Development of Safety Evaluation Model for Management of Navigation Safety in an Entire Ship Route Area

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Development of Safety Evaluation Model for Management of Navigation Safety in an Entire Ship Route Area

(船舶運航海域における航行安全性管理のための評価法の開発)

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Chapter 1

Introduction

1.1 Background

A marine accident can result in tragic consequences such as the loss of ships and materials damage to marine infrastructure and environment. It has led to the economic losses and long time to recover. In order to prevent such marine accidents, safety is a significant issue in shipping and ship navigation in industrial fields. Therefore, many safety regulations pertaining to ship design and equipment have been developed to promote ship safety. However, significant marine accidents continue to occur, and it has come to light that one of the main causes of marine accidents is human error. Human factors were adopted among the causes to be investigated in marine accidents in Resolution A.884 (21) (IMO, 2000). A large proportion of marine accidents are ship collisions caused by human error. As one of the major sources of human error, navigators play an important role in navigating ships.

The need to ensure safety of navigation has led to the implementation in terms of supporting a navigation officer operating a ship. It has come to light the need for safety evaluation methods to estimate risk involved in ship navigation. This quantitative approach using the evaluation methods is able to predict risk and manage potential risk. Other approach is that VTS (vessel traffic service) is established in Resolution A.857 (20) (IMO, 1997). It has a role to monitor navigation situation and to assist navigation officers for manage potential risk in observation area.

1.2 Purpose of the study

The primary of this thesis introduces a new model for evaluation of the navigation safety zone throughout an entire ship route for use by a port safety authority or vessel traffic service center. In evaluating the risks associated with a navigation situation, this model considers a variety of factors that affect a navigation officer's perceptions while navigating. A risk quantification method reflecting the knowledge of navigators was incorporated in this model, and a new algorithm was developed for evaluating safety in an entire ship route. To verify the effectiveness of the proposed model, a simulation was carried out for the Osaka Bay area. The proposed model was found to be effective in quantifying navigation safety throughout an entire ship route in Osaka Bay. This model can be helpful to vessel traffic centers and port safety authorities in ship navigation safety management.

This thesis is structured as follows. The literature review in terms of existing safety evaluation models is presented in Section 2 and Section 3 describes safety index as risk quantification to identify risk in ship navigation in this model. An algorithm developed to evaluate risk on an entire ship route area is presented in Section 4. Simulation results in Osaka bay utilizing proposed model are exemplified in Section 5. The findings and proposals for future work are included in Section 6. The dissertation flowchart is shown in figure 1-1

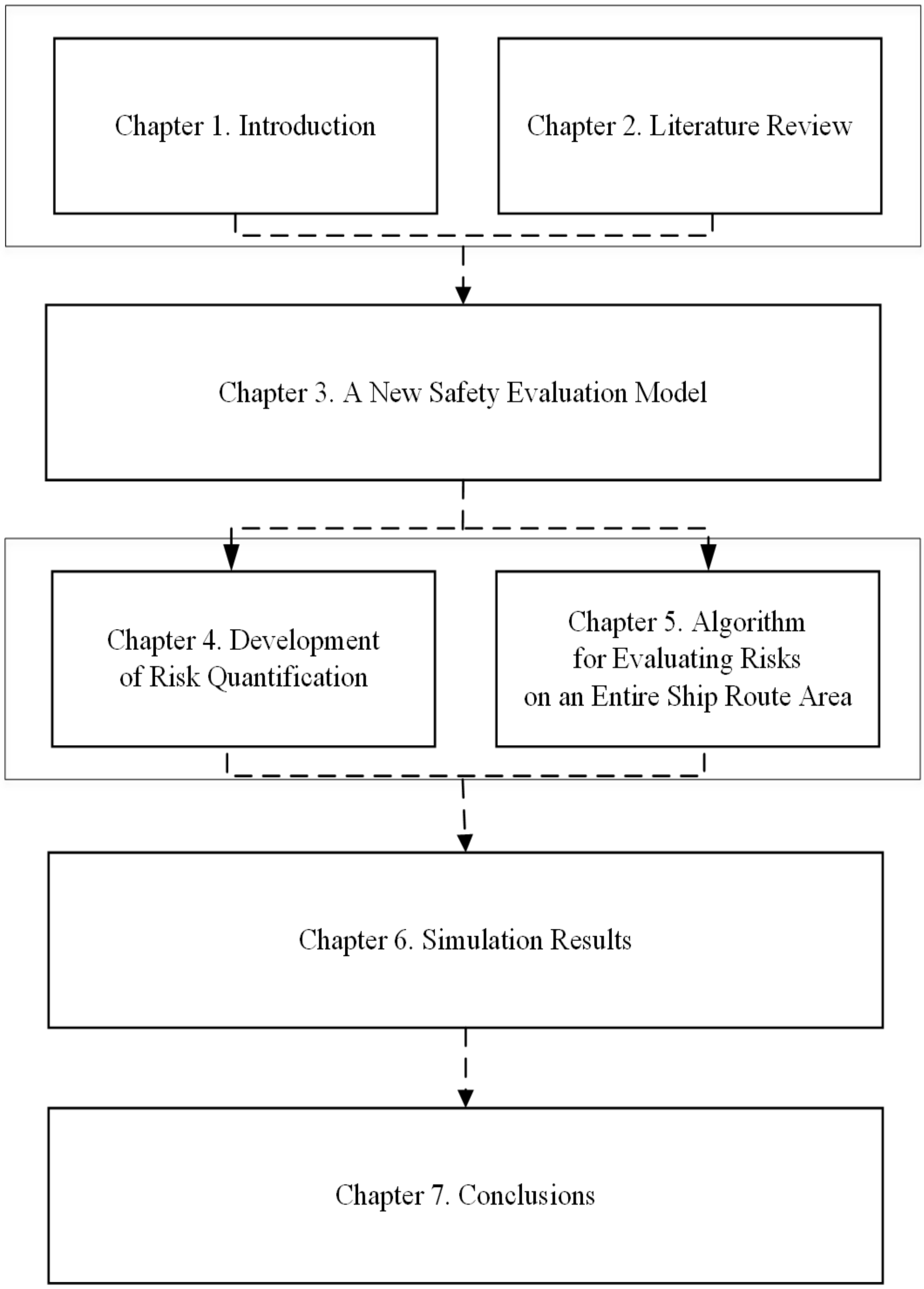


Figure 1-1 Dissertation Flowchart

Chapter 2

Literature Review of Existing Safety Evaluation Model

2.1 Introduction

Safety management in shipping and ship navigation is very important issue in order to prevent marine accidents. For safety efficiency management, various navigational safety evaluation models have been proposed. These models are the process of estimating the potential risk depending on ship navigation situation. It is helpful methods to keep watching and managing potential risk in port area in order to assess a ship's navigation situation and enhance ship navigation safety. Safety evaluation model plays a positive role in reducing marine accidents and improving navigation efficiency. Many researchers have presented various safety evaluation models. However, they used a basic definition and concepts of existing models as shown in table 2-1.

Table 2-1 Representative safety evaluation models

Safety Evaluation Models	
Risk probability model	Fujii(1971), Macduff(1974)
Ship domain model	Goodwin(1975), Fujii(1971)
Estimate risk considering a navigation officer' decision making process	Hara(1995), Inoue(2000), Hasegawa(1997)

The purpose of safety evaluation model can be divided into two major groups. Firstly, it is to support the navigation officers when they take some action to avoid ship collision. Secondly, it is to support the manager of port authority to manage ship route area. This section will explain the overview of existing models how risks in ship navigation may be quantified and how to evaluate the ship navigation situation. .

2.2 Risk Probability Model

Fujii (Fujii, 1971) and Macduff (Macduff, 1974) indicated that a safe navigational zone can be determined from the probability of ship collisions or groundlings. In these studies, the level of navigational safety in the observation zone was calculated using statistical analysis of marine accidents and the traffic data. Hence, the safety level obtained indicates the potential risk of a ship collision or grounding. The risk level is calculated as follows:

$$\boldsymbol{P = N_a \times P_c} \quad (1)$$

where

N_a : the number of collision or grounding candidates

P_c : causation probability

This type of safety evaluation method can be helpful in distinguishing between navigational safety and hazard zones. On the other hand, the safety level determined using this type of method is calculated using historical data. It is not possible, using this type of method, to evaluate the safety level of a ship route using navigational situations in real time. In addition, this approach does not consider human factors which are the main causes of marine accidents.

