analyzed as a combination of technology (the vessel, engine, equipment, instruments, etc.) and a social system (the crew, their culture, norms, habits, customs, practices, etc.) [4]. The STE system analysis of maritime accidents looks at system error rather than organizational or human error.

As a very complex and large-scale STE, the combination of social – technical environment occurs frequently. In terms of maritime transportation, ships that is the main object for transporting the goods is supported by various stakeholders that guarantee the process of transferring goods from one place to another goes well. These stakeholders is create as the function of it special aim and take part to complete each other. For example, to make an equal the level of playing field in world`s shipping requirements, International Maritime Organization (IMO) was created and established the policy that concern to shipping activities. To assist the seafarers to enter and leave the seaport, the pilotage was born. Classification society also initiated to assure that the ships that used as main transportation tools is safely functioned. There are possibilities that another maritime stakeholder will establish in order to make shipping activities and other maritime-related transportation become safer.

2.3 Number of operated ship

World`s ships number is increasing year by year, shown in Fig. 2.1. In 2011, the number of ships is recorded at 83,283 units, while in 2016, the number of ships that going in the ocean is 90,917 ships [1]. This fact shows that sea trading is still a favorable choice to transport goods from a country to another. Besides, it indicates the development of MTS. Ships is also constructed with the latest technology to make it as a tool that can assure the high level of safety, with as much as it can in term of ships capacity, and harmless for environment.

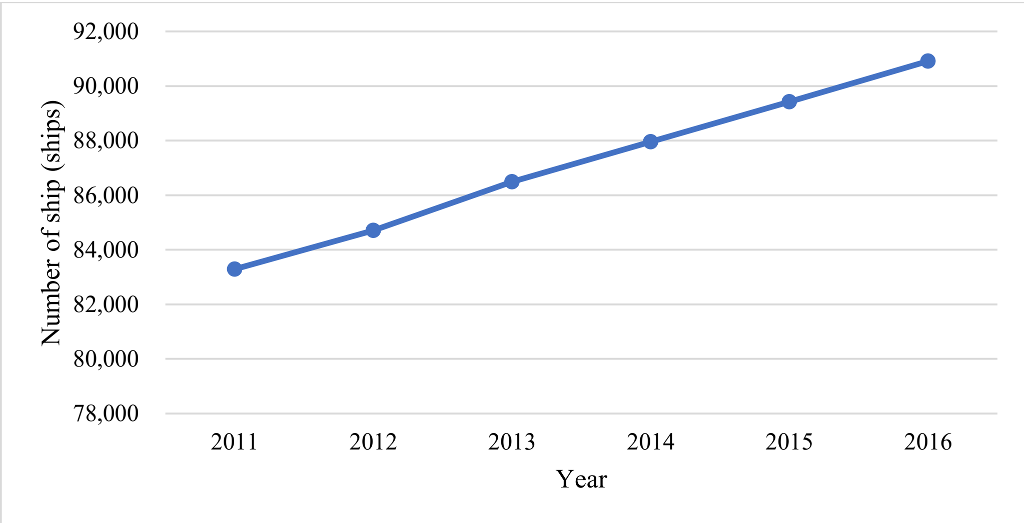


Fig. 2.2 The Number of Ships in the World in 2011-2016

In the website, UNCTAD break down all the ships registered in each country. Fig. 2.3 below show the number of ship in Japan, United Kingdom (UK), United States (US), and Australia that are also analyzed in this study.

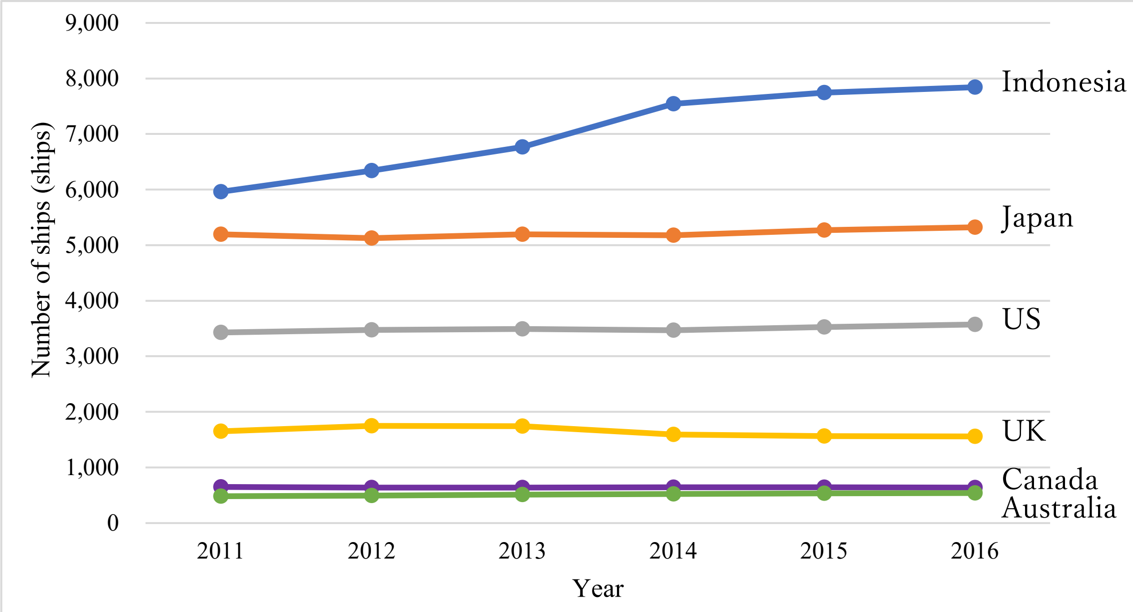


Fig. 2.3 The number of ships in Indonesia, Japan, US, UK, Canada, Australia in 2011-2016

From Fig. 2.2, it shows that only ships in Canada is decreased, meanwhile the other are increased.

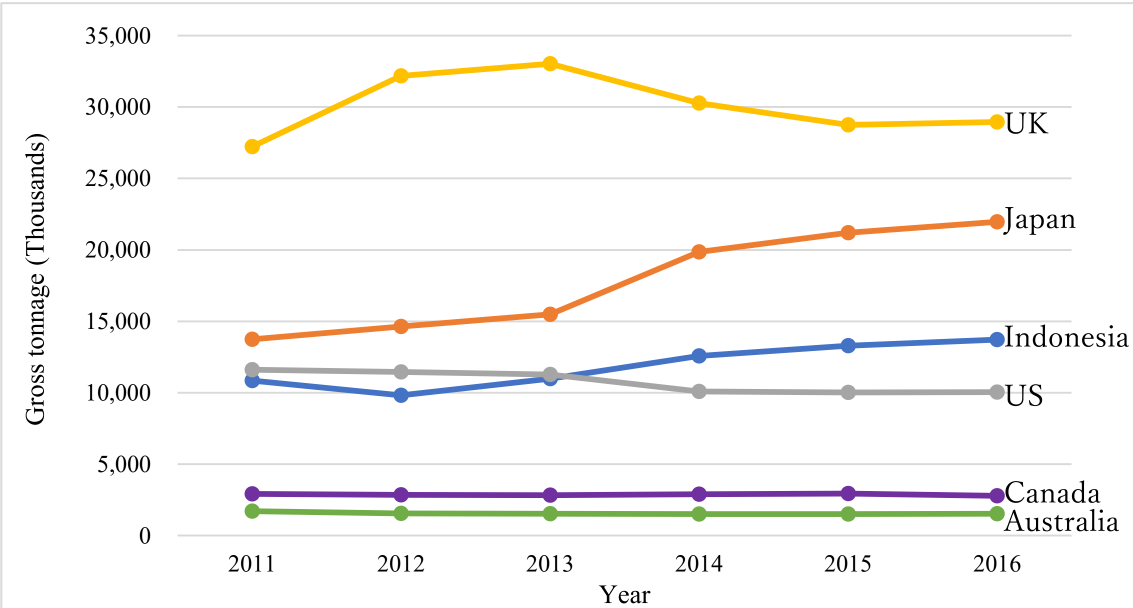


Fig. 2.4 The total amount of gross tonnage in Indonesia, Japan, US, UK, Canada, Australia in 2011-2016

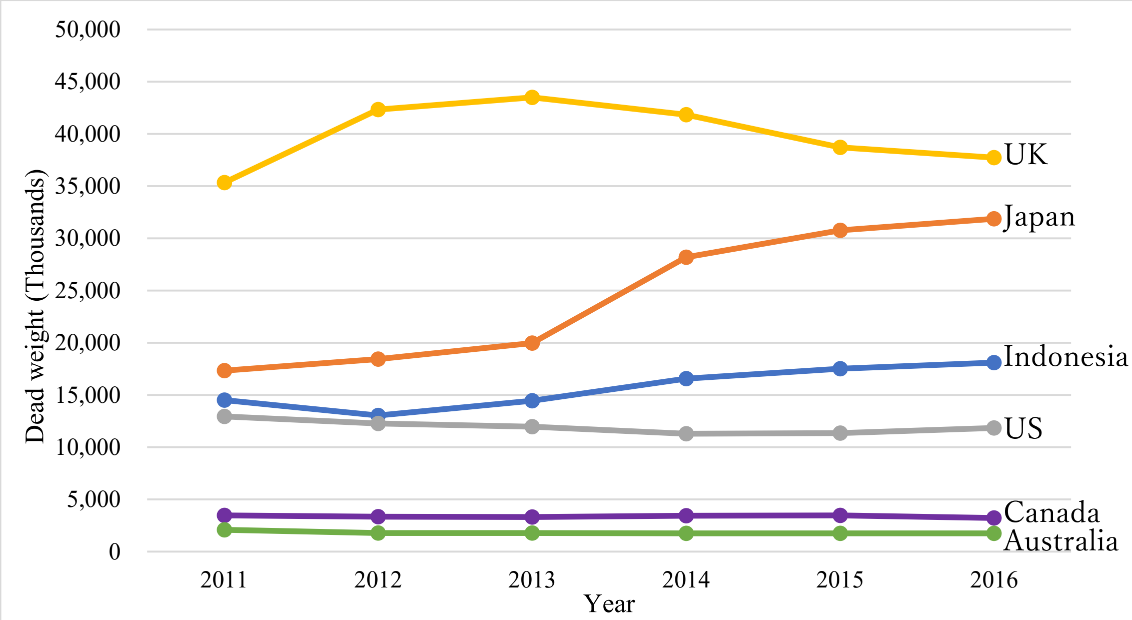


Fig. 2.5 The total amount of dead weight in Indonesia, Japan, US, UK, Canada, Australia in 2011-2016

Fig. 2.3-2.4 shows the total gross tonnage and dead weight. UK, Japan, and Indonesian ships are increased, but US, Canada, and Australia are not.

2.4 Accidents

2.4.1 Definition

Accident is an event that leads to damage, environmental consequences, with injuries or fatalities and economic loss [7]. Even though the technology, regulation, training, etc. are always developed to ensure the safety of the MTS, accidents are still occurred. Because of the large amount of loss caused by the accidents, many countries establish Maritime Transportation Safety Agency (MTSA) to prevent the accidents. This body usually investigate the accidents carefully, finds the causative factors of the accidents, learn it as a part of countermeasure action, and to conclude some safety recommendation to avoid the same event that lead to an accident. The examples of MTSA and its total investigation report publications are:

1. Japan Transport Safety Board (JTSB), 9684 investigation reports (64 reported in English) [12] [13].
2. Indonesia National Transportation Safety Committee (NTSC), 54

investigation reports.

3. United Kingdom Marine Accident Investigation Branch (MAIB), 536 investigation reports [14].
4. Transportation Safety Board of Canada (TSB), 3270 investigation reports [15].
5. Australian Transportation Safety Bureau (ATSB), 339 investigation reports [16].
6. United States National Transportation Safety Board (NTSB), 225 investigation reports [17].
7. European Maritime Safety Agency (EMSA), 566 investigation reports [18].

From the investigation report published by MTSA, author found interesting classification of the accident based on the types, time occurrence, and place occurrence. In terms of accident place, it is classified into accident that occur on the sea, on the port, and along the river. In terms of time occurrence, accidents are classified into 3 times, inter alia:

Day time is time range covering the period in which the sun is above the horizon, starting thirty minutes after nautical dawn and ending thirty minutes before nautical dusk begins

Night time is the time range that includes the time between thirty minutes after nautical dusk and thirty minutes before nautical dawn

Twilight time the twilight time is a combination of nautical dawn and dusk, including thirty minutes before and after the nautical time.

There are several types of accidents. Sometimes different MTSA use a same term for the same type of accident and sometime different. Hereby the definition of accident that is analyzed in this study, taken by EMSA definition:

Occupational accident is the accident that affect to the person who work whether on the ship or the proses of transporting goods.

Collision is the accident caused by ships striking or being struck by another ship, regardless of whether the ships are underway, anchored or moored. This type of casualty event does not include ships striking underwater wrecks. The collision can be with other ship or with multiple ships or ship not underway.

Contact is the accident caused by ships striking or being struck by an external object. The objects can be: Floating object (cargo, ice, other or unknown); Fixed object, but not the sea bottom; or Flying object. However, in this study, author analyses contact together with collision become one category, namely collision.

Fire/explosion is an uncontrolled ignition of flammable chemicals and other materials on board of a ship. Fire is the uncontrolled process of combustion characterized by heat or smoke or flame or any combination of these. Explosion is an uncontrolled release of energy which causes a pressure discontinuity or blast wave.

Capsizing/Listing is a condition where the ship no longer floats in the right-side-up mode due to: negative initial stability (negative metacentric height), or transversal shift of the center of gravity, or the impact of external forces. Capsizing when the ship is tipped over until disabled. Listing when the ship has a permanent heel or angle of loll.

Damage to equipment is damage to equipment, system or the ship not covered by any of the other casualty type.

Grounding/stranding is a moving navigating ship, either under command, under Power, or not under command, Drift(ing), striking the sea bottom, shore or underwater wrecks.

Flooding/foundering is an accident when the ship is taking water on board. Foundering will be considered when the vessel has sunk. Foundering should only be regarded as the first casualty event if we do not know the details of the flooding which caused the vessel to founder. In the chain of events foundering can be the last casualty event in this case there is the need to add accidental events. Flooding refers to a casualty when a vessel takes water on board and can be progressive (if the water flow is gradual) and massive (if the water flow is extensive)

Hull failure is a failure affecting the general structural strength of the ship.

Loss of control is a total or temporary loss of the ability to operate or maneuver the ship, failure of electric power, or to contain on board cargo or other substances (electrical, power, directional control, and containment).

Missing is accident to a ship whose fate is undetermined with no information having being received on the loss and whereabouts after a reasonable period of time.