2.3 Ship Domain Model

The concept of a ship domain has been introduced in research on navigational safety evaluation method. A certain area around a ship that should remain clear of other ships is identified on the basis of the safe distance between ships. This area is referred to as the ship domain. Based on the shape of the ship domain, navigators can maintain a safe distance from other ships. The safe distance can be calculated on the basis of statistical analysis of marine traffic data (Goodwin, 1975; Fujii, 1971), fuzzy logic (Szlapczynski 2006; Pietrzykowski, 2008; Wang 2009), or questionnaire results and fuzzy logic (Pietrzykowski, 2009; Wang, 2010). The shape and size of a ship's domain is determined by the calculated safe distance. Two-dimensional domains such as circular, rectangular, elliptical, and polygonal shapes have been proposed as shown in Figure 2-1. Several methods for determining the safe distance have been proposed for use in this approach to safety evaluation. As a result, this approach has been helpful in supporting navigators' decisions. However, this approach has limitations in terms of its ability to consider navigational situations in the safety evaluation.

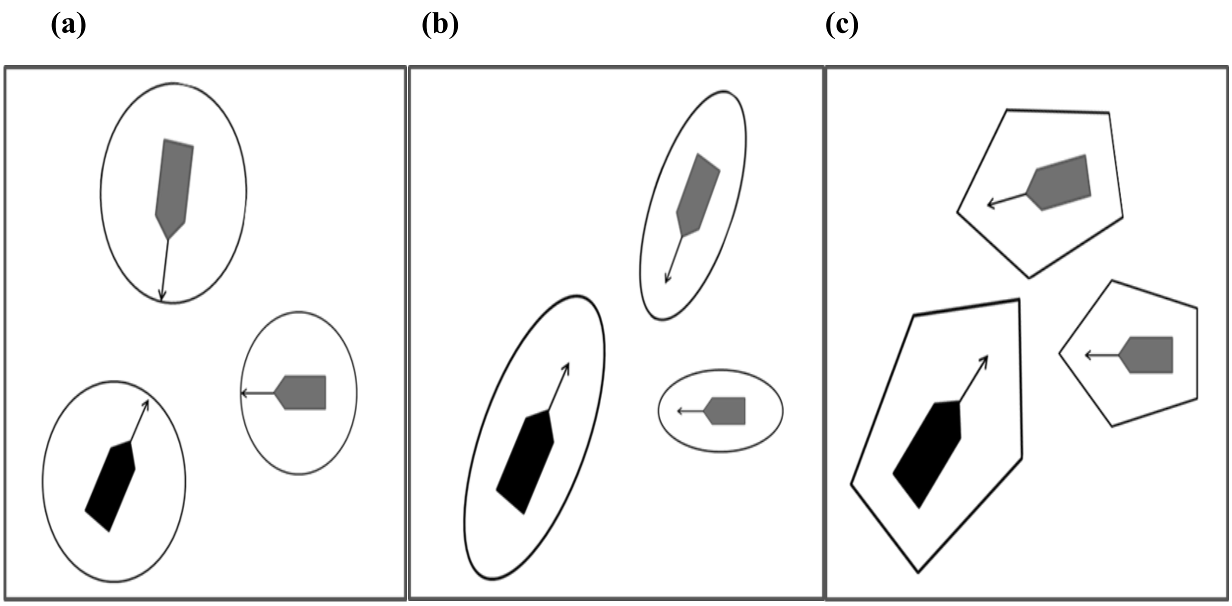


Figure 2-1 Several shapes of ship domain model (a) circle (b) ellipse (c) polygon

2.4 Estimate Risk Considering Navigation Officers' Decision Making

As a quantitative approach to safety management by using the navigation officers' perceptions, It has been proposed that risk assessment for navigational areas should consider the decision-making processes of navigators in avoiding ship collisions. The risks associated with navigation situations can be quantified on the basis of navigators' knowledge and competence.

Hara(Hara, 1995) proposed the concept of the SJ-value (subjective judgment) as an index to quantitatively express the degree of collision risk with another ship felt by the ship handler. A risk quantification method that considers factors such as the distance between ships, the rates of change of the ships' directions, and the approaching speed was developed by Hara (Hara, 1995). The SJ value is calculated as follows:

$$\boldsymbol{SJ_i = a_i\Omega + b_iR' + c_i\dot{R}' + d_i} \quad (2)$$

where

SJ_i	subjective judgment value
V_r	relative speed
L	length of the ship(m)
V	ships speed(m/sec)
$\boldsymbol{\Omega}$	non-dimensional rate of change of relative directions
R	relative-distance
R'	non-dimensional relative distance((R'=R/L)
$\dot{R}'$	non-dimensional approaching speed(R'=V_r/V)
a_i, b_i, c_i, d_i	coefficient of each parameter

Inoue(Inoue, 1993, 1996, 1997, 2000) proposed an ES(environment stress) model to evaluate the difficulty of ship handling for navigation purposes. In this model, the risk is quantified by measuring a navigator's physical stress when operating a ship handling simulator and by employing a questionnaire to obtain input from navigators. This risk quantification model considers factors such as the distance between a ship and another ship or an obstacle, the rate of change of the relative directions, and the approaching speed. The value of ES model is found as shown in Equation (3), (4) and Figure 2-2:

$$\boldsymbol{ES_L = \sum (SJ_L)_i} \tag{3}$$

$$\boldsymbol{ES_s = \sum (SJ_s)_i} \tag{4}$$

where

ES_L	:	the degree of stress forced on the mariner by topographical restrictions
SJ_L	:	subjective judgement of mariners in relation to obstacles
ES_s	:	the degree of stress forced on the mariner by traffic congestion
SJ_s	:	subjective judgement of mariners in relation to ships
$\boldsymbol{i}$	:	$-90° \sim +90°$

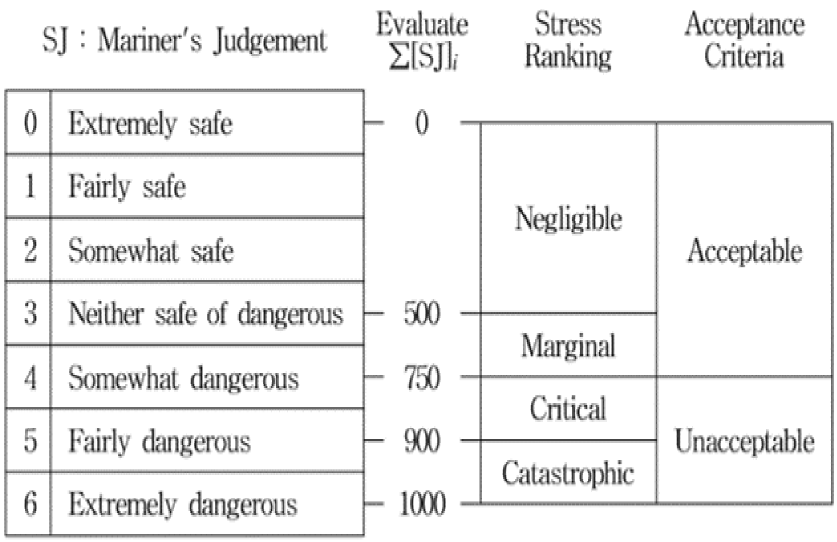


Figure 2-2 Stress ranking and acceptance criteria

Both models are based on a determination of the navigation officers' perceptions in a ship navigation situation. These assessments are usually based on a calculation of the relationship between ships, where the navigation officers can only control the speed and course of their own ship, and is used to determine their responses to circumstances that affect them to avoid a collision. Such approaches emphasize the importance of expressing the navigation officers' perceptions in numbers to manage safety efficiently by reproducing the ship's navigation situation.