2.4.2 Accident Models

There are several analysis terms used to describe accident phenomena, such as approaches, techniques, frameworks, methodologies, methods, and models. Several researchers, such as Leveson [19], Grabowski et al [20], Nikolas et al in 2004, Laracy in 2006, which are included in Mullai and Paulson use an *accident model* [11]. According to Mullai and Paulson, an accident model is an abstract concept representing the occurrence and development of an accident. This tool is also used to view and think about how and why an accident can occur and make predictions.

All accident models can be distinguished as three main types, sequential, epidemiological, and systemic [21] [11] [22]. This categorization relates to assumptions of accident causation. It helps researchers explain system theory concepts into accident models [22]. Each Model description will be explained in the following sections.

i. Sequential Accident Models

This is the simplest type of accident model describing accidents as the result of time-ordered sequences of discrete events. It assumes that an undesirable event, i.e. a ‘root cause’ initiates a sequence of events which lead to an accident and that the cause-effect relation between consecutive events is linear and deterministic. This implies that the accident is the result of this root cause which, if identified and removed, will prevent a recurrence of the accident [22].

Examples of this model are:

- Domino Model (Heinrich in 1931),
- Five Whys Method (Ohno in 1988),
- Framework for Maritime Risk Assessment (Harrald et al in1998),
- Fault Tree Analysis (Watson, 1961 cited in Ericson in 1999)
- Bowtie Model (Hollnagel in 2008).

Hollnagel said that this model is attractive because it encourages thinking in a causal series rather than causal nets [23]. Furthermore, this model can be described by graphics, which facilitates communication of the results.

This model works well for losses caused by physical component failures, or the actions of humans in relatively simple systems, and generally offers a good description of the events leading up to an accident. However, the cause-effect relationship between the management, organizational, and human elements in a system are poorly defined by this model and they are unable to depict how these causal factors trigger the accident.

ii. Epidemiological Accident Models

This model describes an accident like a disease, an outcome of a combination of factors, some manifest and some latent, that happen to exist together in space and time [21]. In other words, contributing failures are ‘latent’ and ‘active’ failures [22]. Latent conditions, e.g. management practices or organizational cultures, are likened to resident pathogens and can lie dormant within a system for a long time. Such organizational factors can create conditions at a local level, i.e. where operational tasks are conducted, which negatively impact on an individual's performance (e.g. fatigue or high workload). The scene is then set for 'unsafe acts', such as errors and violations, to occur. Therefore, adverse consequences of latent failures breach the defenses of a system.

Examples of this model are:

- Swiss Cheese Model (Reason in 1990 and 1997)
- 'Sharp end'-'blunt end' interactions (Wood et al in 1994)
- Cognitive Reliability and Error Assessment Method (CREAM) (Hollnagel in 1998)
- Human Factors Analysis and Classification System (HFACS) (Wiegmann and Shappel in 2003)
- Models of pathological system (organization) states
- Tripod Beta

Hollnagel (2008) says that epidemiological models are valuable because they provide a basis for discussing the complexity of accidents that overcome the limitations of sequential models [23]. The notion of latent factors simply cannot be reconciled with the simple idea of a causal series, but requires a more powerful representation, at least that of a causal network. This means that the analysis cannot be a search for simple causes, but must involve an account of more complex interactions among different factors. Unfortunately, this epidemiological model is no longer able to account for the increasingly complex nature of STE Systems [22].

iii. Systemic Accident Models

The systemic model is designed to describe characteristic performance at the level of the system as a whole, rather than on the level of specific cause-effect "mechanisms" [21]. It describes the losses as the unexpected behavior of a system caused by uncontrolled relationships between its constituent parts (Underwood and Waterson, 2013). In Underwood and Waterson's report, accidents are not created by a combination of latent and active failure, or the result of a sequence of cause-effect events. Accidents are the result of humans and technology operating in ways that seem rational at a local level, but unknowingly create unsafe conditions within the system that remained uncorrected. Simply removing the 'root cause' from a system is not the key for preventing the recurrence of an accident. A holistic approach is required, whereby safety deficiencies throughout the entire system must be identified and addressed.

Examples of this model are:

- Control Theory (Sheridan in 1992)
- Accimap (Rasmussen in 1997)
- Neural Networks (NN) Concept (Hashemi et al in 1995; Le Blanc et al in 2001)
- Simulation and Expert judgement (Harrald et al in 1998)
- Fuzzy Logic (Sii et al in 2001)
- Bayesian Belief Network concept (BBN) (Merrick and Singh, 2003; Trucco et al in 2008)
- Systems Theoretic Analysis Model and Processes Model (STAMP) (Leveson in 2004 and 2011)
- The Functional Resonance Analysis Method (FRAM) (Hollagel in 2004 and 2012)
- Risk Based Approaches (Vanem and Skjong in 2006; Celik et al in 2010)

The distinction between the epidemiological and systemic perspective of accidents, therefore, seems to be subtle. Whilst the system model is arguably the dominant concept within accident analysis research, systemic models are yet to gain widespread acceptance within the practitioner community [22].

2.4.3 Accident Model Selection

Even though Systemic Accident Models provide a depth of understanding of complex accidents better than other models, it is not efficient to apply this model for simple accidents [22]. Therefore, the model should be correctly utilized based on the complexity of the accident or the system. In order to determine a system's characteristics, Hollnagel proposed a means of characterizing a system, modifying the work of Perrow in 1984, which describes a system using the dimensions of *coupling and manageability* [23] as shown in Fig. 2.5.

The coupling of a system can vary between being loose and tight and refers to how the subsystem and/or components are functionally connected or dependent upon each other [22]. Tightly coupled systems can be characterized as follows:

- Buffers and redundancies are purposely part of the design
- Delays in processing are not possible
- Process sequences are invariant
- The substitution of supplies, equipment, and personnel are limited and anticipated in the design
- There is little slack possible in supplies, equipment, and personnel
- There is only one method to reach the goal
- Tightly coupled systems are difficult to control because an event in one part of the system will quickly spread to other parts.

The complexity of the system can be seen by how easy it is to manage, is it tractable or intractable? The characteristics of a tractable system are:

- The principles of the system's functioning are known
- System descriptions are simple and with few details
- The system does not change while it is being described

While Hollnagel proposed the chart to categorize the type of the system [23], Underwood and Waterson modified the chart and wrote the names of each area to make it easier to be understood [22]. With the chart (Fig. 2.5), the researcher can utilize or develop the correct model to analyze the accident in each field.

Underwood and Waterson has provided where the MTS in the chart. From that figure, reader can easily select epidemiological accident model. This means that MTS is better analyzed by finding the latent and active failures to describe how the accident occurred.

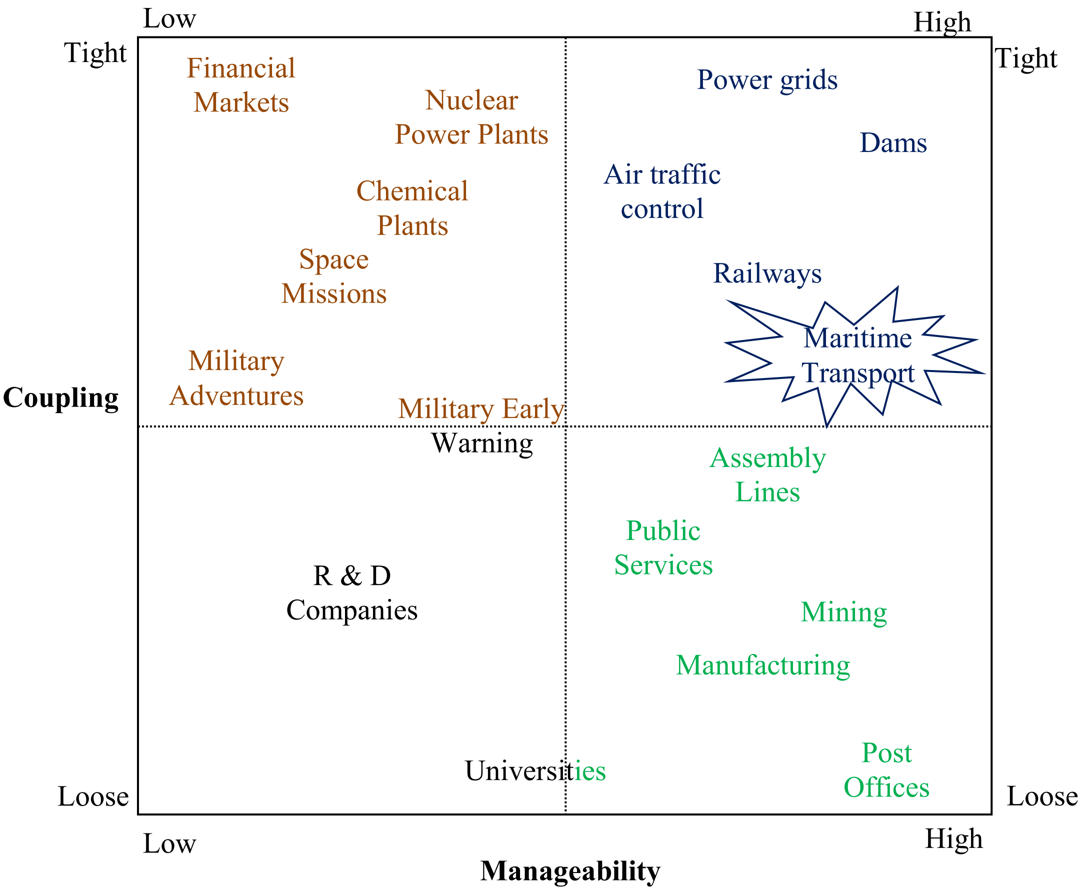


Fig. 2.6 Accident Model Categorization, whether Sequential, Epidemiological, or Systemic (adapted from [22])

Chapter 3
4M Overturned Pyramid (MOP) Model

3.1 Introduction

The proposed MOP model was developed for the maritime domain. As stated previously, MTS is better explained by the epidemiological model that consists of latent conditions, barriers, and active conditions. The proposed MOP model is a combination of the epidemiological, Septigon, and IM models.

The Septigon model categorizes the MTS into seven domains: society and culture, physical environment, practice, technology, individual, group, and organizational environment networks [4]. Fig. 3.1 show the septigon model and table 3.1 explain the definition of its domains. All domains are connected to and affected by each other in the MTS. Any error in one domain can affect the entire system.

In 2000, Furusho proposed a simpler system called the IM model. This model consists of 4M factors (man, machine, media, and management) that are connected by the individual element (I) as the core of the system [5] [6].

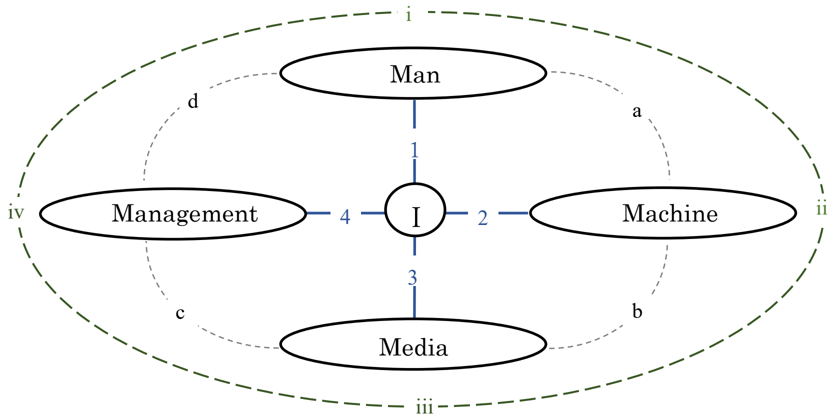
Fig. 3.1 The Septigon Model: Society and culture, Physical Environment, Practice, Technology, Individual, Group, and Organizational environment Network [4]

Table 3.1 The Septigon Model Term Definitions

Term	Definition
Society and culture.	It refers to the sociopolitical and economic environment in which the organization operates.
Physical Environment.	It refers to the surrounding environment, such as weather, visibility conditions, obstructions to vision, physical workspace environment (air quality, temperature, lighting conditions, noise, smoke, vibration, ship motion, etc.)
Practice.	It refers to such aspects as informal rules and custom. However, these are not related to written procedures or instructions.
Technology.	It refers to equipment, vehicles, tools, manuals, and signs, and also deals with human machine interaction issues.
Individual.	It refers to the human component, and incorporates such aspects as individual physical or sensory limitations, human physiology, psychological limitation, individual workload management and experience, skill, and knowledge.
Group._	It refers to the relational and communication aspects, such as communication, interactions, team skills, crew/team resource management training, supervision, and regulatory activities. Group also deals with leadership, and teamwork.
Organizational environment.	It refers to the company and management as well as the procedures, policies, norms, and formal rules.

Table 3.2 Description of the 4 M Factors in IM Model

4M Factors	Descriptions
Man	This term means the individual error of person such as master, an officer, a pilot, a VTIS's officer, and crew on board. This error has relation of "Human Factors" including the mind stress or the mistake without the problem of responsibility
Machine	This term means defect and breakdowns such as damages of hull and failures of engines and ship's other facilities.
Media	This term has a considerably wide meaning and indicates and environmental condition that affects the information on the communication and the service, the weather condition, the harbor facilities, and the navigational aids for sailing.
Management	The activity of the company, the group, and the administration for safety.



Internal Concept:
1 Human Relation
2 Human Interface
3 Media Information
4 Self Control

Intermediate Concept:
a Man-Machine Interface for Navigation
b Information Aids for Navigation
c Maritime Environmental Protection
d Bridge Resource Management

External Concept:
i STCW
ii SOLAS
iii MARPOL
iv COLREG

Fig. 3.2 IM Model (revised [5] [6])

IM Model is shown in Fig. 3.2 and the definition of 4M Factors in IM model is written in Table 3.2. However, the IM Model is designed for the navigational domain. All the relation whether are internal or intermediate concept are the interaction among the system to the safe in navigational activity. Since the Maritime Traffic System is wider than navigational activity, this model can be developed to a wider activity including the process of the preparation activity before sailing, the regulation, maintenance of the ships, and so on.

The proposed MOP model is drawn three-dimensionally as a three-sided inverted pyramid with four corners, representing the 4M factors, and six edges, representing an interaction between two 4M factors that are connected by the edges, as shown in Fig. 3.3.

The edges, called line relations, show that the system is a result of interactions among the 4M factors. Failures that are classified in a corner of the MOP model do not always occur only because of that particular corner. Often, the failure is caused by some effect from the other corners. When there are failures caused by several corners, this implies that the line relations connecting those corners also contribute to the instability of the system. For example, consider a failure in communication. Communication cannot be classified into one corner because communication is related to all four corners. A failure in communication among seafarers is classified as man factor (M1) because this type of communication depends on a person. Often, several seafarers do not share information with other seafarers. However, communication failures among ships and between port administrations do not belong to the man factor. They can belong to either the management or the machine factor and can be affected by the media factor. The classification of failure depends on the condition of the accident. When a line relation contributes to an accident, a preventive action for the line relation has to be determined. Thus, for a safe system, all corners and edges should be reliable and balanced.

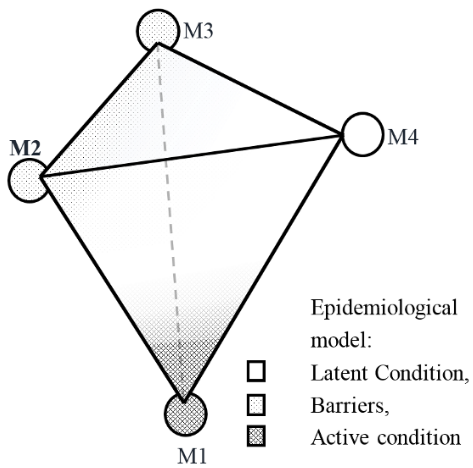


Fig. 3.3 MOP model

Because the MTS consists of latent conditions, barriers, and active conditions, any accident that occurs in the MTS should be traced for each of these factors separately. Each factor (corner) of the MOP model is represented in the epidemiological model as shown in Fig. 3.1. In this figure, the individual, M1 (man factor), receives some information from M3 (media factor: environment) and from M2 (machine factor: crew complement); subsequently, this information is used for decision making. Hazard perceptions are also influenced by M4 (management factor).

Table 3.3 lists the definitions and examples of the corners in the MOP model. By understanding the definitions, it is easier to determine the causes of the accidents using the epidemiological model, and then, preventive actions can be considered. In addition, the characteristics of several accidents can be explored by analyzing their accident reports for any tendencies, as carried out in this research.

Table 3.3 Definitions and examples of MOP Model

4M Factors	Definition	Examples
Man (M1)	Human elements that affect people doing their tasks	Knowledge, Skills, Abilities, Memory, Motivation, Alertness, Experience, etc.
Machine (M2)	Tools that help people to complete their tasks, including technology	Equipment, Information displays, Environmental design, Crew complements, Construction, etc.
Media (M3)	Environmental factors that affect the system and/or people	Climatic/ weather conditions (temperature, noise, sea state, vibration, wave, tide, wind, etc.), Economic conditions, Social politics, Culture, etc.
Management (M4)	All elements that can control the system and/or people	Training scheme, Communication, Work schedule, Supervising/ monitoring, Regulatory activities, Procedures, Rules, Maintenance, etc.

There are 2 steps to analyze accident reports using MOP model, Corner Analysis (CA) and Line Relation Analysis (LRA). These 2 steps will be explained in detail in the next subsection.

3.2 The Concept

The MOP model consists of two steps to describe the occurrence of an accident.

3.2.1 Corner Analysis (CA)

This step traces and lists all failures that caused accidents and classifies them into 4M based on the definitions of each corner of the MOP model. Then, we count the number of failures after all reports are analyzed. The failures listed are causative factors (CFs), which is the outcome of this step.

CFs are also listed based on the accident development stage of the accident (ADS). There are three stages of accident development, the beginning, the accident itself, and the evacuation process, labeled as stage 1, 2, and 3, respectively [24]. In analyzing accidents, especially to find the causative factors, the accident development stages need to be carefully considered because the failure may have occurred in any one of these stages or even in all the stages. The failures that occurred before the accident, or in other words the fails/ problems/ conditions leading to the accident, are categorized in Stage 1. After the probability of the accident is identified by the seamen, preventive action should be carried out. However, sometimes seamen face several problems at the same time and this causes them to fail to avoid the accident. This failures are categorized in Stage 2. Finally, after an accident occurs, the stakeholders related to the accident, should take some post-accident remediation. The failure that occurred in this post-accident remediation is categorized in Stage 3. Any failure in Stage 3 can cause other problems such as pollution and other accidents. For example, if the master does not carry out a post-collision check correctly, the other ship can be sunk and or capsized and there may be many victims.

3.2.2 Line Relation Analysis (LRA)

CFs listed in the result of CA do not only belong in one corner. Most of the CF has relation with other CFs, whether caused by or causing other CFs. In this step the relationship among all the CFs listed in the corners of the MOP model are explored. The relation of several CFs makes line relation and if we figure the relation to the geometry of MOP model (the inverted pyramid), the edge lines are existed representing the relation that perform chain. The chains made by several CFs are called causative chains (CCs). By performing line relation analysis, we can understand which line relation is the most vulnerable to failure.

3.3 Developments

This section contains the development of the MOP model from the beginning to the last stage. This development gives the model the ability to analyze accident reports in more detail. This makes up the originality of this dissertation. Elements of this development of MOP model have been documented in detail in proceeding, journals, and prior publications in Table 3.4.

Table 3.4 The development of MOP Model in MTS

No.	Year	Development	Published on	Title	Case study
1.	2012-2013	Creating MOP Model from 4M Factors	ANC 2013	A Study of Ship Accidents in Indonesia Using 4 M Factors [25]	Case of Fire in Indonesia
2.	2014	1. Defining MTS 2. Defining 4 corners of MOP Model	ANC 2014	The 4M Overturned Pyramid (MOP) Model in Maritime Traffic System for Safety at Sea [26]	Explanation of MOP Model
3.	2015	1. 2 step analysis: CA and LRA	TransNav 2015	4M Overturned Pyramid (MOP) Model: Case Studies on Indonesia and Japanese Maritime Traffic Systems (MTS) [27]	Comparing Indonesian & Japanese Accidents
4.		2. Detail analysis: 3 Stages of accident development	ANC 2015	Analysis of Ship-Collision Accidents in United Kingdom using MOP Model [28]	Case of collisions in UK
5.	2016	1. 3 time occurrence zones	ISOCEEN 2015	Introducing 4M Overturned Pyramid (MOP) Model to Analyze Accidents in Maritime Traffic System (MTS): A Case Study on Collisions in Japan Based on Occurrence Time [29]	Case of collisions in Japan
6.		2. Detail LRA for improper look-out	ANC 2016	Improper Look-out Leading to Ship Collisions in Japan [30]	
7.		3. Adding a causative chain list as the final outcome of MOP Model	SENTA 2016	Causative Chain that Leads to Ship Collisions in Japanese Maritime Traffic System (MTS) as Final Outcome of MOP Model	
8.	2017		Transnav 2017	Causative Chain Difference for each Type of Accident in Japanese Maritime Traffic Systems (MTS) [31]	Cases of collision and occupational accident in Japan

The MOP model is generally based on Man-Machine-Media-Management (4M)

Factors. It is started from 4M factors concept and then evolved to MOP model. Back in 2012, the idea is to find the causative factor of ship accident in Indonesia. 4M factor was utilized to analyze the accident and causative factors was found. In 2013 until the beginning of 2014, the concept of 4M factor was developed to three dimensionally looks alike become three-sided inverted pyramid namely 4**M** **O**verturned **P**yramid model or abbreviated to MOP model. The terms of "mop" is so familiar in daily life. Mop is a tool to clean up the dirty things. Hopefully MOP model also can be one alternative tool to clean up or reduce the ship accidents.

In the end of 2014, the further development of MOP model is to make a detail definition of Marine Traffic Systems (MTS) and the definition of each 4M factors of MOP model itself. The definition of each 4M factors must be specified as the reference of the analysis, to focus the discussion regarding the exact definition of each 4M factors, remembering there are a lot of definition regarding 4M factors. In 2015, the development of MOP model is in the analysis step. From the previous MOP model which just one step analysis called Corner Analysis (CA), the analysis that focus on the accident based on 4M factors only, become two steps. The first step is CA and the second step is Line Relation Analysis (LRA). LRA covers the relationship between each corner, so which corner-corner relation that have significant relation causing the accident could be known.

In the end of 2015, the development is keep on going, this time the detailed CA was established. CA is consisted of four corners producing Causative Factor (CF) that represent in each corner as Man Corner, Machine Corner, Media Corner, and Management Corner. The development was conducted by adding analysis in 3 different stages of accidents development. These stages are:

Stage 1: Leading to accident (before the accident)
Stage 2: Failure in avoiding accident (the accident time)
Stage 3: Failure in evacuation process (after the accident)

The aim of this addition is to get know in which stage the accident was happened. Is the behavior of seafarers before the accident that lead to accident, is the effort of seafarers to avoiding the accident effective, or is the evacuation process effective enough to reduce the risk or fatality of the accident. The analysis of each stage could make the MOP model more detail in the analysis.

In 2016, interesting analysis result regarding time occurrence was obtained. Based on 2008-2013 accident investigation report, the average day, night, and twilight periods were 12h 45m, 8h 10m, and 3h 05m, respectively. Accidents that happened at twilight were 154 cases during 3h 05m period works out to about 51 collisions per hour, while the number of accidents that happened at night were 240 cases during 8h 10m period works out to only 30 collisions per hour. These facts stimulate the need to research the characteristic differences of collisions that happen in each time occurrence zone. Another interesting result is in collision accident, the dominant causative factor was “improper lookout”. Thus, the detailed analysis, especially LRA regarding the causing and caused CF by the improper lookout was needed. This analysis was the idea to add more detailed analysis to improve LRA in MOP model better.

Because the CF of each accident was not standing alone, the LRA was established. More detail in LRA, the relation of each CF was modified into Causative Chain (CC) that allow us to know what CF causing another CF and caused by another CF. The development of MOP model is still on progress, the latest condition of MOP model development is the outcome of each analysis. The outcome of CA is CF list, while the LRA outcome is CC list.

Chapter 4
Accidents in Several Countries Analyzed by MOP Model

4.1 Introduction

In order to see how reliable the MOP model is in characterizing accidents, the MOP model is applied to accidents in several countries in this chapter. Details of the steps of the MOP model are explained here. The data analyzed here is from accidents investigated by MTSA listed in Chapter 2. However, because of limitations in the data, only accidents in Japan, UK, US, and Australia are provided here. Fig. 4.1 shows the number of investigated accidents from those countries.

In Fig. 4.1, we can see the available data that can be re-analyzed by MOP model. Collision/contact was chosen for the analysis because it involves the largest number among all accident types. The number of ship involved in the accidents is more than the number of cases, as shown in Fig. 4.2.

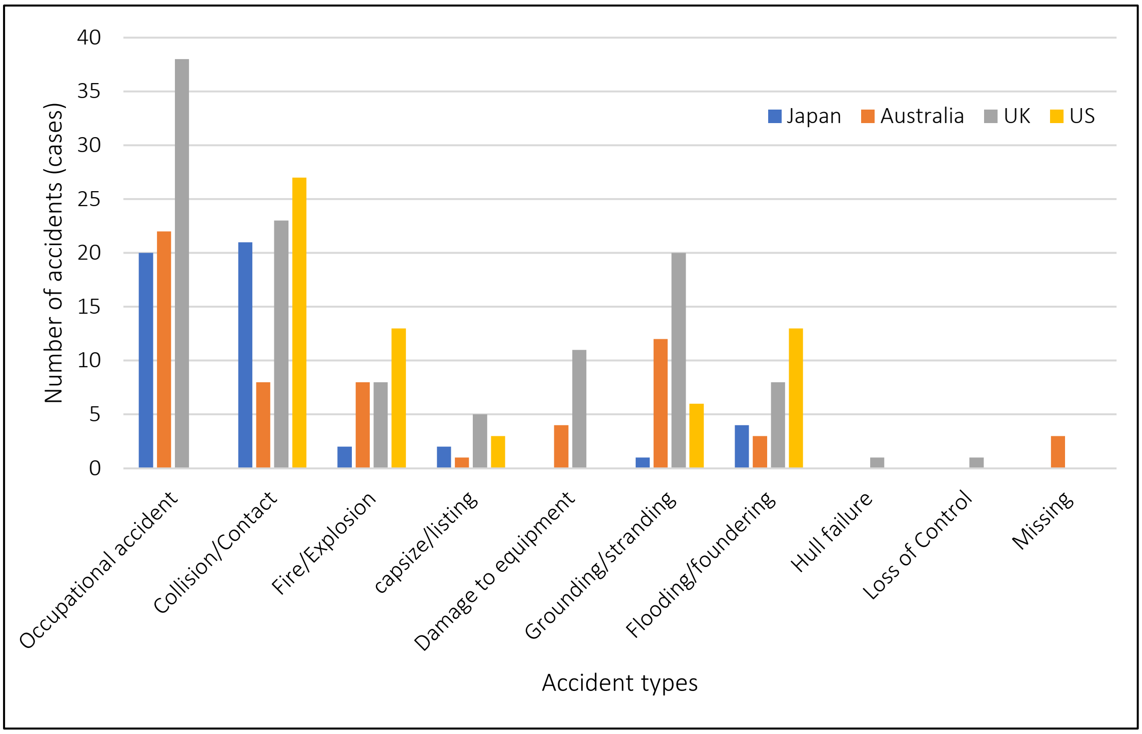


Fig. 4.1 Number of investigation reports classified by accident type in 2008-2013

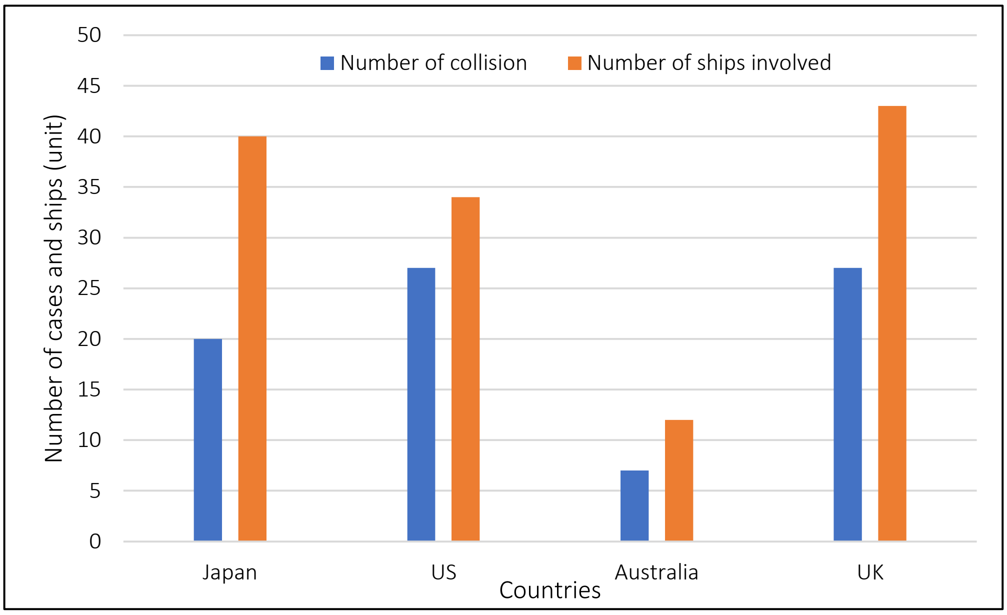


Fig. 4.2 Number of collision cases and the ships involved in 2008-2013

Fig. 4.2 provides the number of cases and ships involved that are analyzed in this dissertation. In total, there are 81 collisions and 129 ships involved in this research.