Hasegawa(Hasegawa, 1987, 1997) has proposed collision risk model (CR) to avoid ship collision for supporting navigation officers. The risks associated with navigation officers' decision making can be quantified. The risk quantification is calculated by a collision. The collision is defined as a meeting of ships based on the DPCA (distance to the closest point of approach) and the TCPA (time to the closest point of approach). These factors are computed as follows:

$$\boldsymbol{TCPA' = TCPA\frac{V}{L}} \tag{5}$$

$$\boldsymbol{DCPA' = DCPA\frac{1}{L}} \tag{6}$$

where

$TCPA'$: non-dimensional time to the closest point of approach

V : ships speed(m/sec)

L : length of the ship(m)

$DCPA'$: non-dimensional distance to the closest point of approach

These models are useful to evaluate the ship navigation situation based on their own risk quantification based on the process of navigation officer's decision making. As a result, this type of safety evaluation method is useful in evaluating marine traffic situations on the basis of factors that influence a navigator's perspective. On the other hand, this type of approach does not consider a variety of factors that can affect a navigator's perspective while navigating. In addition, this type of approach can only be used to evaluate the navigational safety of the surroundings of an individual ship.

2.5 Conclusions

In literature, the common point of the various methods of safety evaluation models consists of risk quantification and algorithms how to evaluate the ship navigation situation. In table 2-2, a summary of each safety evaluation model is shown. In order to develop a new safety evaluation model, it is important to consider two steps as follows. Firstly, safety evaluation models have their own risk quantification to estimate navigation environment. Secondly, Algorithm is developed to evaluate risks associated with navigation situation between ships.

Table 2-2 Summary of each safety evaluation model

Model	Purpose	Risk quantification	Method to calculate	Elements
Fujii and MacDuff **Ship probability**	To determine the safe navigational zone to manage port	P: probability of ship collision	Calculate the probability based on historical marine traffic data	P=Na x Pc Na: the number of ship collision Pc: Causation probability
Goodwin and Fujii **Ship Domain**	To determine the safe distance to avoid ship collision	Safe distance	Statistical analysis based on marine traffic data	Ship position(long, lat), course of ship, speeds and so on
Hasegawa **Collision Risk**	To avoid ship collision to support navigation officers	CR (Collision Risk)	Fuzzy (ship handling simulator)	DCPA(Distance to the closest point of approach), TCPA(Time to the closest point of approach)
Hara, **SJ model**	To evaluate the ship route based on navigation officers' perception	SJ value (Subjective Judgement value)	Fuzzy(ship handling simulator)	Relative speed, relative distance, approaching speed
Inoue, **ES model**	To evaluate the ship route based on navigation officers' perception	ES model (Environment Stress model)	Statistical methods (measuring a navigator's physical stress)	Relative speed, relative distance, approaching speed

The common point of the various methods of navigational safety evaluation that have been mentioned is that they involve various methods for risk quantification. These methods have been shown to be useful tools for evaluating the risk associated with ship navigation. However, safety evaluation methods that use risk quantification based on a navigator's knowledge are limited to being applicable only to evaluating the ship navigation situation of an individual ship. Therefore, while these methods help navigators on board ships to avoid collisions, they cannot be used to determine the navigational safety zone anywhere along an entire ship route at a specific time, which would be useful to port safety authorities and vessel traffic service centers in managing ship navigation safety. Other safety evaluation methods using risk probability assessment can be used to determine the navigational safety zone, but the risk is quantified on the basis of analysis of historical data. As a result, this approach does not reflect real-time navigational situations and navigators' perspectives as factors in the occurrence of marine accidents.

These methods are classified according to three improvement points. Firstly, the risk is calculated on the basis of surrounding changes depends on a ship movement. These models that are CR, Ship domain, SJ model and ES model belong to this case. Secondly, they consider factors that affect navigation officers' decision-making to operate their own ship, in case of CR, SJ model and ES model. Thirdly, the probability model is able to determine navigational safety zone. The value of risk using model depends on historical data, which means it is not suitable to support navigation officers on board ship in real-time.

Chapter 3

A New Safety Evaluation Model

3.1 Introduction

A new safety evaluation model is presented in this chapter 3. Table 3-1 shows the improvement points of existing safety evaluation model. This thesis proposes the solution to these problems as shown in table 3-1. To work out this problem efficiently, a proposed model has designed so as to reflect the navigation officer's perception. An algorithm utilizing this safety index has been developed to assess risk in an entire ship route area. In addition, risk in an entire ship route area is calculated in real-time. The application of proposed algorithm is able to determine navigational safety zone depending on the navigation situation changes in real-time.

Table 3-1 Improvement points of a new safety evaluation model

To improvement points	Safety Evaluation Models	A new model
Evaluate safety of the surroundings of an individual ship	CR, Ship domain, SJmodel, ESmodel	To assess an entire ship route area at specific time
To assess risk for safety navigational zone based on historical data	Risk probability assessment	To reflect real-time navigational situations to determine navigational safety zone
Consider navigation officers' opinion to assess the navigation situation of an individual ship	CR, SJmodel, ESmodel	To consider navigation officers' opinion as an user for port safety management

This model is developed to support VTS. The role of VTS is that they monitor the navigation situation in observation area and determine the navigational safety zone in order to assist a navigation officer on board-ship. It is important to take in a situation quickly from the point of view of a navigation officer that does not even recognize their situation danger. In aspect of this, various factors in this model are established to reveal the perception of navigation officers. These factors simplify to estimate risk associated with navigation situation. An algorithm is developed in this model. The risk values can be calculated in an entire ship route area, which makes a decision easily whether navigational safety zone or not.

3.2 Definition of safety index

The main purpose of safety index indicates a variety of navigation situation quantitatively, which takes into consideration of a navigation officer’s perception. A navigation officer’s perception is affected by encounter situations. Encounter situations of an individual ship, which are head-on situation, crossing situation and overtaking situation. Navigation officers have to obey the rule which is the COLREGs (international regulations for preventing collisions at sea). It is published by the IMO to prevent collisions between ships and navigation officers have to obey this rules when to take a proper action. According to given situation, the ship is determined to give away or keep their course and speed. A navigation officer on board ship considers various factors to avoid collision. Therefore, the most common methods to estimate risk in navigation situation are on the basis of an individual ship’s behaviors or movement. The calculation of the risk associated with surrounding situation of an individual ship is good to determine the own ship’s behavior to avoid collision. It has the limitation to manage navigation safety in port or navigational area.

Because navigation situations foamed by many ships navigating is complex. Each movement of ship affects a navigation officer’s perception while navigating own/other ships each other. It is shown in Figure 3-1 as (a), (b), (c) and (d). In Figure 3-1 (a), two ships approach each other. Figure 3-1(c) shows the ship in black is determined as give-way ship, at that time, own ship is in black and target ship is in green. It is shown that the ship in green is stand-on ship as own ship and target ship is in black in figure 3-1(d). Likewise, a proper action of a navigation officer changes according to own ship’s encounter situation as shown in figure 3-1 (c) and (d). Each action which are stand on/give-way affects the navigation officer’s perception. The safety level also changed depending on which ships consider own ship. Therefore, a definition of a section is adopted in order to solve this problem. A section is defined as one of the meshes that an entire ship route is divided into several sections. Navigation situations indicate each encounter situation of all ship in a section. The details are shown as follows: Firstly, set the specific a section as shown in figure 3-1 (b). Secondly, encounter situation foamed all the ships in a section. Based on this definition of navigation situation, the safety index is developed as follows:

(i) All the ships in a section consider own ship

(ii) Estimate risk associated with navigation situation of all the ships

Figure 3-2 shows the concept of safety index. Safety index indicates the risk in a section that includes navigation situation of all the ships. In order to estimate risk associated with navigation situation reflecting a navigation officer’s perception, safety index considers various factors that reveal a navigation officer’s perception. The details are described in the following part.