4.2 Corner analysis (CA)

In this step, all the causative factors (CFs), from every ship that led to collision are broken down, and classified into three stages of accident development. Each causative factor may have several failures. Thus, every ship has a maximum of three failures if it fails in every stage for every CF. If the collision involves two ships, the maximum number of failures is 6. In total, there are 129 ships involved in collisions, this means that the maximum number of failures is 387 for every CF, again if all the ships failed in every stage of accident development. Tables 4.1 - 4.4 provide the list of CF as outcome of this step and are categorized as man (M1), machine (M2), media (M3), and management (M4) factor.

We can see from the tables that CF in M1 has the highest number of failures. These are from careless seaman monitoring/identifying any risk, or in maintaining proper lookout, or communications among seamen (or with pilot), and in understanding conditions (wrong judgement/decision).

The comparisons of each country are provided in Fig. 4.3 - 4.7. The comparisons use occurrence ratio, not number of failures, because the number of ships analyzed is different between Japan, US, Australia, and UK. The occurrence ratio of each CF is counted by dividing the total number of failures by the maximum number of failures for each country.

Table 4.1 Number of failures for each CF categorized as M1

Codes	Causative Factors (CF)	Number of failures				
		J	US	A	UK	T
CARELESS SEAMAN						
M101-01	in communication among the seamen (or with pilot)	8	12	5	19	44
M101-02	in maintaining proper lookout	25	7	10	18	60
M101-03	in monitoring/identifying any accident risk	23	12	9	18	62
M101-04	in understanding condition (wrong judgement/decision)	12	14	6	9	41
M101-05	in deciding speed	10	7	0	6	23
M101-06	in deciding course alteration	9	2	0	7	18
M101-07	doing erratic/ineffective action in avoiding accident	3	1	4	11	19
M101-08	in flashing light signal	1	0	1	0	2
M101-09	in blasting sound signal	2	3	0	7	12
M101-10	in wearing/utilizing safety/survival devices	2	1	1	3	7
M101-11	in preventing flooding	1	1	0	0	2
M101-12	in carrying out / following some procedures/ rules	0	3	4	14	21
INCAPABILITY OF SEAMAN/PERSONNEL						
M102-01	in operating navigational equipment (unfamiliar)	4	3	1	8	16
M102-02	in understanding signal from other vessels	1	0	0	1	2
M102-03	in controlling the operation	0	13	1	12	26
M102-04	in arranging working procedure (mooring, berthing, towing)	0	9	3	11	23
M102-05	in performing crossing agreement	0	1	0	0	1
M102-06	in executing commands from master/pilot/company rule	0	3	2	1	6
M103-01	focus of the seamen was distracted	11	6	2	5	24
SOME SEAMEN WERE NOT ON THE BRIDGE						
M104-01	watch keeper was not on the bridge	3	0	1	1	5
M104-02	master was not on the bridge	2	0	1	1	4
HUMAN ELEMENT PROBLEM						
M105-01	fatigue	1	1	1	6	9
M105-02	lethargy	0	0	0	1	1
M105-03	sleep inertia	0	0	0	1	1
M105-04	stress	0	0	0	1	1
M105-05	intoxication	0	2	0	2	4
M105-06	complacent attitude	0	0	0	3	3
	TOTAL FAILURES	118	101	52	166	437

Table 4.2 Number of failures for each CF categorized as M2

Codes	Causative Factors (CF)	Number of failures				
		J	US	A	UK	T
EQUIPMENT FAILURE						
M201-01	AIS*/radar could not show information	3	1	1	1	6
M201-02	whistle/audio signal was not working	3	1	1	0	5
M201-03	propeller/thruster problem	0	0	0	5	5
M201-04	course was not changed	0	1	1	0	2
M201-05	electrical failure	0	1	1	0	2
M201-06	main engine failure	0	2	0	1	3
M201-07	steering ability was reduced	0	2	1	0	3
M201-08	equipment strength below operational standard	0	3	0	1	4
CONSTRUCTION DAMAGE						
M202-01	mooring line broken	0	1	0	0	1
M202-02	hull damage	0	1	0	0	1
M202-03	bollard damaged	0	1	0	0	1
UNINSTALLED EQUIPMENT						
M203-01	safety navigational equipment was not installed (AIS*, VDR**)	0	1	1	0	2
M203-02	some equipment was missing/ not installed	0	1	0	0	1
DESIGN FAILURE						
M204-01	engine control console not ergonomic	0	2	1	1	4
M204-02	field of vision restricted	0	0	0	4	4
M204-03	bridge design not ergonomic	0	0	0	3	3
	TOTAL FAILURES	6	18	7	16	47

*AIS= Automated Identification System

**VDR=Voyage Data Recorder

Table 4.3 Number of failures for each CF categorized as M3

Codes	Causative Factors (CF)	Number of failures				
		J	US	A	UK	T
M301-01	busy traffic	8	6	0	2	16
M302-01	strong flow tide	4	0	0	4	8
M303-01	strong wind	4	4	1	4	13
M304-01	rain	6	1	0	3	10
M305-01	strong current	0	2	0	1	3
M306-01	submerged debris	0	1	0	0	1
M307-01	flood	0	1	0	0	1
M308-01	restricted visibility (fog, rainfall, obstruction)	0	7	0	5	12
M309-01	poor lighting (too light or too dark)	0	5	0	1	6
M310-01	narrow waterways	0	3	0	0	3
M311-01	sound pollution	0	0	0	2	2
	TOTAL FAILURES	22	30	11	22	85

Table 4.4 Number of failures for each CF categorized as M4

Codes	Causative Factors (CF)	Number of failures				
		J	US	A	UK	T
POOR COMMUNICATION			0	0	0	0
M401-01	among onshore & other vessel utilizing radio	5	1	0	4	10
INCOMPLETE SAFETY MANAGEMENT SYSTEM			0	0	0	0
M402-01	no night order in busy track	0	0	0	1	1
M402-02	insufficient post collision check lists	0	0	0	3	3
M402-03	in an operation plan	0	0	1	8	9
M402-04	guidance on navigation practices was not included/effective	0	0	1	5	6
POOR MANAGEMENT OF PERSONAL ON BOARD			0	0	0	0
M403-01	in understanding the passage plane (in new area)	2	2	1	0	5
M403-02	in monitoring the hours of work and rest	1	1	0	8	10
M403-03	number of men on the bridge	1	0	0	4	5
M403-04	sole lookout in busy/ danger area	1	0	0	1	2
M403-05	seaman has an expired/ illegal certificate	3	0	0	1	4
M403-06	in distributing job tasks	3	1	0	3	7
M404-01	poor application of safety management system	2	6	1	6	15
POOR MANAGEMENT FROM ONSHORE			0	0	0	0
M405-01	in identifying/monitoring/communicating any accident risk	4	9	0	5	18
M405-02	in monitoring pilot performance	0	0	0	2	2
M405-03	company did not establish/follow equipment change procedures	0	4	0	3	7
	TOTAL FAILURES	22	24	4	54	104

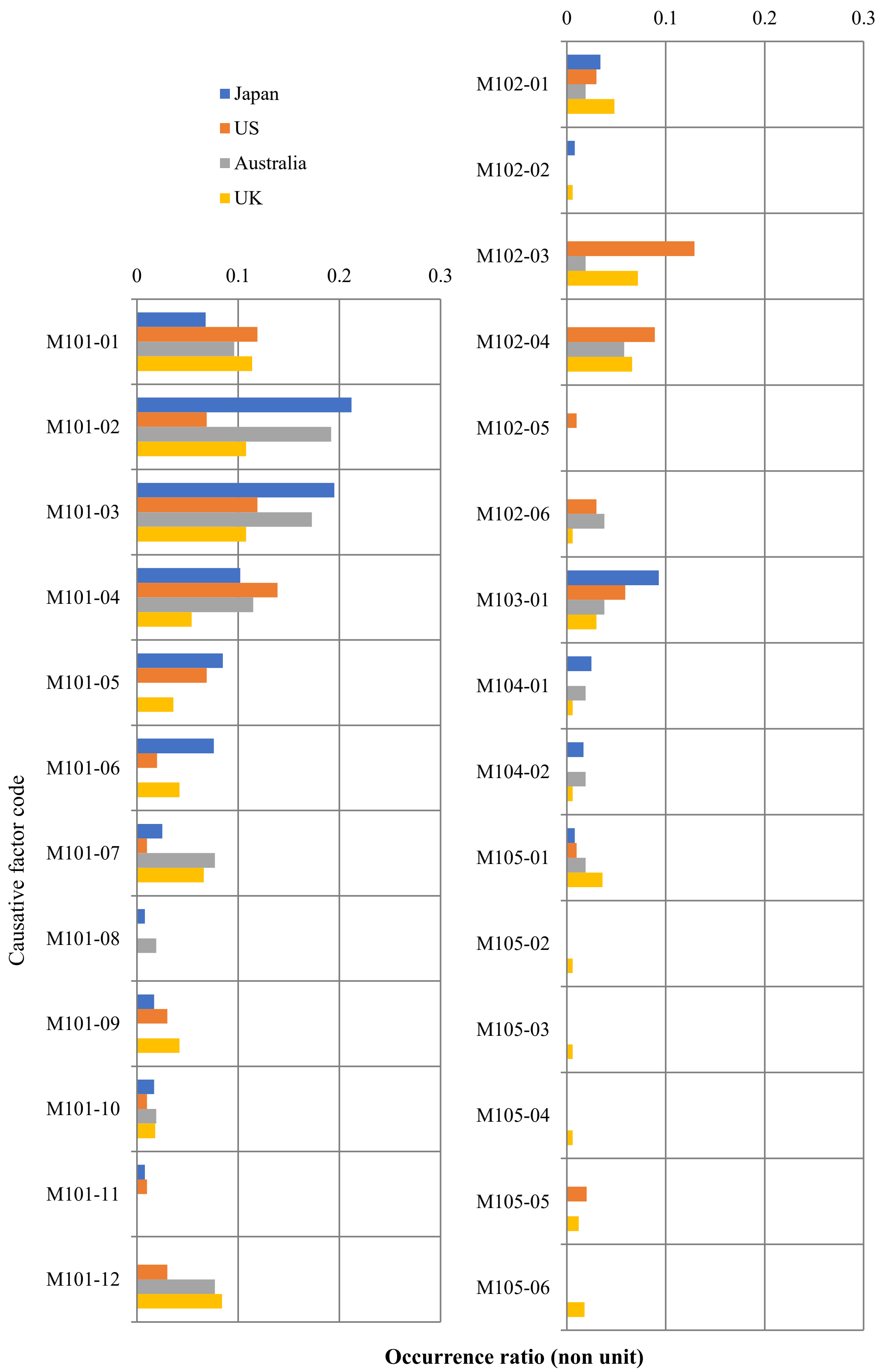


Fig. 4.3 Occurrence ratio of CF in man factor

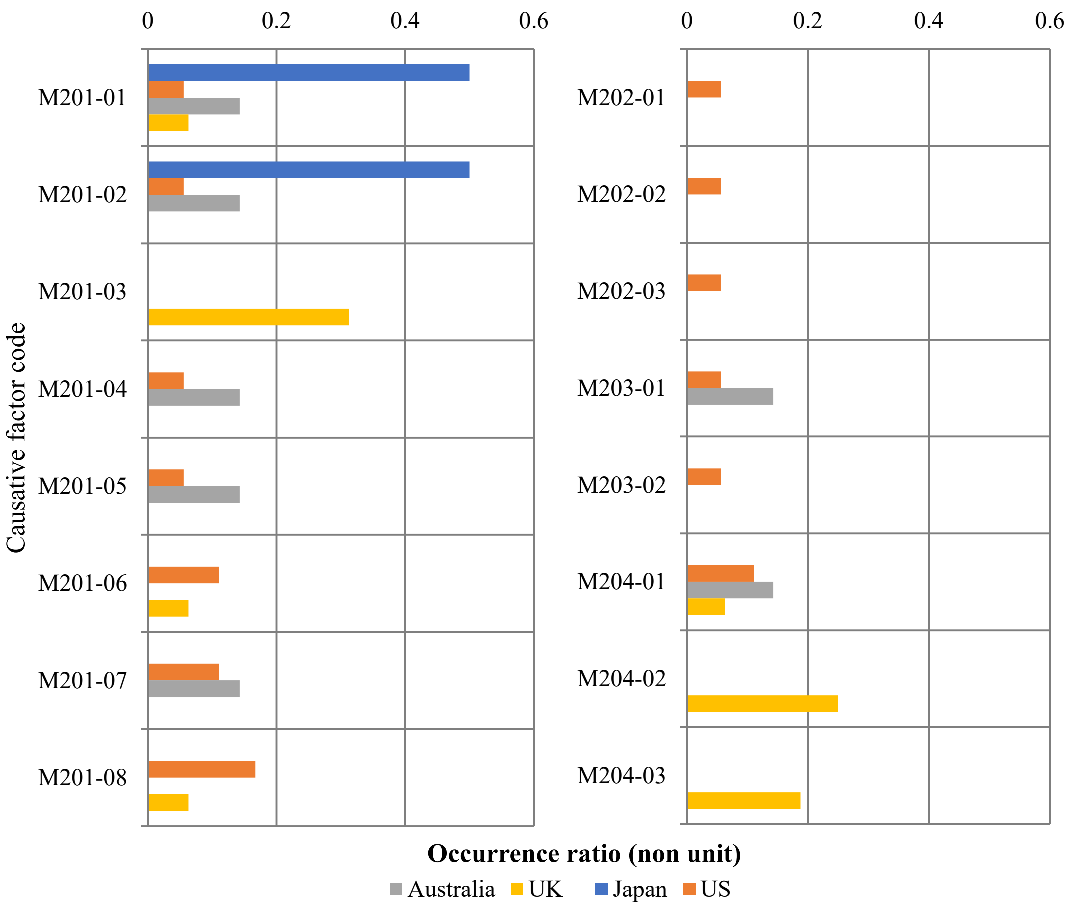


Fig. 4.4 Occurrence ratio of CF in machine factor

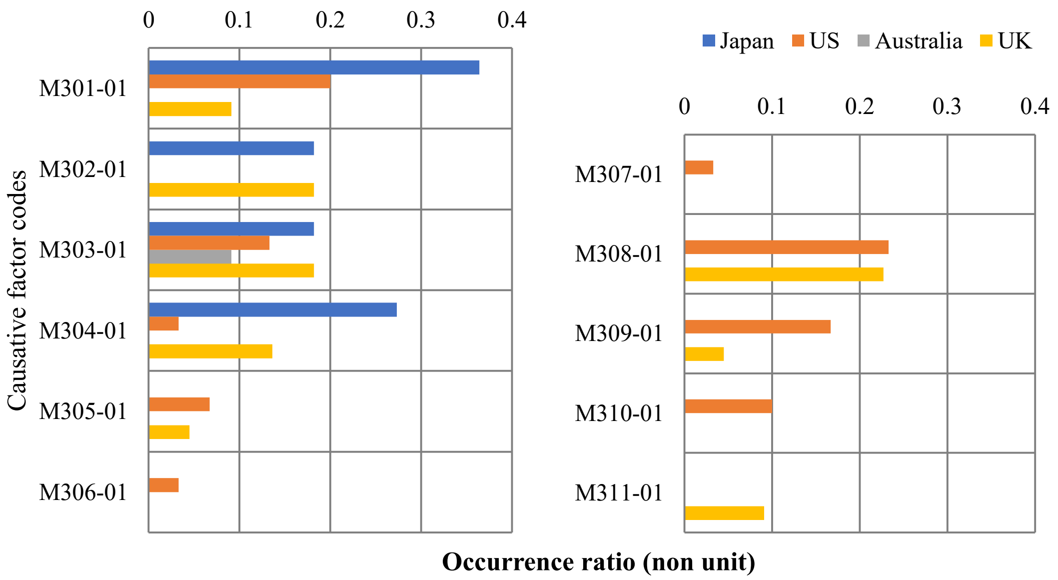


Fig. 4.5 Occurrence ratio of CF in media factor

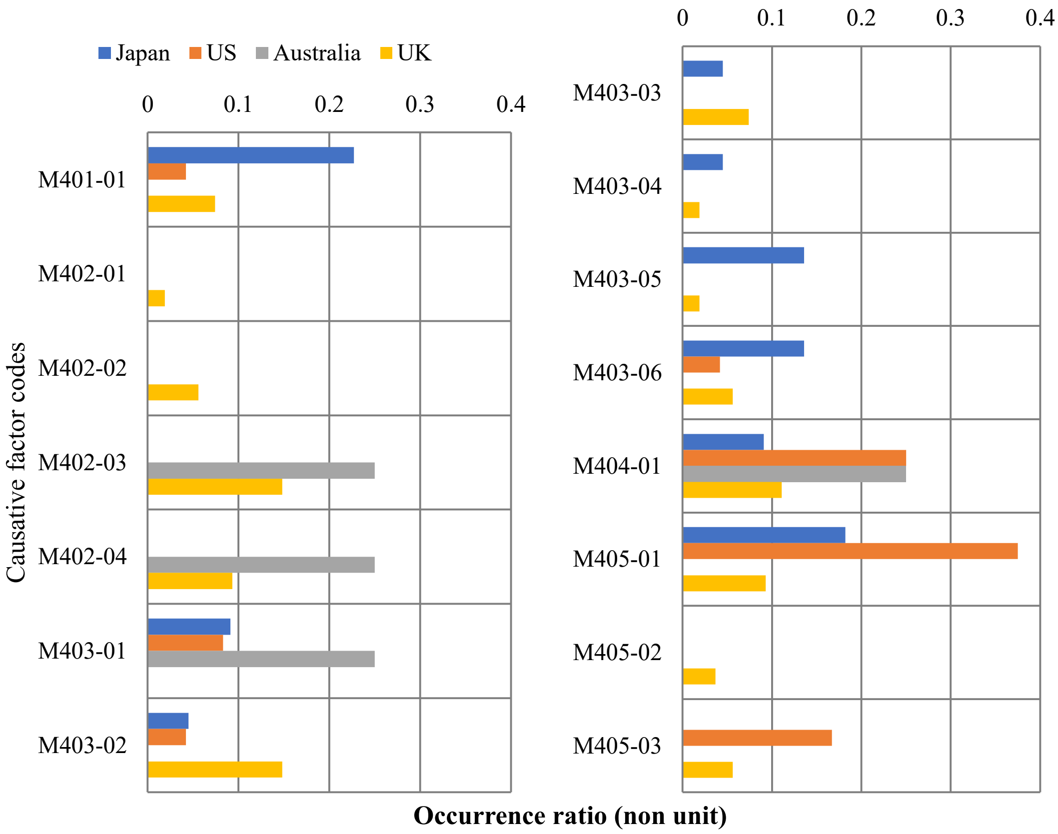


Fig. 4.6 Occurrence ratio of CF in management factor

4.3 Line Relation Analysis (LRA)

After getting all the CFs, this step connects several CFs to establish causative chains (CCs). Tables 4.5 – 4.8 below is the result of the LRA and the CC as the outcome is broken down in each country. The first CF code on the left means that that CF causes the CF following ‘>’. For example, in Table 4.5, CC number 1 is M103-01> M101-03. This means that M103-01 (Focus of the seamen was distracted) causing M101-03 (Careless seaman in monitoring/ identifying any accident risk). This CC happened only once in the 40 ships involved in Japanese ship collisions in 2008-2013. Another example is CC number 12, which had the largest number of occurrences, five. This means that this CC happen 5 times or there were 5 ships that collided because of this CC. This implies that there are many seamen that lose focus (mainly related to lookout), which do not keep proper look-out, thus they fail to monitor/identify any accident risk. This kind of chain need to be found to initiate preventive action.

Table 4.5 Number of causative chains that lead to collision in Japan, 2008-2013.

No.			Causative Chain	(CC)			amount
1			M103-01>	M101-03			1
2			M101-08>	M101-03>	M101-06		1
3			M101-01>	M101-03			1
4				M101-03>	M101-09		1
5		M102-01>	M101-02				2
6			M101-02>	M101-03>	M101-07		1
7		M403-06>	M101-02>	M101-03			1
8		M401-01>	M101-02>	M101-03			1
9		M403-01>	M101-02>	M101-03>	M101-04		1
10	M103-01>	M101-04>	M101-02>	M101-03			1
11		M101-04>	M101-02>	M101-03			2
12	M403-02>	M105-01>	M101-02>	M101-03			1
13		M104-01>	M101-02>	M101-03>	M101-05		1
14	M101-04>	M104-01>	M101-02>	M101-03			1
15	M101-04>	M103-01>	M101-02>	M101-03			1
16		M103-01>	M101-02>	M101-03			5
17		M103-01>	M101-02>	M101-03>	M101-05.	M101-06	1
18			M301-01>	M101-03>	M101-05.	M101-06	1
19				M101-03>	M101-05.	M101-06	1
20		M304-01>	M201-01>	M101-03>	M101-05.	M101-06	1
21			M101-01>	M102-02>	M101-05.	M101-06	1
22			M301-01>	M101-04>	M101-05.	M101-06	1
23				M101-04>	M101-02>	M101-06	1
24				M101-04>	M101-05		1
25			M101-01>	M101-04>	M101-06		1
26			M101-01>	M101-04			1
27		M403-06>	M101-01>	M101-04			1
28			M101-01>	M101-05			1
29		M105-01>	M101-01>	M101-07			1
30	M302-01>	M101-05					1
31	M304-01>	M201-01					2
32	M401-01>	M405-01					2
33	M403-01>	M403-03>	M403-04				1

In Tables 4.5- 4.8, those causative chain (CC) not aligned on the left are aimed at showing that there are causative factor (CF) that make chains but with different heads and/or tails. The most common CF that forms a chain in Japanese accident (from Table 4.5) is M101-02 (Careless seaman in maintaining proper look-out) and M101-03 (Careless seaman in monitoring/identifying any accident risk) which are also the most common CF gained from corner analysis (CA). The CC (M101-02> M101-03) is called the core CC. This core CC has several heads or causing CFs and tails or caused CF.

Table 4.6 Number of causative chains that lead to collision in US, 2008-2013.

No.	Causative Chain					(CC)					amount
1					M101-02>	M103-01					1
2				M102-06>	M101-02>	M103-01					1
3				M103-01>	M101-02						1
4			M101-05>	M102-03>	M101-02						1
5			M105-05>	M102-03							1
6		M201-06>	M201-02>	M102-03							1
7		M102-04>	M101-10>	M102-03							1
8		M201-07>	M101-01>	M102-03							1
9		M403-01>	M404-01>	M102-03							1
10		M310-01>	M301-01								1
11		M310-01>	M301-01>	M102-03>	M101-04>	M101-03>	M102-04>	M103-01			1
12					M101-04>	M101-03>	M101-07				1
13						M101-03>	M101-01				1
14						M101-03>	M102-03				1
15					M102-04>	M101-03>	M101-06>	M102-01			1
16				M102-04>	M101-01						1
17	M304-01>	M303-01>	M308-01>	M102-04>	M101-01>	M101-03					1
18			M308-01>	M201-01>	M102-03>	M101-03					1
19					M102-03>	M101-03>	M101-04>	M102-06>	M103-01		1
20					M203-01>	M101-03>	M101-04				1
21					M403-01>	M101-03>	M101-04>	M101-05>	M101-01>	M101-09	1
22							M101-04>	M101-05>	M308-01		1
23							M101-04>	M101-06			1
24							M101-04>	M102-04>	M101-03>	M202-01	1
25							M101-04>	M101-01>	M401-01		1
26						M303-01>	M101-04				1
27						M102-03>	M101-04>	M101-05>	M403-06		1
28						M101-01>	M101-04				1
29				M102-01>	M101-12>	M101-01					1
30				M105-05>	M101-12>	M102-01>	M101-05				1
31				M308-01>	M101-12>	M101-05>	M102-03				1
32				M308-01>	M201-08						1
33					M201-08>	M405-03>	M404-01				1
34				M405-03>	M201-08>	M202-01					1
35				M202-02>	M201-05>	M101-11					1
36				M303-01>	M202-03						1
37				M305-01>	M202-01						1
38				M306-01>	M201-07						1
39				M201-06>	M201-07						1
40			M307-01>	M405-01							1
41				M405-01>	M404-01						1
42				M405-01>	M405-03>	M404-01					1

Table 4.7 Number of causative chains that lead to collision in Australia, 2008-2013.

No.	Causative Chain			(CC)		amount
1		M403-01>	M101-01>	M102-04>	M101-03		1
2			M101-02>	M101-04>	M101-03>	M101-01	1
3			M101-02>	M101-04>	M101-03		3
4			M101-02>	M104-02>	M101-03		1
5			M101-02>	M104-01			1
6	M101-03>	M103-01>	M101-02				1
7		M103-01>	M101-02>	M102-01>	M101-04>	M101-03	1
8					M101-04>	M101-12	1
9	M101-01>	M102-03>	M101-07>	M102-06			1
10	M402-03>	M102-04					1
11	M201-05>	M201-07>	M201-04				2

Table 4.8 Number of causative chains that lead to collision in UK, 2008-2013.

No.	Causative Chain (CC)							amount
1	M402-01>	M105-02>	M101-02>	M101-03>	M101-12>	M101-09>	M101-07	1
2				M105-06>	M101-12>	M402-02		1
3					M101-12>	M405-02		1
4					M101-12>	M101-04		1
5					M101-12>	M101-04>	M101-03	1
6		M403-02>	M403-03>	M105-01>	M101-12>	M101-02>	M101-03	1
7				M105-05>	M101-12>	M101-06		1
8			M105-06>	M101-03>	M101-12			1
9			M105-06>	M102-03>	M101-12>	M101-05		1
10			M102-04>	M101-01>	M102-03			1
11			M102-04>	M101-01>	M101-04			1
12	M201-03>	M101-06>	M102-04					1
13		M101-01>	M102-04					1
14		M101-01>	M102-04>	M101-03				1
15		M101-01>	M102-04>	M102-03				1
16			M201-06>	M102-03>				1
17			M403-06>	M102-03				1
18				M102-03>	M101-01			1
19		M101-06>	M101-03>	M102-03>	M101-07			1
20	M101-01>	M101-06>	M101-07>	M102-03				1
21			M101-01>	M102-03				1
22		M302-01>	M303-01>	M102-03				1
23	M308-01>	M101-02>	M102-01>	M102-03				1
24			M105-04>	M102-03>	M101-03>	M101-05		1
25				M101-04>	M101-03>	M102-04>	M101-07	1
26						M101-01>	M101-07	1
27	M102-01>	M201-01>	M101-02>	M101-03>	M101-05>	M101-06>	M101-07	1
28			M101-01>	M102-02>	M101-09>	M101-03>	M101-07	1
29		M101-02>	M101-01>	M101-04>	M101-06>	M101-03>	M101-07	1
30				M104-01>	M101-02>	M101-03>	M101-07	1
31					M311-01>	M101-03>		1
32				M204-01>	M101-02>	M101-03		1
33			M101-01>	M402-02				1
34		M101-04>	M101-01>	M101-02>	M102-01			1
35			M204-02>	M101-02				1
36				M101-02>	M102-01>	M102-03>	M101-03	1
37				M101-02>	M102-01>	M102-04		1
38				M101-02>	M103-01>	M101-07>	M101-09	1
39				M101-02>	M101-03			1
40	M304-01>	M308-01>	M201-01>	M101-02>	M403-02>	M105-01		1
41					M403-02>	M105-01		1
42						M105-01>	M403-02	1
43				M402-03>	M403-06>	M405-01>	M201-03	2
44				M404-01>	M402-04>	M405-01		2
45				M402-03>	M402-04>	M405-01		2
46				M402-03>	M201-03			2
47			M404-01>	M402-03				2
48	M405-01>	M402-04>	M101-01>	M102-01				1
49	M102-06>	M101-10						1
50	M403-03>	M403-04						1
51	M104-02>	M101-01						1
52	M201-03>	M204-01						1
53	M105-03>	M102-01						1
54	M302-01>	M101-04>	M101-03					1
55	M404-01>	M405-02>	M405-01					1

There are several highlighted causative factors and causative chain in Tables 4.5 – 4.8. Table 4.9 explains the definition of the highlights.

Table 4.9 Terms and definitions of highlighted CF

Type of highlight	Terms	Definitions
CF	Repeated CF	The CF that occurred repeated in the accidents
CF	Connecting CF	The CF that connected or in between 2 repeated CFs
CF1> CF2	Repeated CC	The CC that consists of 2 CFs and occurred repeated in the accidents
CF1> CF2> CF3	Repeated CC	The CC that consists of 3 CFs and occurred repeated in the accidents

From Tables 4.5 – 4.8, the causing and caused repeated CF can be known. Thus, CA provides what CF causing the accident, what CF were repeated, how many times those CFs occurred and what CF were significant causing the accident. Then LRA provides the connections, what CF are leading to, as well as the CF that occurred after, the repeated and/or significant CF, what CFs form CC and how many CC occurred.

Chapter 5
Specific Topics

As a simple model, MOP can be used for specific topics depending on requirements. We will look at two examples, the utilization of MOP model to examine the characteristics of accidents that happen in three-time occurrences (day, night, and twilight) and the characteristics of improper look-out.

5.1 Introduction

MOP model has been utilized to characterize accidents in several countries. From these, the author found an interesting pattern about time occurrence of the accidents. Accidents can be categorized base on time occurrence, day, night, or twilight. The number of collisions occurring at twilight is almost the same with the number of collisions occurring at night; although a larger number of collisions occurred during the day [28]. However, the total number of hours included in twilight are much shorter than the number considered as night. This simple observation suggests that the characteristics of collisions occurring at twilight need further studied.