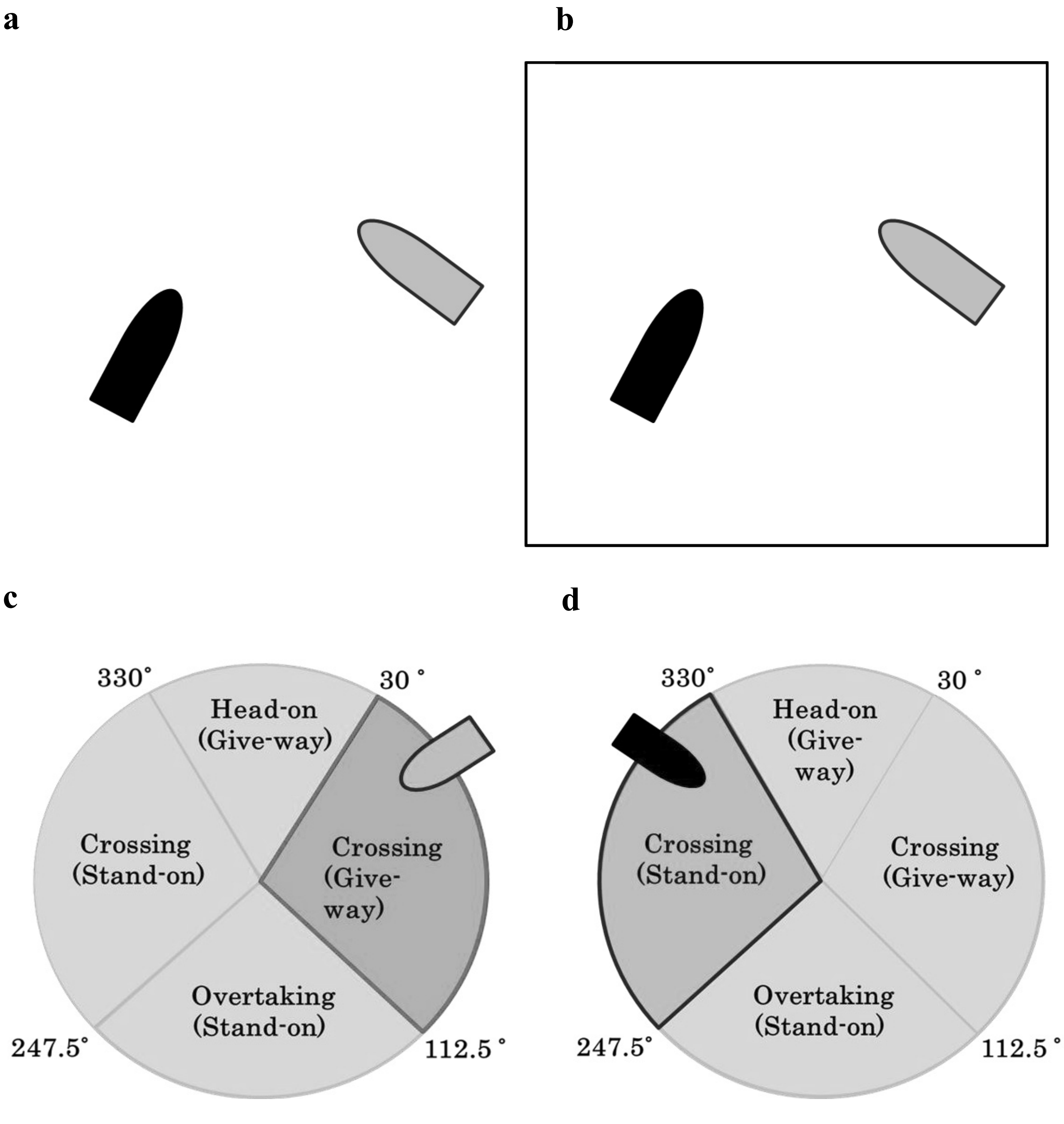


Figure 3-1 various encounter situation in a section

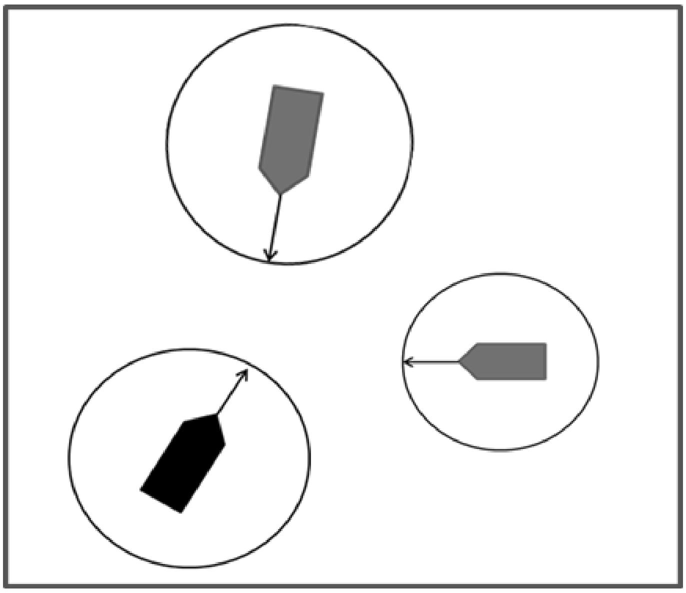


Figure 3-2 Safety index indicates risks in a section that includes various navigation situation foamed by all ship in restricted section

3.3 Safety Index Factors

Figure 3-3 shows the process of a navigation officer's decision making when encountering other ships. A navigation officer operating own ship observes other ships. At that time, the navigation officer tries to estimate risk associated with given situation such as, distance between ships, speed of own/other ship and bearing. In given situation, the officer has to determine their proper action according to the COLREGs. A variety of factors can be taken into account in the model. Factors are classified according to ship information, relationship between ship and environmental situation (time, day) as follows:

(i) Ship information: ship type, length of ship

(ii) Relationship between ships: relative speed, distance difference between ships, encounter situations

(iii) Environmental situation: time, day

Ship information is grouped according to ships' types and length of ship. This factor affects the navigation officers make decisions based on such information, which is important when considering maneuverability. In addition, these can exhibit the attributes of traffic route and ship speed. Relationship between ships is classified according to relative speed, distance difference between ships and encounter situations. It has impact when the navigation officer alters own ship's course/speed. According to encounter situations, proper action of ship is different. Environmental situation is grouped according to time and day. Sailing time includes the information who navigates a ship, which means that a navigation officer's experience will be taken into consideration. It is shown as in table 3-2.

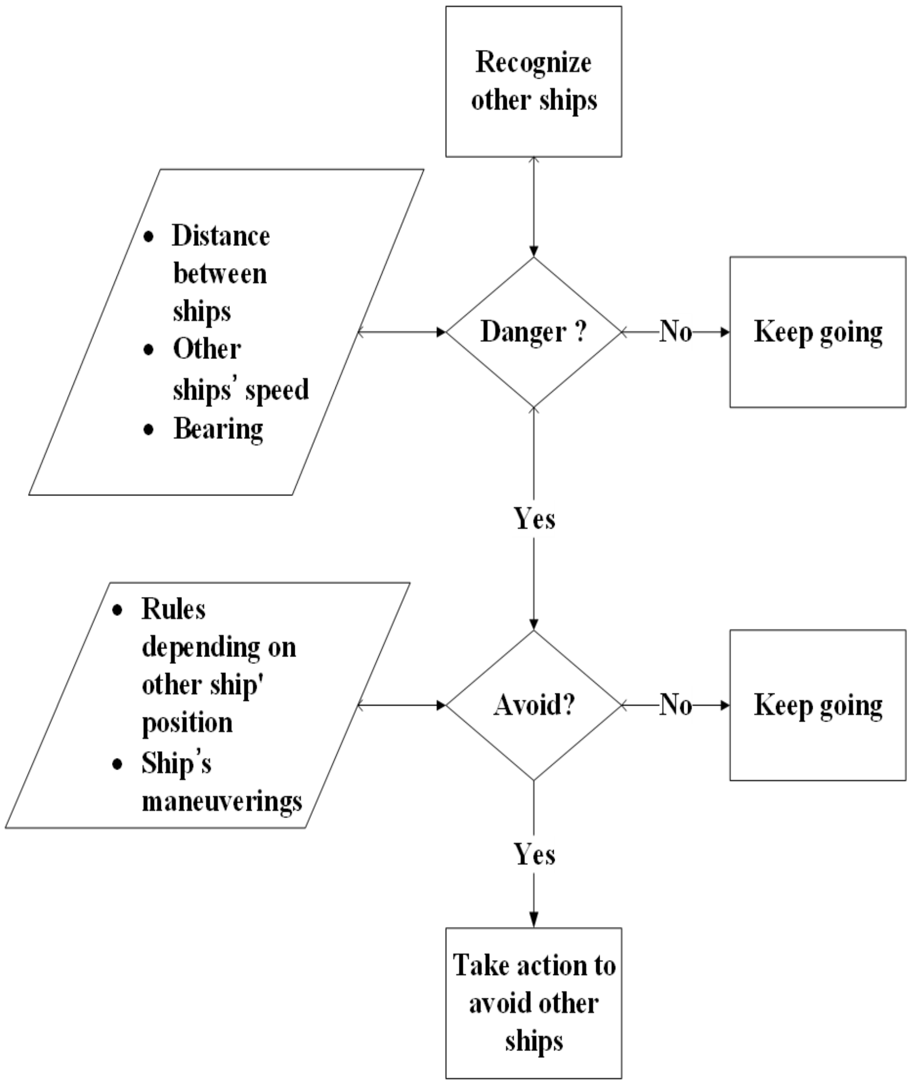


Figure 3-3 The process of a navigation officer's decision making when encountering other ships