This chapter provides an analysis of collisions found in Japanese MTS from 2008 - 2013 utilizing MOP model based on three time occurrences. The Japan coast guard

(JCG) and Japan P&I club (JPIC) have reported that most collisions in Japan occur between 4 and 6 am [32] [33], and many are due to improper look-out. JCG reported collisions occurring in 2008 for all types of vessels and JPIC reported collisions for cargo ships in 2011.

Our analysis found that the most frequent cause of collision was improper look-out. Even though the International Maritime Organization (IMO) has developed rules for navigation, The 1972 International Regulations for Prevention of Collisions at Sea (COLREGs), improper look-out is still the dominant factor. In rule 5 regarding Look-out, "every vessel shall, at all times, maintain a proper look-out by sight and hearing as well as by all available means appropriate in the prevailing circumstances and conditions so as to make a full appraisal of the situation and the risk of collision" [34]. Proper look-out is very important because most of collision worldwide are caused by improper look-out.

The aims of this chapter are to discuss more details about improper look-out which dominate the cause of collision, as well as the reasons for failure that cause the improper look-out. In addition to all accidents, accidents related to improper look-out will be classified into three time occurrence zones.

5.2 Data

The data analyzed in this chapter refer to the collision accident reports in Japan from 2008 to 2013 published on Japan Transportation Safety Board's (JTSB) website with a total of 1090 cases from 3090 total maritime accidents [12]. The number of accidents that happen in three time occurrence zones as well as the number of reports written in English are shown in Fig. 5.1.

In this study, time occurrence has been divided into three groups, namely, day, night, and twilight. Day time covers the period in which the sun is above the horizon, starting thirty minutes after nautical dawn and ending thirty minutes before nautical dusk. Night time is the time between thirty minutes after nautical dusk and thirty minutes before nautical dawn. Twilight time is a combination of nautical dawn and dusk, including thirty minutes before and after nautical time. It was decided to include thirty minutes before and after the true nautical twilight in twilight time, because sometimes accidents had a proceeding incident about 30 minutes before the accident, or the incident itself may have been affected by light caused by the sun's movement.

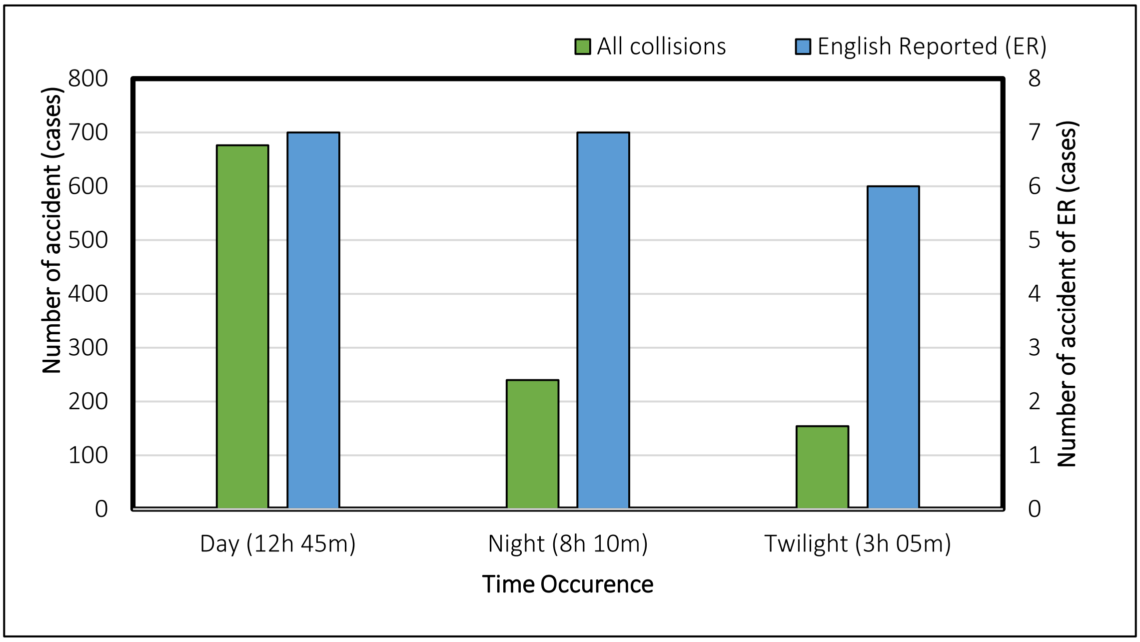


Fig. 5.1 Number of collisions at each time occurrence

From the 1,090 collisions that occurred during 2008-2013, the average day, night, and twilight periods were 12h 45m, 8h 10m, and 3h 05m, respectively, traced by the timeanddate.com website [35]. An interesting observation obtained from the data shown in Fig. 5.1 is that the ratio between the number of accidents that happened at twilight (154 cases) and during the twilight period (3h 05m) works out to about 51 collisions per hour, while the number of accidents that happened at night (240 cases) and during the night period (8h 10m) works out to only 30 collisions per hour. These facts stimulate the need to research the characteristic differences of collisions that happen in each time occurrence zone. After obtaining the characteristics of the accidents for each time occurrence zone, the next step is to define the preventive action needed to avoid repetition of the same accident.

In this chapter, all the collision reports, which were written in English and published on the JTSB website between 2008 and 2013 are re-analyzed. During this period, the number of collisions that happened at day, night, and twilight were 7, 7, and 6, respectively [13]. In total, 20 collisions involving 40 ships have been re-analyzed.

5.3 Results

Both steps of the MOP model have several results, which are reported below.

Corner Analysis (CA). From the 7, 7, and 6 collisions that happen at day, night, and twilight, respectively, there were 63, 49, and 51 failures, respectively, shown in Fig. 5.2. From the figure, we can see that the number of failures during the twilight is higher than those during the night time even though the number of collisions that are analyzed is smaller. This means that shipping operations at twilight are statistically more probable to have a failure than those at night time. From the corners in the Fig. 5.2, we can clearly see that the corner that dominates collisions in Japan is the one associated with the man factor.

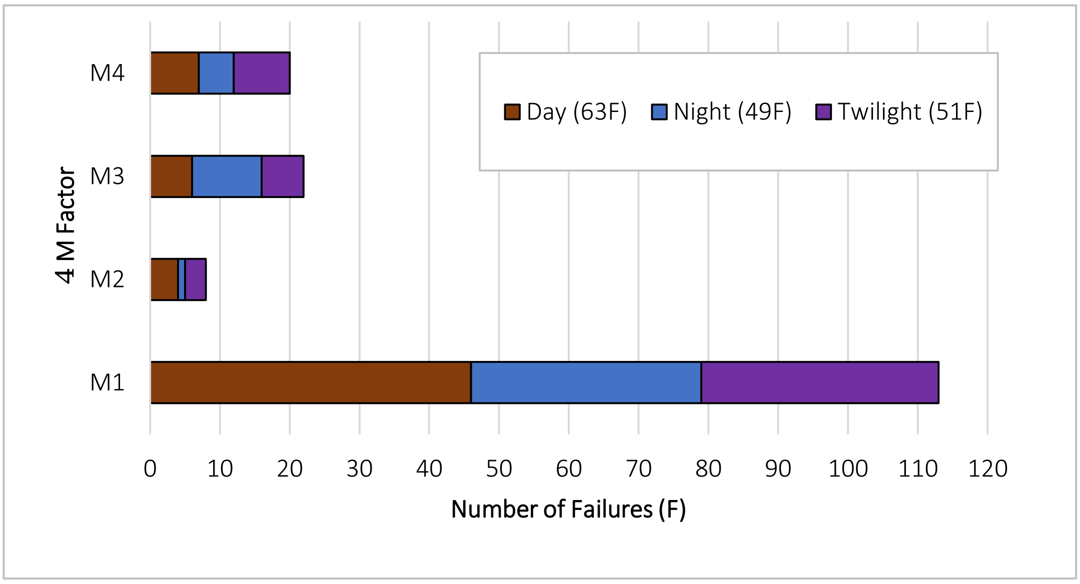


Fig. 5.2 Recapitulation of the results of CA

Tables 5.1-5.4 show the list of CFs and the number of failures in each time occurrence zone, day, night, and twilight time abbreviated as D, N, and T, respectively.

Table 5.1 Number of failures for each causative factor categorized as M1.

Code	Causative Factors (CF)	D	N	T	Total
CARELESS SEAMAN					
M11-01	in communicating among the seamen (or with pilot)	7	0	1	8
M11-02	in maintaining proper look-out	6	11	8	25
M11-03	in monitoring/identifying any accident risk	6	6	11	23
M11-04	in understanding condition (wrong judgment/ decision)	5	4	3	12
M11-05	in deciding speed	8	1	1	10
M11-06	in deciding course alteration	6	2	1	9
M11-07	doing erratic/ineffective action in avoiding accident	0	1	2	3
M11-08	in flashing light signal	0	1	0	1
M11-09	in blasting sound signal	0	1	0	1
M11-10	in wearing/utilizing safety/survival devices	1	1	0	2
M11-11	in preventing flooding	0	0	1	1
INCAPABILITY OF SEAMAN					
M12-01	in operating navigational equipment (unfamiliar)	2	1	0	3
m12-02	in understanding signal from another vessel	1	0	0	1
m13-01	focus of the seamen was distracted	3	3	5	11
m14-01	master was not on the bridge	1	1	0	2
HUMAN ELEMENT PROBLEM					
M15-01	fatigue	0	0	1	1

Table 5.2 Number of failures for each causative factor categorized as M2.

Code	Causative Factors	D	N	T	Total
EQUIPMENT FAILURE					
M21-01	AIS/Radar could not show information	2	1	0	3
M21-02	whistle/audio signal was not working	2	0	1	3
M21-03	course was not changed	0	0	1	1

Table 5.3 Number of failures for each causative factor categorized as M3.

Code	Causative Factors	D	N	T	Total
M3-01	busy traffic	4	0	4	8
M3-02	strong flow tide	0	4	0	4
M3-03	strong wind	0	2	2	4
m3-04	rain	2	4	0	6

Table 5.4 Number of failures for each causative factor categorized as M4.

Code	Causative Factors	D	N	T	Total
POOR COMMUNICATION					
M41-01	among onshore & other vessel utilizing radio	2	2	1	5
POOR MANAGEMENT OF PERSONAL ON BOARD					
M42-01	in understanding the passage plane (in new area)	1	0	1	2
M42-02	in monitoring the hours of work and rest	0	0	1	1
M42-03	number of man on the bridge	0	0	1	1
M42-04	sole lookout in busy/ danger area	0	0	1	1
M42-05	seaman has an expired/illegal certificate	0	2	1	3
M42-06	in distributing job task	0	0	1	1
M43-01	poor application of Safety Management System	0	1	1	2
POOR MANAGEMENT FROM ONSHORE					
M44-01	in identifying/monitoring/communicating any risk accident	4	0	0	4

After getting the results from Tables 5.1-5.4, we know that improper look-out (M11-02) is the most common CF. Thus, Table 5.5 was made to break down improper look- out in more detail.

Table 5.5 Number of improper look-out

Code	Improper look-out	D	N	T	Total
M11-0211	not noticing other vessel on opposite side of seamen	0	2	1	3
M11-0221	not responding/hearing call through VHF	0	2	1	3
M11-0231	not noticing/confirming compass bearing changes of other vessel	1	2	1	4
M11-0232	not keeping watch of other vessel	1	2	1	4
M11-0233	not utilizing radar correctly	1	2	1	4
M11-0241	non at all	3	1	3	7
	Total	6	11	8	25

There are several articles that have reviewed what the mean of proper lookout is, such as those of Llana and Wisneskey [34] and The ACTs project consortium [36]. There are 3 ways of look-out stated in COLREGs rule 5, namely by sight, by hearing and by all available means. First, by sight means observing another vessel by the naked eye or by binoculars. Second, by hearing means detecting another vessel by her sound signals. Third, by all available means includes using several navigational tools, such as Radio Detection and Ranging (RADAR), Differential Global Positioning System (DGPS) satellite navigation equipment, Automatic Identification Systems (AIS), Night vision equipment, Information and communication via Very High Frequency (VHF) from other vessels or Vessel Traffic System (VTS), Information from navigational warnings or any other Navigation and piloting instruments.

Based on the explanation above, improper look-out has been divided into three categories, namely by sight (M11-021), by hearing (M11-022) and by all available means (M11-023). However, there is an additional improper lookout named M11-024 (non at all). This improper look-out means that the seamen were not conduction any proper look-out, neither by sight, hearing, nor all available means.

Table 5.5 lists the improper look-out that happened in 14 out of 20 cases, since 6 cases were not related to improper look-out, but rather were caused by other CFs.

Line Relation Analysis (LRA). Table 5.6 below shows how this step characterizes the improper look-out based on the time occurrence zone. Details of improper look-out listed in Table 5.5 are written in the center portion of the table with causing factor on the left and caused factor on the right. The causing factor is the CF leading to the improper look-out. The caused factor is the CF that happens after and includes the impact of improper look-out.

Table 5.6 Line relation analysis and its number of relations in each time occurrence

Numb of relation				Causing Factors	**Improper Look-out**	Caused Factors	Numb of relation			
D	N	T	(Total)				(Total)	D	N	T
0	1	0	(1)	M11-09	**M11-0211**	M11-03	(2)	0	2	0
0	0	1	(1)	M13-01		M11-04	(1)	0	0	1
0	2	1	(3)	M13-01	**M11-0221**	M11-03	(2)	0	1	1
0	0	1	(1)	M11-0241	**M11-0231**	M11-03	(2)	1	0	1
1	0	0	(1)	M11-0232		M11-06	(1)	0	1	0
0	2	0	(2)	M11-04						
1	1	1	(3)	M13-01	**M11-0232**	M11-03	(2)	0	1	1
0	1	0	(1)	M11-04		M11-0231	(1)	1	0	0
0	0	1	(1)	M43-01	**M11-0233**	M11-0231	(1)	0	0	1
1	0	0	(1)	M12-01		M11-0211	(1)	1	0	0
0	1	0	(1)	M13-01						
2	0	2	(4)	M13-01	**M11-0241**	M11-03	(7)	3	1	3
1	1	0	(2)	M14-01						

Table 5.6 can be illustrated in a 3-dimensional graph shown in Fig. 5.3. This shows our modification of the MOP model for our specific need, improper look-out. In the case of improper look-out, there are no CF associated with the factors of machine (M2) and media (M3), however, in the management factor (M4) there is one CF that leads to improper look-out.

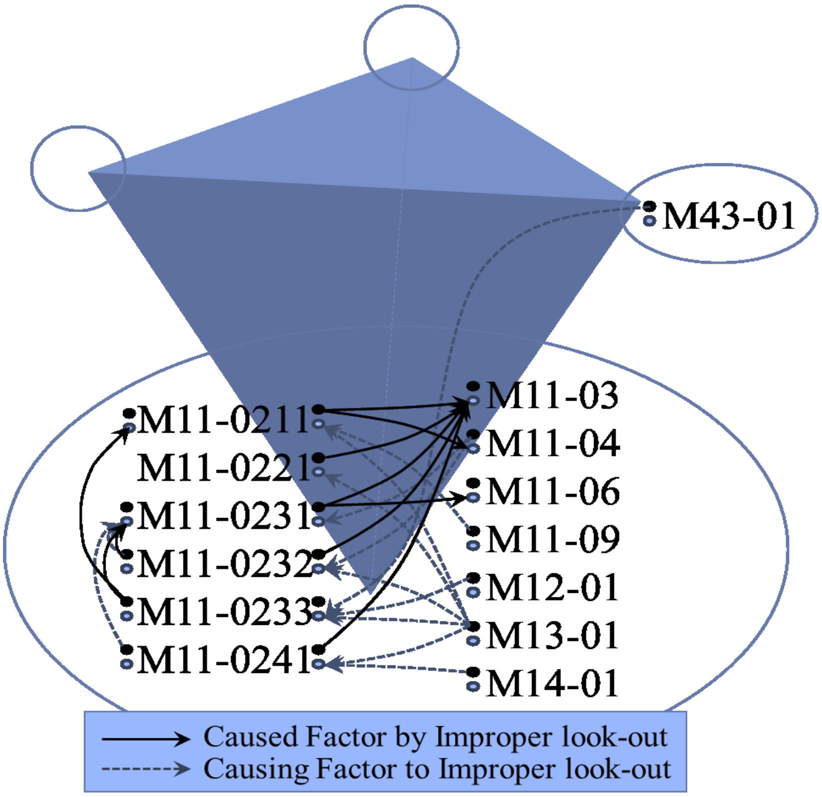


Fig. 5.3 Illustration of improper look-out in LRA

5.4 Discussion

The discussion is divided into two subsections.

5.4.1 Time occurrence zone

In this part, since there are no special characteristics for the time occurrence from LRA, more details related to the results from CA are discussed. From Tables 5.1 - 5.4, we compare the number of failures from each CF to see if there are any characteristic differences for each time occurrence zone.

Day time. CFs that are significant in the day time are M11-01, M11-04, M11-05, M11-06, and M44-08. This means that in the day time, failures that often occur are caused by careless seaman in communicating with other the seamen, understanding conditions (wrong judgment), deciding speed, deciding course alteration, and poor management from onshore in identifying/monitoring/communicating any risk of accident. Accidents that are caused by poor management from onshore in identifying/ monitoring/ communicating any risk of accident only occurred in the day time. Different from other CFs, this CF was not seen to occur at night or at twilight time.

Night time. While the highest number of failures mostly occur in the day time, night time also has several CFs with a high number of failures, such as M11-02 and M3-01. M3-02 only happens at night. This means that CFs that occur at night do not vary a lot in comparison with those of the day time.

Twilight. CF that are significant in the twilight time compared to other time occurrence zones are M11-03 and M13-01. M11-03 refers to careless seaman monitoring/identifying any risk of accident and M13-01 incapability of seaman to focus due to some distraction. Perhaps even caused by the glare of the sun or changes in light conditions.

5.4.2 Improper look-out

As Table 5.5 shows, we could not find any special characteristics for improper look-out in any of the time occurrence. The number of cases being re-analyzed are perhaps not enough to show any differences, even from the LRA in Table 5.5. However, from Table 5.6 and Fig. 5.3, we find 8 CFs that are affected or affecting improper lookout, namely M11-03: careless in monitoring/identifying any accident risk, M11-04: careless by misunderstanding condition (wrong judgment), M11-06: careless in deciding course alteration, M11-09: careless in blasting sound signal, M12-01: lack of knowledge in operating navigational equipment (unfamiliar), M13-01: focus of seamen was distracted, M14-01: Master was not on the bridge, and M43-01: poor application of Safety Management System. Of the 8 CFs, only 1 CF is not associated to M1. This means that failure in keeping proper look-out is highly related to a man factor (M1).

The CF most associated with improper look-out is M13-01: Focus of the seamen was distracted. There were 12 ships that were not focused on during look-out because there were several other things to do. For example, in a fishing area, there were many fishing vessels about, thus vessel A was perhaps focused on avoiding vessels C, D, etc., and did not realize vessel B was ahead. In another example, a fishing vessel was engaged in fishing activities and did not maintain a look-out.

Improper look-out affecting several CFs in M1. The most affected CF from LRA is M11-03: careless seamen monitoring/identifying any risk of accident. If we look at CA, Table 5.1, this CF also has a high number of failure. Out of 23 failures, 13 of them happen because of improper look-out. This makes sense because if seamen fail to maintain proper look-out in Stage 1 in the development of an accident, seamen will fail to identify any accident risk as well that happen in stage 2. Seamen will then fail to monitor the risk of accident.

Chapter 6
Summary of the Analysis and Discussion

The accidents have been re-analyzed by MOP model begin with corner analysis (CA) and closed by line relation analysis (LRA). The outcome of CA is causative factor (CF) list and LRA is causative chain list. From those lists, we can see what is the most common causative factors and causative chains happen lead to the accidents in four countries, Japan, United States (US), Australia, and United Kingdom (UK). The reason why only those four countries analyzed here because they represent each continent in the world except Africa. Author could not find any accident investigation report in Africa.

In this chapter, author bring reader to understand the most common CF for each factor and the CC. In Man factor, there are two outstanding numbers of CF that occurred as the common cause of accidents, “Careless seaman in maintaining proper lookout” and “Careless seaman in monitoring/identifying any accident risk”, both CF are classified as “Careless Seaman”. In Machine factor, the most common CF is “Equipment failure: AIS/radar could not show information”, in Media factor is “Busy Traffic”, while in Management factor, “Poor management from onshore in identifying/ monitoring/ communicating any accident risk” become the most common CF that contribute in accidents. All of the most common CF will be explained in the next section.

6.1 Careless seaman in maintaining proper lookout (M101-02)

This is the most common CF in analysis together with “careless seaman in monitoring/ identifying any accident risk” with the code M101-03. As seen on the Fig. 4.3 regarding the occurrence ratio (OR), the CF of M101-02 has the highest number of OR followed by M101-03. It means that, in terms of occurrence in each country, M101-02 is often happened except in the U.S. in terms of failures, M101-03 with the failures of 62 which is bigger than M101-02with 60 failures. However, these two CFs are having outstanding number of failures compared with the other CFs.

Maintaining proper lookout is very important task for bridge crew, as stated in “rule 5 of COLREG: Every vessel shall at all times maintain a proper lookout by sight and hearing as well as by all available means appropriate in the prevailing circumstances and conditions so as to make a full appraisal of the situation and risk of collision”. It is very understandable if there is a special rule regarding proper lookout, since if the officer not doing it well, accident will be regarded as a consequence. Maintaining proper lookout is one of difficult task on ship, the difficulty level increased when there are several limitations, such as visibility restriction, focus disruption by another thing, busy traffic, work time schedule of officer, etc. The failure in maintaining proper lookout is not a stand-alone failure, it is also affected by another activity. Thus, all bridge member should have a good team work to maintain proper lookout.

6.2 Careless seaman in monitoring/identifying any accident risk (M101-03)

Compared to maintaining proper lookout, careless from seaman in monitoring/ identifying any accident risk is slightly different in term of responsibility. This CF is more to individual responsibility. It means that all the failures are based on individual knowledge and ability. For example, the case of collision in narrow channel of river bank, the pilot who have advantage of knowledge and routine of the channel, should know how to pass the channel safely, but in fact it is often happened the pilot can not overcome the river`s hydrodynamics force or flood current. In another case, the pilot can overcome the forces, but can not take proper anticipation of his move and then accident happened.

Actually, this CF can be overcome if the seafarer discuss or share their consideration in overcome the difficulties with another crew, so there are communication and knowledge exchange. Another big solution to overcome this CF is, keep on studying to increase the knowledge of safety rules and good seamanship.

6.3 Equipment failure: AIS/ radar could not show information (M201-01)

This CF have close relationship with maintaining proper lookout AIS/ radar is included in "all available means appropriate" in need of doing proper look-out. Thus, the failure of this navigational aid can cause the accident. The main problem of the failure is the difference type of AIS class. Some problems that contribute to the failure are the difference type of AIS class among the ships, which result in AIS could not show information. Another problem is the failure of AIS/radar itself, so it could not give the information to seafarer. The knowledge and ability of seafarer in using AIS/ radar is the closest relation that contribute to the failure of this device.

6.4 Busy traffic (M301-01)

As commonly happened in road transportation, the busier traffic the bigger risk of accident. But, the risk in sea transport is bigger than road transport, as ships could not immediately stop if there are something wrong. This busy traffic can be experienced by seafarer in open sea where the area are commonly used by fishing vessel. Most of this condition are occurred in Japan and Australia. In US and UK, most of the accident occurred in river and this is also busy traffic. This CF can be avoided by understanding the area, maintaining proper lookout and make good communication with VTS. The communication among seaman and pilot also important to reduce the risk of accident in busy traffic.

6.5 Poor management from onshore in identifying/ monitoring/ communicating any risk accident (M405-01)

The coordination between onboard crew and onshore management is very important thing to support the sea going activity going well. Good communication, good schedule of work of personnel, good practice of safety procedures and rules will support the seafarer to reduce the failure that caused accident. In analyzed investigation report, the lack of communication, bad personnel schedule of work, not applying the rule and practicing good Safety Management System are the CF that contributing in accident. Furthermore, the responsibility if ship maintenance also must be done well by the management, so seafarers can do their job on sea very well.

Chapter 7
Conclusion

MOP model has been established and developed. Several cases have been re-analyzed using this new model, from the general cases until the specific purposes. The analysis that is provided in this dissertation is only collision cases even though previously author has published several papers analyzing other accident types. Here are 3 points that concluded the analysis:

1. The dominant factor leading to collision is man factor (M1)

   In general man factor is still act as the main CF of accident, it is supported by the result of analyzed accident report shown the biggest number of failure in MOP model`s CA is on man factor. However, we see from the significant number of failure in each CF, these are the CF that all stakeholder need to consider to reduce the number of accident:

   In Man factor, there are two significant numbers of CF that occurred as the common cause of accidents, “Careless seaman in maintaining proper lookout” and “Careless seaman in monitoring/identifying any accident risk”, both CF are classified as “Careless Seaman”. In Machine factor, the most common CF is “Equipment failure: AIS/radar could not show information”, in Media factor is “Busy Traffic”, while in Management factor, “Poor management from onshore in identifying/ monitoring/ communicating any accident risk".

2. MOP model is one of choice to analyze accident because of its flexibility

Following the result of LRA in MOP model, it implies that MOP model still can be developed to get the maximum result of accident analysis model. Until this stage, The MOP model has 2 analysis steps, Corner Analysis (Ca) that produce Causative Factors (CFs) and Line Relation Analysis (LRA) that produce Causative Chains (CCs). CA provides what CF causing the accident, what CF were repeated, how many times those CFs occurred and what CF were significant causing the accident. Then LRA provides the connections, what CF are leading to, as well as the CF that occurred after, the repeated and/or significant CF, what CFs form CC and how many CC occurred.

As the simple approach, this model can be utilized by organization/company to get the tendency how their accident occurred and modified based on their needs. This flexibility will be the benefit because the researcher can utilize this method started by generating the data needed.

There are many interesting subjects to be researched related to accident in maritime transportation system utilizing this MOP model. Besides, for sure, this MOP model needs to be more developed by being utilized to many accident data, such as:

1. Analyze more accident reports to get more reliable result, for example Canada.
2. Develop a simple software that can help researcher analyze much more data that can generate the CF and CC lists automatically.

References

[1] United Nation Conference on Trade and Development, "Merchant fleet by flag of registration and by type of ship, annual, 1980-2016," UNCTAD, 2017. [Online]. Available: http://unctadstat.unctad.org/wds/TableViewer/tableView.aspx. [Accessed 17 January 2017].

[2] European Maritime Safety Agency, "Annual Overview of Marine Casualties and Incidents 2015," EMSA, Portugal, 2015.

[3] Japan Transport Safety Board, "Annual Report 2016," JTSB, Tokyo, 2016.

[4] M. Grech, T. Horberry and T. Koester, Human Factors in the Maritime Domain, Boca Raton: CRC Press Taylor & Francis Group, 2008.

[5] M. Furusho, "Disaster of Italian Passenger Ship Costa Concordia – a Nightmare 100 Years after the Titanic-," The Mariners's Digest, Japan, 2013.

[6] M. Furusho, "IM Model for Ship Safety," in Inaugural general assembly, Turkey, 2000.

[7] S. Kristiansen, Maritime Transporttion: Safety Management and Risk Analysis, Oxford: Elsevier, 2005.

[8] International Maritie Organization, "Formal Safety Assessment," IMO, London, 2007.

[9] Civil Aviation Authority, "Fundamental Human Factors Concepts," CAA, London, 2002.

[10] A. M. Rothblum, "Human Error and Marine Safety," in The National Safety Council Congress and Expo, Orlando, 2000.

[11] A. Mullai and U. Paulsson, "A grounded theory model for analysis of marine accidents," Accident Analysis and Prevention, vol. 43, pp. 1590-1603, 2011.

[12] Japan Transport Safety Board, "Investigation report search," JTSB, 2016. [Online]. Available: http://jtsb.mlit.go.jp/jtsb/ship/. [Accessed 11 June 2016].

[13] Japan Transport Safety Board, "Marine Accident and Incident Reports," JTSB, 2016. [Online]. Available: http://www.mlit.go.jp/jtsb/marrep.html. [Accessed 11 June 2016].

[14] Marine Accident Investigation Branch, "Marine Accident Investigation Branch reports," MAIB, June 2017. [Online]. Available: https://tinyurl.com/maibmarineaccidents. [Accessed 11 June 2017].

[15] Transportation Safety Board of Canada, "Statistical Summary – Marine Occurrences 2015," TSB, 2015. [Online]. Available: http://tsb.gc.ca/eng/stats/marine/2015/ssem-ssmo-2015-tbls.asp. [Accessed 16 January 2017].