Table 3-2 Office time according to the rank of navigation officers

Navigation officer’s rank	Shift time
Chief officer	04:00-08:00, 16:00-20:00
2nd officer	00:00-04:00. 12:00-16:00
3rd officer	08:00-12:00, 20:00-24:00

3.4 Safety Index Structure

Figure 3-4 shows the procedures of this model, there are three steps. First step is to set the observation area as shown in Figure 3-5 (a), which is an example for Osaka Bay. In order to evaluate risk associated with navigation situation, the observation area is divided into several sections as shown in Figure 3-5 (b). The second step is to calculate safety index in a section for the entire ship route. At that time, this study is to reproduce navigation situation in the entire ship route. AIS (automatic identification system) data has been used to reproduce marine traffic situation and to evaluate the navigation situation. The AIS is a navigation device to transmit ship information data automatically. The AIS is equipped for domestic ships of over 500 GT and international ships of over 300 GT by IMO. AIS data are classified according to static and dynamic, the data consist of MMSI (maritime mobile service identity) number, ship name, current ship position, speed over ground, true heading etc. These data make it easy for the analysis of the entire traffic flow and individual ship movement. Second step is to calculate risk for an entire ship route. To simplify to compare the level of risk and to determine navigational safety zone, it is divided into several sections as a gridded matrix. The level of navigation safety can be quantified by means of safety index model. Third step is to make hazard map depending on the risk level that is calculated. It is helpful to monitor on an entire ship route and to distinguish the navigational safety zone quickly and easily.

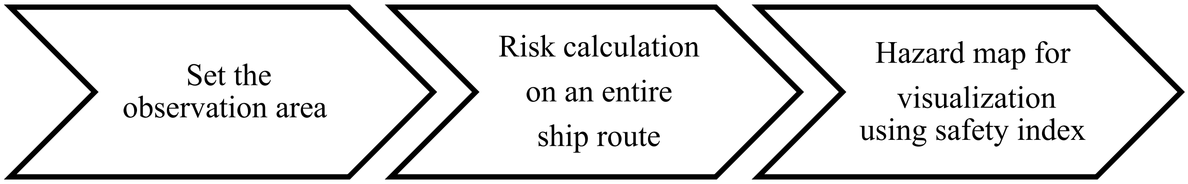


Figure 3-4 Procedures of safety index model

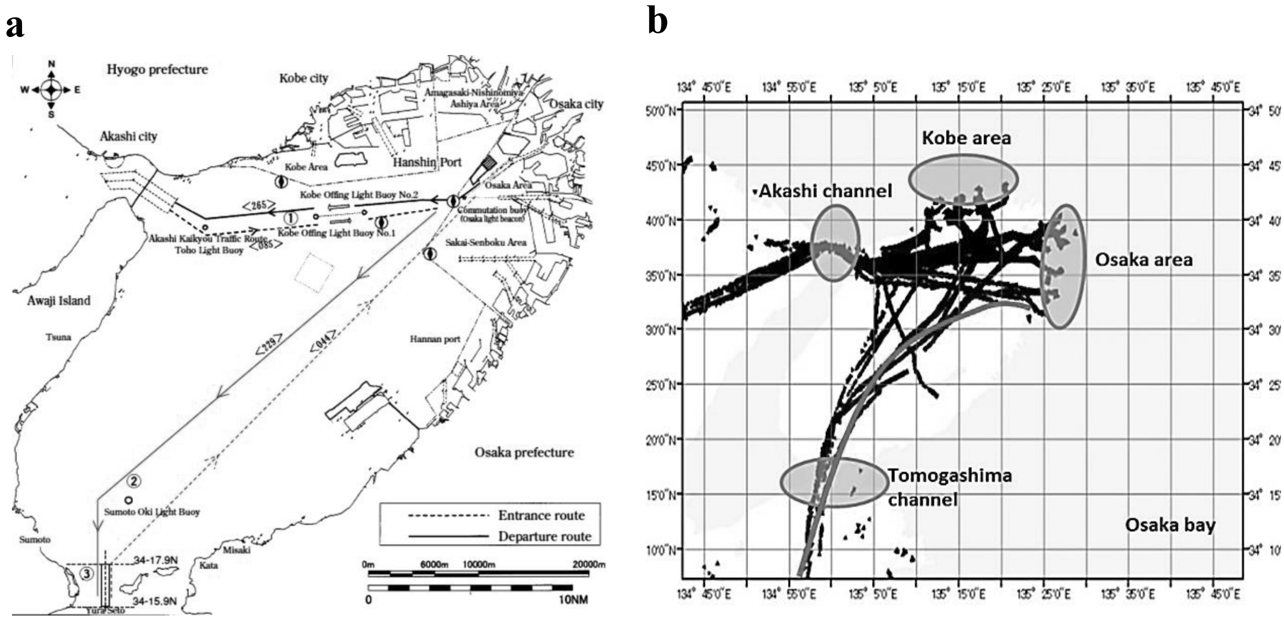


Figure 3-5 Observation area as an example (a) observation area (b) divide observation area into several sections as a gridded matrix

3.5 Conclusions

In this chapter, new model was presented approximatively. In order to complement the existing safety evaluation model, this chapter proposed the solution. The approach was to consider various factors that reveal a navigation officer's perception. Outline of procedures of how to evaluate on an entire ship route was introduced. The risk quantification on basis of factors and algorithm utilizing safety index will be described in detail in the subsequent sections 4 and 5.

Chapter 4

Development of Risk Quantification

4.1 Introduction

Previous chapter already presented the safety index factors. This chapter shows how to define and identify the each factors of safety index model. Accordingly, most researchers emphasize the importance of safety management to prevent marine accidents. The IMO(IMO, 2000) stated, "Historically, the international maritime community has approached maritime safety from a predominantly technical perspective. The conventional wisdom has been to apply engineering and technological solutions to promote safety and to minimize the consequences of marine casualties and incidents. Accordingly, safety standards have primarily addressed ship design and equipment requirements. Despite these technical innovations, significant marine casualties and incidents have continued to occur."

Grech(Grech, 2002) stated, "There are two sides to the technological advances. Improvements in ship design and navigation aids have reduced the frequency and severity of shipping incidents. In turn, the reduction of failures in technology has revealed the underlying level of influence of human error in accident causation." To this extent, analyses of marine accidents that have prompted the International maritime community and the various safety regimes concerned, to evolve from an approach that focuses on technical requirements for ship design and equipment to one which seeks to recognize and more fully address the role of human factors in maritime safety within the entire marine industry.

In common, they have emphasized the importance of analysis of human factor as one of the reason in marine accidents. Regarding of this, IMO (IMO, 2000) mentioned, "One way the maritime community has sought to address the contribution of the human factor to marine casualties and incidents has been to emphasize the proper training and certification of ships' crews. It has become increasingly clear; however, that training is only one aspect of the human factor. There are other factors which contribute to marine casualties and incidents which must be understood, investigated and addressed. The following are example of these factors relevant to the maritime industry: communication, competence, culture, experience, fatigue, health, situational awareness, stress and working conditions."

This study tries to develop safety index factors combining experience and situational awareness, especially, which is regarded as navigation officers' perception in ship navigation. Perception is the process of attaining an understanding of the environment by interpreting information from their experiences. Notably, navigation officers have unique experience on the sea. They have different perception in relation to the surrounding situation although they have an influence on safety management relevant to ship navigation. Although the possibility exists of situational understanding differs even in the same situation, it is difficult to distinguish the degree of the navigation officers' perceptions even in the same situation. Thus, it is important to understand how the navigation officer and ship's navigation environment interacts to quantitatively determine their perception. In order to identify a navigation officer's perception, this study carried out the questionnaire as shown in figure 4-1, it is a useful tool to learn and reveal how navigation officers feel about factors associated with navigation situations. It will be shown in next part.

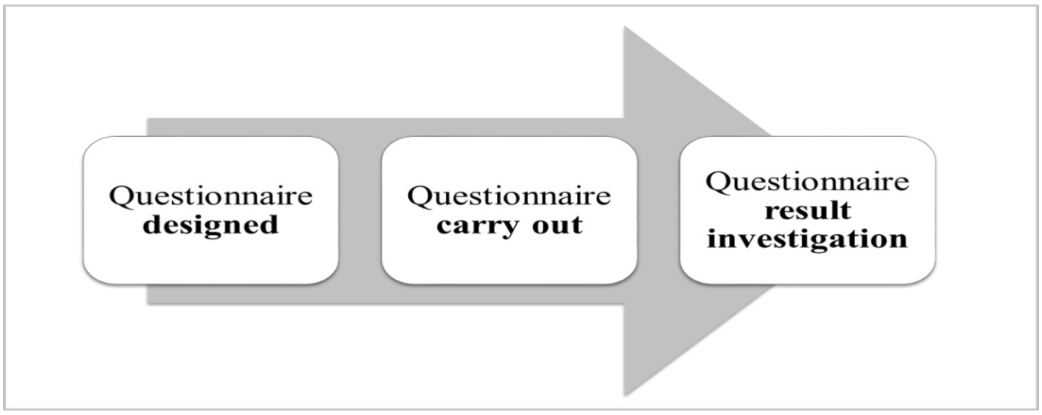


Figure 4-1 Stepwise of questionnaire in order to identify the risk reflecting the navigation officer's perception

4.2 Method of Analysis Factors

This index includes basic indices that are related to ship types, speed, cargo types, length, ship location and their interaction with other vessels, and/or other items. A perspective flow is described based on the relationships between the ships and their navigators' perspectives. In a given navigation situation, it is important to collect ship information such as type of ship, length of ship, and loading state of both own ship and other ships, because navigation officers make decisions based on such information, which is important when considering maneuverability.

Accordingly, the details of ship information help us to understand the decisions of the navigation officers based on their perception. Relationships such as relative speed and distance are also important factor this is when interpreting the navigational situation. Navigation officers understand each other's ship maneuverability, and then, they consider the rules of sea traffic. In particular, the assessment process involves the COLREGs (International Regulations for Preventing Collisions at Sea) or the Public Order in open ports, depending on the encounter situation, be it head-on, crossing, or overtaking, which are imposed on navigation officers by the IMO. The navigation officers obey these rules and decide on the proper action, while keeping safety in mind.

The factors include several elements to define the characteristics of each factor. The elements must be quantified to assess the risk associated with a navigation area based on navigators' perceptions. Hence, a questionnaire was used to obtain input from navigators. The design of the questionnaire used to explore navigators' perceptions is shown in Table 4-1.

Table 4-1 The design of a questionnaire for risk quantification

<table>
<tr><th>Factors</th><th colspan="2">Elements</th></tr>
<tr><td>Type of ship</td><td colspan="2">Container ship, LNG, VLCC, Ferry, Passenger ship, Bulk carrier, Fisher, LPG, PCC, Reefer ship, Tug boat</td></tr>
<tr><td>Length of ship</td><td colspan="2">Under 100 m, 101–150 m, 151–200 m, 201–250 m, 251–300 m, over 301 m</td></tr>
<tr><td>Relative speed</td><td colspan="2">0–1.0 k’t, 1.1–2.0 k’t, 2.1–3.0 k’t, 3.1–4.0 k’t, over 4.1 k’t–</td></tr>
<tr><td>Distance
(L, length of ship)</td><td colspan="2">Under 5L, 6–10L, 11–15L, 16–20L, 21–30L, over 31L</td></tr>
<tr><td rowspan="4">Encounter situations</td><td>Head-on
(give-way)</td><td>On the centerline of the ship showing from right ahead of 30 degrees abaft the beam of either side of ship</td></tr>
<tr><td>Crossing on starboard (give-way)</td><td>On the starboard side showing from right ahead of 30 degrees to 112.5 degrees</td></tr>
<tr><td>Crossing on port (stand-on)</td><td>On the port side showing from port ahead of 30degrees to 247.5 degrees</td></tr>
<tr><td>Overtaking (stand-on)</td><td>At the stern showing 67.5 degrees from right aft on each side of ship,</td></tr>
<tr><td>Time
(LT, local time)</td><td colspan="2">Chief officer’s
04:00–08:00, 16:00–20:00
2nd officer’s
00:00–04:00, 12:00–16:00
3rd officer’s
08:00–12:00, 20:00–24:00</td></tr>
<tr><td>Day</td><td colspan="2">Mon., Tue., Wed., Thur., Fri., Sat., Sun.</td></tr>
</table>

4.3 Analysis of Factors

The questionnaire investigation is a useful tool to learn how navigation officers feel about items related to ship navigation situations. This study used a questionnaire that contained seven questions related to the safety index. The officers' responses were classified according to their estimation of the navigation's safety level and used a nine-scale evaluation score starting from 1st level(1: no influence) and ending with 9th level(9: significant influence) as presented in figure 4-2. An example of safety index factors in questionnaire is designed as shown in table 4-2.

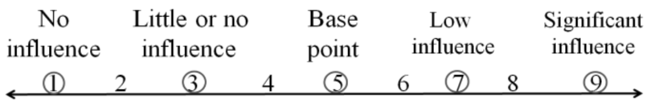


Figure 4-2 A nine-scale evaluation score in order to identify navigation officer's perception of safety index factors

Table 4-2 An example of safety index factors in questionnaire is designed

Type of ship	
1. Container ship	1 2 3 4 5 6 7 8 9
2. LNG tanker	1 2 3 4 5 6 7 8 9
3. VLCC	1 2 3 4 5 6 7 8 9
4. Ferry ship	1 2 3 4 5 6 7 8 9
Length of ship	
1. Less than 50 m	1 2 3 4 5 6 7 8 9
2. 50 m =< L < 100 m	1 2 3 4 5 6 7 8 9
3. 100 m =< L < 150 m	1 2 3 4 5 6 7 8 9
4. 150 m =< L < 200 m	1 2 3 4 5 6 7 8 9
5. 200 m =< L < 250 m	1 2 3 4 5 6 7 8 9

A total of 95 navigation officers were given the questionnaires and only 53 officers responded to the questionnaire, a return rate of questionnaires was about 55%. With regard to responders' experience or carrier on board the ship, the number of respondents over 15 years was 54.72 %, 12 to 15 years was 11.32 %, 9 to 12 years was 11.32 %, 6 to 9 years was 5.66 %, 3 to 6 years was 13.21%, less than 3 years was 2.77 % as presented in Table 4-3.

Table 4-3 Responders' demographic characteristics

Valid (years)	Frequency	Percent	Valid Percent	Cumulative Percent
~ 3	2	3.77	3.77	3.77
3 ~ 6	7	13.21	13.21	16.98
6 ~ 9	3	5.66	5.66	22.64
9 ~ 12	6	11.32	11.32	33.96
12 ~ 15	6	11.32	11.32	45.28
15 ~	29	54.72	54.72	100
Sum	53			

In this model, each element in question is quantified using equation (1):

$$\boldsymbol{I_{ij}} = \frac{\sum_{1}^{N} \boldsymbol{R_{ij}}}{\boldsymbol{N}} \tag{1}$$

Where,

Iij : average of numerical values for j^{th} element of i^{th} item

Rij : answer value for j^{th} element of i^{th} item (=1-7)

N : number of respondents

i : item number of questionnaire (=1-8)

j : element number of each item

The results of the quantification of each element obtained using the questionnaire are shown in Table 4-4.