[16] Australian Transportation Safety Bureau, "Marine safety investigations & reports," ATSB, 2017. [Online]. Available: https://tinyurl.com/ATSBmaritimeaccidentaustralia. [Accessed 18 January 2017].
[17] National Transportation Safety Board, "Marine Accident Reports," NTSB, 2017. [Online]. Available: https://www.ntsb.gov/investigations/AccidentReports/Pages/marine.aspx. [Accessed 18 January 2017].
[18] European Maritime Safety Agency, "Annual overview of marine casualties and incidents," EMSA, Lisboa, 2016.
[19] N. Leveson, "A New Accident Model for Engineering Safer Systems," Safety Science, vol. 42, pp. 237-270, 2004.
[20] M. Grabowski, J. R. W. Merrick, J. R. Harrald, T. A. Mazzuchi and J. R. v. Dorp, "Risk Modeling in Distributed, Large-Scale Systems," IEEE Transactions on Systems, Man, And Cybernetics—Part A: Systems And Humans, vol. 30, no. 6, pp. 651-660, 2000.
[21] E. Hollnagel, "Understanding accidents from root causes to performance variability," in IEEE 7 Human Factor Meeting, Scottsdale Arizona, pp. 1-1-6, 2002.
[22] P. Underwood and D. P. Waterson, "Accident Analysis Models and Methods: Guidance for Safety Professionals," Loughborough University, Loughborough, 2013.
[23] E. Hollnagel, "The Changing Nature Of Risks," Ergonomics Ausralia Journal, vol. 22, pp. 33-46, 2008.
[24] A. Nurwahyudi, Contemporary Issus in Domestic Ro-Ro Passenger Ferry Operation in Developing Countries: Identification of safety issues in domestic ferry operation based on accident investigation reports on ferry involved accidents in Indonesian waters, Malmo: World Maritime University, 2014.
[25] W. Mutmainnah, K. Hirono and M. Furusho, "A Study of Ship Accidents in Indonesa Using 4M Factors," in Asian Navigation Conference (ANC) 2013, Busan, pp. 367-375, 2013.
[26] W. Mutmainnah and M. Furusho, "The 4M Overturned Pyramid (MOP) Model in Maritime Traffic System for Safety at Sea," in Asia Navigation Conference (ANC) 2014, Xiamen, 2014.
[27] W. Mutmainnah and M. Furusho, "4M Overturned Pyramid (MOP) Model Utilization: Case Studies on Collision in Indonesian and Japanese Maritime Traffic Systems (MTS)," TransNav, the International Journal on Marine

Navigation and Safety of Sea Transportation, vol. 10, no. 2, pp. 257-264, 2016.

[28] W. Mutmainnah and M. Furusho, "The characteristics of ship collision accidents in United Kingdom analyzed by MOP model," in Asia Navigation Conference 2015, Kitakyushu, pp. 443-449, 2015.

[29] W. Mutmainnah and A. B. F. M. Sulistiyono, "Introducing 4M Overturned Pyramid (MOP) Model to Analyze Accidents in Maritime Traffic System (MTS): A Case Study on Collisions in Japan Based on Occurrence Time," Applied Mechanics and Materials, vol. 862, pp. 220-225, 2017.

[30] W. Mutmainnah and M. Furusho, "The Improper Look-out that Leads to Ship Collisions in Japan," in Asia Navigation Conference (ANC) 2016, Yeosu, pp. 443-449, 2016.

[31] W. Mutmainnah, L. P. Bowo, A. B. Sulistiyono and M. Furusho, "Causative Chain Difference for each Type of Accidents in Japanese Maritime Traffic Systems (MTS)," TransNav, the International Journal on Marine Navigation and Safety of Sea Transportation, vol. 11, no. 3, pp. 489-494, 2017.

[32] Japan Coast Guard, "A Present situation and provision about marine casualty in 2008," 2008. [Online]. Available: http://www.kaiho.mlit.go.jp/info/kouhou/h21/k20090331/k090331-honpen.pdf.. [Accessed 11 June 2017].

[33] Japan P&I Club, "P&I Loss Prevention Bulletin, Vol. 2," January 2014. [Online]. Available: https://www.piclub.or.jp/lossprevention/guide/?action=common_download_main&upload_id=3452. [Accessed 18 January 2017].

[34] C. Llana and G. Wisneskey, "Handbook of the Nautical Rules of the Road," The Naval Institute Press, 30 October 2006. [Online]. Available: http://navruleshandbook.com/index.html. [Accessed 11 June 2017].

[35] timeanddate.com, "Sunrise and Sunset Calculator for Japan," timeanddate.com, [Online]. Available: https://www.timeanddate.com/sun/?query=Japan. [Accessed 11 June 2016].

[36] The ACTs project consortium, "Learn COLREGs Faster and More Efficiently!," ACTs project, 2016. [Online]. Available: http://www.ecolregs.com/index.php?lang=en. [Accessed 11 June 2016].

List of Publication

Journal:

1. W. Mutmainnah and M. Furusho, "4M Overturned Pyramid (MOP) Model Utilization: Case Studies on Collision in Indonesian and Japanese Maritime Traffic Systems (MTS)," TransNav, the International Journal on Marine Navigation and Safety of Sea Transportation, vol. 10, no. 2, pp. 257-264, 2016.
2. W. Mutmainnah and A. B. Sulistiyono and M. Furusho, "Introducing 4M Overturned Pyramid (MOP) Model to Analyze Accidents in Maritime Traffic System (MTS): A Case Study on Collisions in Japan Based on Occurrence Time," Applied Mechanics and Materials, vol. 862, pp. 220-225, 2017.
3. W. Mutmainnah, L. P. Bowo, A. B. Sulistiyono and M. Furusho, "Causative Chain Difference for each Type of Accidents in Japanese Maritime Traffic Systems (MTS)," TransNav, the International Journal on Marine Navigation and Safety of Sea Transportation, vol. 11, no. 3, pp. 489-494, 2017.

Proceeding:

1. W. Mutmainnah and M. Furusho, "The 4M Overturned Pyramid (MOP) Model in Maritime Traffic System for Safety at Sea," in Asia Navigation Conference (ANC) 2014, Xiamen, 2014.
2. W. Mutmainnah and M. Furusho, "The characteristics of ship collision accidents in United Kingdom analyzed by MOP model," in Asia Navigation Conference 2015, Kitakyushu, pp. 443-449, 2015.
3. W. Mutmainnah and M. Furusho, "The Improper Look-out that Leads to Ship Collisions in Japan," in Asia Navigation Conference (ANC) 2016, Yeosu, pp. 443-449, 2016.

Presentation:

1. W. Mutmainnah and M. Furusho, "The 4M Overturned Pyramid (MOP) Model in Maritime Traffic System for Safety at Sea," in Asia Navigation Conference (ANC) 2014 in Xiamen, China, on November 6th-8th 2014
2. W. Mutmainnah and M. Furusho, "4M Overturned Pyramid (MOP) Model Utilization: Case Studies on Collision in Indonesian and Japanese Maritime Traffic Systems (MTS)," in Conference of Transportation and Navigation (TransNav) 2015 in Gdynia, Poland, on June 17th-19th 2015
3. W. Mutmainnah and M. Furusho, "The characteristics of ship collision accidents in United Kingdom analyzed by MOP model," in Asia Navigation Conference (ANC) 2015 in Kitakyushu, Japan, on November 19th – 21st 2015
4. W. Mutmainnah and A. B. Sulistiyono and M. Furusho, "Introducing 4M Overturned Pyramid (MOP) Model to Analyze Accidents in Maritime Traffic System (MTS): A Case Study on Collisions in Japan Based on Occurrence Time," in International Seminar on Ocean, Coastal Engineering, Environmental and Natural Disaster Management (ISOCEEN) 2015 in Surabaya, Indonesia, on December 2nd 2015
5. Mutmainnah W., Furusho M., "The Improper Look-out that Leads to Ship Collisions in Japan, " in Asia Navigation Conference (ANC) 2016, on November 10th -12th 2016, Korea: Yeosu.
6. Mutmainnah W., Bowo L.P., Sulistiyono A. B., Furusho M., "Causative Chains that Leads to Ship Collisions in Japanese Maritime Traffic System (MTS) as Final Outcome of MOP Model", in SENTA 2016, on December 15th -16th 2016, Indonesia: Surabaya.
7. Mutmainnah W., Bowo L.P., Sulistiyono A. B., Furusho M., "Causative Chain Difference for each Type of Accidents in Japanese Maritime Traffic Systems (MTS)," in Conference of Transportation and Navigation (TransNav) 2017 in Gdynia, Poland, on June 21th-23th 2017

Appendix A

Example of Analyzed Investigation Reports

In this section, the detail steps utilizing MOP model is broken down, started from getting investigation reports until founding the causative chain lists. The source where all the investigation reports analyzed in this book is in references [12] and [13] for Japan, [14] for UK, [16] for ATSB and [17] for US.

Only several parts of the analysis that represent all the procedures will be written here. For example, the first case was from Japan in 208. The investigation report is downloaded from this URL: http://www.mlit.go.jp/jtsb/ship/rep-acci/2010/MA2010-5-1_2008tk0003.pdf

The report is started from the general information about the accident as shown in Fig. A-1. The probable causes that were written in the report are:

Vessel A had 2 pilots that did not have a clear job task between them and their communication was not good. Besides, Master of this vessel did not notice the existence of Vessel B and did not confirm to or receive any information from nearest coast guard (Kanmon) until vessel B is very near to vessel A. at the time Pilot 2 realize the existence of vessel B, he thought that vessel B will pass ahead without confirming.

In other hand, pilot of vessel B thought that vessel A will give way but between Pilot and Master did not share their thinking, then the communication was not good as well as among the vessels and Kanmon. The pilot chose wrong alteration to avoid the collision and the information that is inputted to the AIS was wrong, thus vessel A could not recognize the existence of vessel B earlier.

MARINE ACCIDENT INVESTIGATION REPORT

Vessel type and name:	Cargo ship "NORD POWER"
IMO number:	9271626
Gross tonnage:	88,594 tons
Vessel type and name:	Cargo ship "HAI YING"
IMO number:	8410873
Gross tonnage:	1,312 tons
Accident type:	Collision
Date and time:	0742:30 , July 22, 2008 (local time, UTC + 9 hours)
Location:	Kanmon Passage, Kanmon Port 185° true, around 1,630meters from Daibahana Lighthouse (approximately 33° 56. 09'N 130° 52.33'E)

April 22, 2010

Adopted by the Japan Transport Safety Board

Chairman Norihiro Goto

Member Tetsuo Yokoyama

Member Tetsuya Yamamoto

Member Toshiyuki Ishikawa

Member Mina Nemoto

Fig. A-1 Page 1 in investigation report

Appendix B

Corner Analysis

Several probable causes are written by the investigators and experts in the investigation report. To see the characteristic of accidents, this first step of MOP model, corner analysis (CA), is done. It shows the causative factor list that led to accident, whether directly or indirectly. At first, after reading the report, all the failures are listed and categorize into 4M factor based on the definition in Table 3.3. In this section, the failures that led to accident in appendix A is traced for each involved ship in Table B-1.

Table B-1. Failures led to collision case 1

No.	Ship	Failures	Stage
1	A	careless seaman in communication among the seamen (or with pilot)	1
2	A	careless seaman in understanding condition (wrong judgement/decision)	2
3	A	poor communication among onshore & other vessel utilizing radio	1
4	A	poor management of personal on board in distributing job tasks	1
5	A	poor management from onshore in identifying/monitoring/communicating	1
6	B	careless seaman in communication among the seamen (or with pilot)	1
7	B	careless seaman in understanding condition (wrong judgement/decision)	2
8	B	careless seaman in deciding course alteration	2
9	B	incapability of seaman/personnel in operating navigational equipment (unfamiliar)	1
10	B	poor communication among onshore & other vessel utilizing radio	1
11	B	poor management from onshore in identifying/monitoring/communicating	1

To get the causative factor list, all the failures from 81 collisions and 129 ships involved are summarized, then categorized into several classifications, finally the code were set. The term of failures is changed into causative factor after they are summarized. Table B-2 gives the example how is the summary of Japanese collision. In Table B-2, 1A means collision number 1 and involved ship A, based on the report.

Table B-2. Summary example of failures in corner analysis or the list of causative factors for each ship in each case (Japanese collision- Man factor/ M1)

Code	Causative Factors	1A			1B			2A			2B			.	.	20B			Total Failures
		1	2	3	1	2	3	1	2	3	1	2	3	.	.	1	2	3	
CARELESS SEAMAN														.	.				
M101-01	in communication among the seamen (or with pilot)	o			o									.	.				8
M101-02	in maintaining proper lookout							o	o		o			.	.				25
M101-03	in monitoring/identifying any accident risk								o		o			.	.				23
M101-04	in understanding condition (wrong judgement/decision)		o			o			o			o		.	.		o		12
M101-05	in deciding speed													.	.				10
M101-06	in deciding course alteration					o								.	.				9
M101-07	doing erratic/ineffective action in avoiding accident													.	.				3
M101-08	in flashing light signal													.	.				1
M101-09	in blasting sound signal							o						.	.				2
M101-10	in wearing/utilizing safety/survival devices													.	.				2
M101-11	in preventing flooding													.	.				1
M101-12	in carrying out / following some procedures/ rules													.	.				0
INCAPABILITY OF SEAMAN/PERSONNEL														.	.				
M102-01	in operating navigational equipment (unfamiliar)				o						o			.	.				4
M102-02	in understanding signal from other vessels													.	.				1
M102-03	in controlling the operation													.	.				0
M102-04	in arranging working procedure (mooring, berthing, towing)													.	.				0
M102-05	in performing crossing agreement													.	.				0
M102-06	in executing commands from master/pilot/company rule													.	.				0
M103-01	focus of the seamen was distracted										o			.	.				11
SOME SEAMEN WERE NOT ON THE BRIDGE														.	.				
M104-01	watch keeper was not on the bridge													.	.				3
M104-02	master was not on the bridge													.	.				2
HUMAN ELEMENT PROBLEM														.	.				
M105-01	Fatigue													.	.				1
M105-02	Lethargy													.	.				0
M105-03	sleep inertia													.	.				0
M105-04	Stress													.	.				0
M105-05	Intoxication													.	.				0
M105-06	complacent attitude													.	.				0
	Total	1	1	0	2	2	0	2	3	0	4	1	0	.	.	0	1	0	118

Appendix C

Line Relation Analysis

After getting the codes for each causative factor, the causative factor's codes are arranged into causative chains based on what happen first, second, third, and so on from stage 1, 2 until 3. For example in case 1 (appendix A), the probable causes have been listed become causative factors and its code in corner analysis.

The line relation analysis is begin by arranging the causative factors based on the order what happen first to the last, called as line relation by the codes. There are two line relations that was created in case 1. First is M403-06 > M101-01 > M101-04 and second is M101-01 > M101-04 > M101-06. The CFs that perform line relation sometimes affecting and/or affected by other CF more than once or the reverse, some time there is CF that did not perform line relation.

All the line relations from each country is collected and ordered. The same CFs are placed in the same column, then we can see the characteristics. For example, in case 1, the order become:

M403-06 >	M101-01 >	M101-04		
	M101-01 >	M101-04 >	M101-06	

After 20 cases of collision that happen in Japan are collected, the line relation term is changed into causative chain (as written in Table 4.5)