Table 4-4 Risk quantification of each element determined using questionnaire

Items		Score	
Type of ship		5.3-8.1	
Length of ship		4.5-8.1	
Relative speed		5.1-7.5	
Distance (L, length of ship)		3.8-7.8	
		Passing	Meeting
Encounter situations	Head-on (give-way)	7.9	4.0
	Crossing on starboard (give-way)	7.9	3.2
	Crossing on port (stand-on)	7.3	2.2
	Overtaking (stand-on)	7.4	2.4
Time (LT, Local time)		4.38-5.50	
Day		4.91-5.08	

4.4 Conclusions

This chapter described how to identify the risk of each factor in this model. Risk quantification was proposed in order to calculate safety index associated with navigation situation in a section. Elements of each factor were designed, which were quantified by the result of questionnaire investigation. A questionnaire is useful tool to measure the degree of risk. In the questionnaire, navigation officers were asked how much each factor affects their perception, using a nine-level evaluation scale. The results reflect the navigation officers' opinion in a quantitative manner that can be incorporated into the safety evaluation model.

Chapter 5

Algorithm for Evaluating Risks on an Entire Ship Route Area

5.1 Introduction

In section 4, risk quantification of each factor in this model was developed by means of questionnaire. Factors are able to indicate navigation officers' perception while navigating a ship. This section proposes an algorithm that includes a new concept in order to determine the navigational safety zone in real-time. The concept is to divide entire ship route area into several sections as a gridded matrix and then calculate the risk associated navigation situation in each section simultaneously. The algorithm proposes that level of risk indicates each navigation situation of all ships in a section. This is the solution to be able to compare risk in each section so as to determine the navigational safety zone and also the algorithm has been designed to visualize the risk in order to support to distinguish safety zone easily and quickly. This chapter shows the number of steps of algorithm.

5.2 Algorithm to Evaluate an Entire Ship Route

Figure 5-1 shows the stepwise process of the algorithm to evaluate the safety throughout an entire ship route area. Firstly, the entire ship route area is divided into several sections. It is shown in Figure 5-2 as (a) and (b). Figure 5-2(a) shows some observation area divided several sections. Next step, at specific time, is to collect ship data of each section throughout observation area as shown in Figure 5-2 (b). It captures all navigation situations at specific time, risks can be calculated and also it is possible to compare with risks of each section. At this time all ships in each section considers own ship, which is one of the characteristics in this model. This model is developed to consider encounter situations that affect the ship's behavior such as stand-on and give-way ship. It changes the perception of a navigation officer associated with navigation situation. Therefore, in step 2, all ship considers own ship and collect other ships data to define the relationship between ships in step 3.

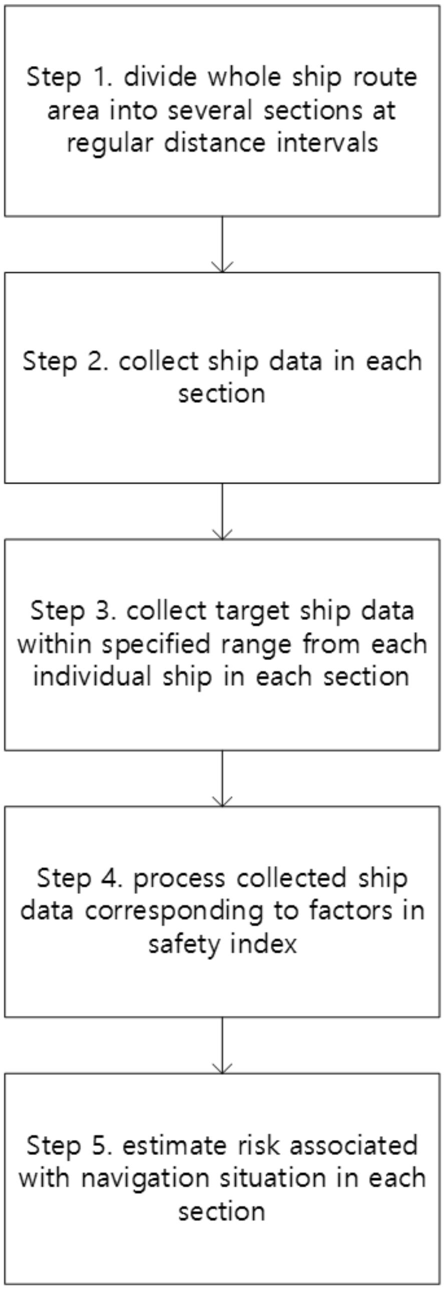


Figure 5-1 The process of evaluating safety of an entire ship route area

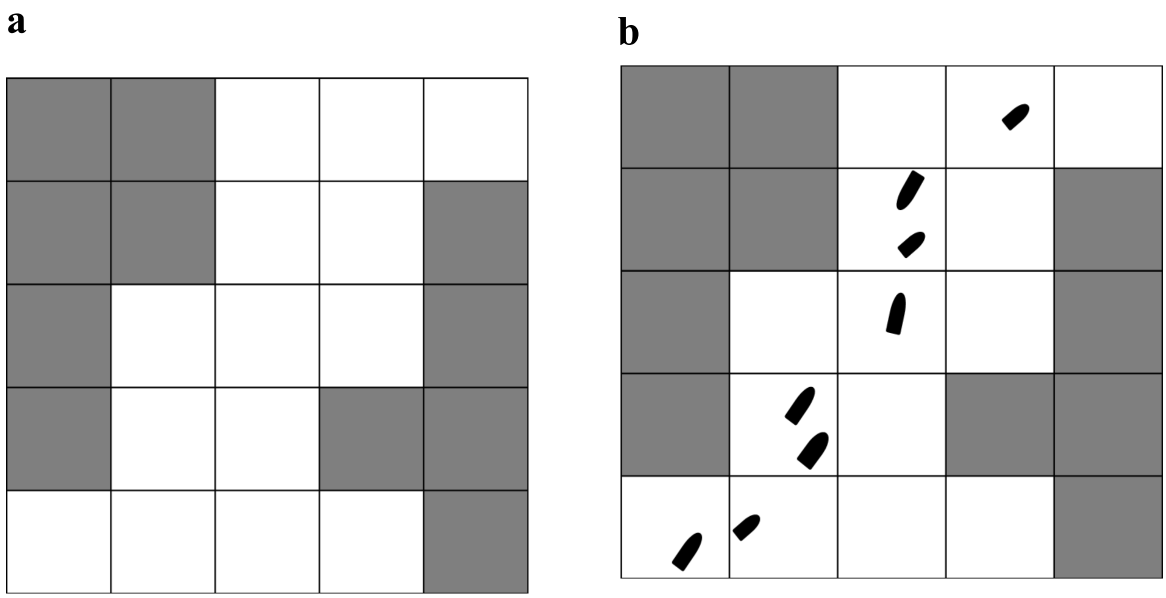


Figure 5-2 Observation area and reproduction of navigation situation in an entire ship route (a) step 1: set the observation area (b) step 2: collect ship data in each section to reproduce navigation situation

Figure 5-3 shows the concept that all the ships in a section are regarded as own ship and how to define the relationship when own ship encounters other ships. In a section, there are two ships as shown in Figure 5-3 (a) and (c), which are in color such as orange and green. Each ship in a section meets three ships within specified range as shown in Figure 5-3 as (b) and (d). At that time, the factors in safety index are analyzed on the basis of given situation. Two ships are in the same section but their relationship between ships is different. This model includes the differences. In step 4, each factor based on ship data is evaluated and quantified with respect to the navigation officers' perception. In the calculation, each factor influences the risk quantification. The safety level of each section is calculated by summing the quantified risks associated with the factor in the model as step 5. Therefore, the safety index indicates the risks of various navigation situations of all ships in a section, which includes ship information, the relationship between ships and environmental situation. Using the proposed algorithm, the safety level can be calculated for an entire navigational area, which reflects the navigation officer's perception. As a result, a representative value for each section is assigned a safety index.

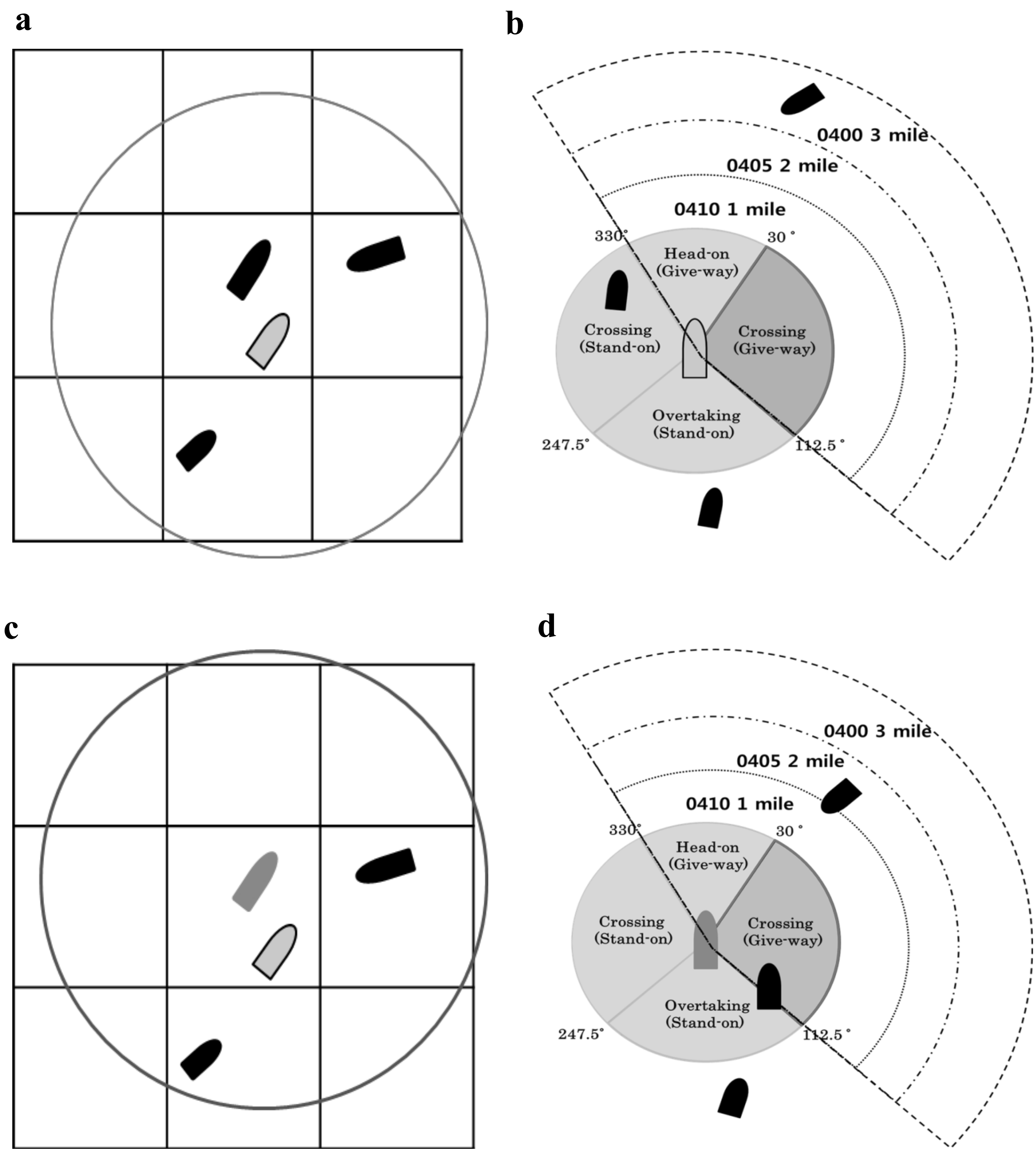


Figure 5-3 Collect target ship data within specified range from each individual ship in each section and process collected ship data corresponding to factors in safety index

5.2.1. Data Structure in Safety Index Model

Figure 5-4 shows the data structure to evaluate a risk associated with navigation situation, which are AIS data to simulate navigation situation and safety index to identify risks on the basis of navigation officers' perception. Firstly, AIS data is classified as either static or dynamic data as shown in Figure 5-5 as (a) and (b). The classification and the time interval of typical data are as follows.

a. Static data: MMSI (maritime mobile service identity), ship name, length, beam, type of ship (every 6 min)

b. Dynamic data: position, time, speed, direction angle, course (2~12 s)

Figure 5-5(a) shows dynamic data; it is possible to calculate factors of relationship in safety index. And also ship information and environmental factors can be calculated by static data as shown in Figure 5-5(b). These data make it easy for the analysis of both the entire traffic flow and individual ship movement. Next is to estimate risks of factors corresponding to risk quantification of safety index.

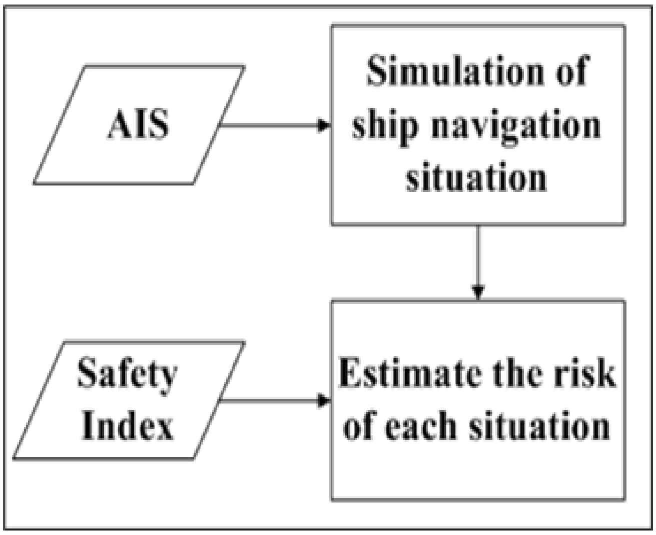


Figure 5-4 Data stricter: marine traffic simulation and safety index for evaluating risk of a navigation situation

a

Date	Time			MMSI	SOG	Longitude	Latitude	COG	True Heading					
2013-03-01	5:21:56	1	0	3.73E+08	13.2	135.1015	34.41103	42	42	0	0	0	5	0.045058
2013-03-01	5:21:57	1	0	4.31E+08	19.4	135.2917	34.55131	91.1	90	0	0	0	5	0.042303
2013-03-01	5:21:58	1	0	4.32E+08	17.9	135.2745	34.59651	76	75	0	0	0	2	4:14:55
2013-03-01	5:21:58	1	0	4.32E+08	17.9	135.2745	34.59651	76	75	0	0	0	2	4:14:55
2013-03-01	5:21:59	1	0	4.32E+08	19.8	135.2783	34.52556	77.2	76	0	0	0	6	4:28:57
2013-03-01	5:22:00	1	0	4.31E+08	8.4	135.4295	34.64455	256.1	346	0	0	0	4	4:39:58
2013-03-01	5:22:02	1	0	4.31E+08	17.9	135.1852	34.56928	96.1	97	0	0	0	0	4:52:01

b

Date	Time	MMSI	Cargo type	Dimention A	Dimention B	Dimention C	Dimention D
2013-03-01	5:21:56	3.72E+08	79	104	16	13	8
2013-03-01	5:22:05	4.31E+08	52	12	31	6	4
2013-03-01	5:22:07	4.31E+08	0	57	11	3	8
2013-03-01	5:22:07	4.31E+08	70	60	13	5	8

Figure 5-5 AIS data to reproduce navigation situation in an entire ship route (a) dynamic data, (b) static data

5.2.2. Calculation Process of Safety Index

The algorithm flow to represent the safety index of each section is shown in Figure 5-6. It shows the number of process of the algorithm to evaluate the safety throughout entire ship route area. The flow is a step by step procedure for performing as follows:

(a) Set the observation area divided l x m meshes with 1 square rectangular. L indicates column number and m is row number.
(b) Set the specific time t
(c) Collect all the ships data in each section(l, m) and set the position of each ship OS(own ship)
(d) Find other ships within specified range from all ship, TS(target ship)
(e) Process collected ship data corresponding to factors in safety index
(f) Estimate risk corresponding to risk quantification is safety index
(g) Express safety index in each section(l, m) throughout an entire ship route

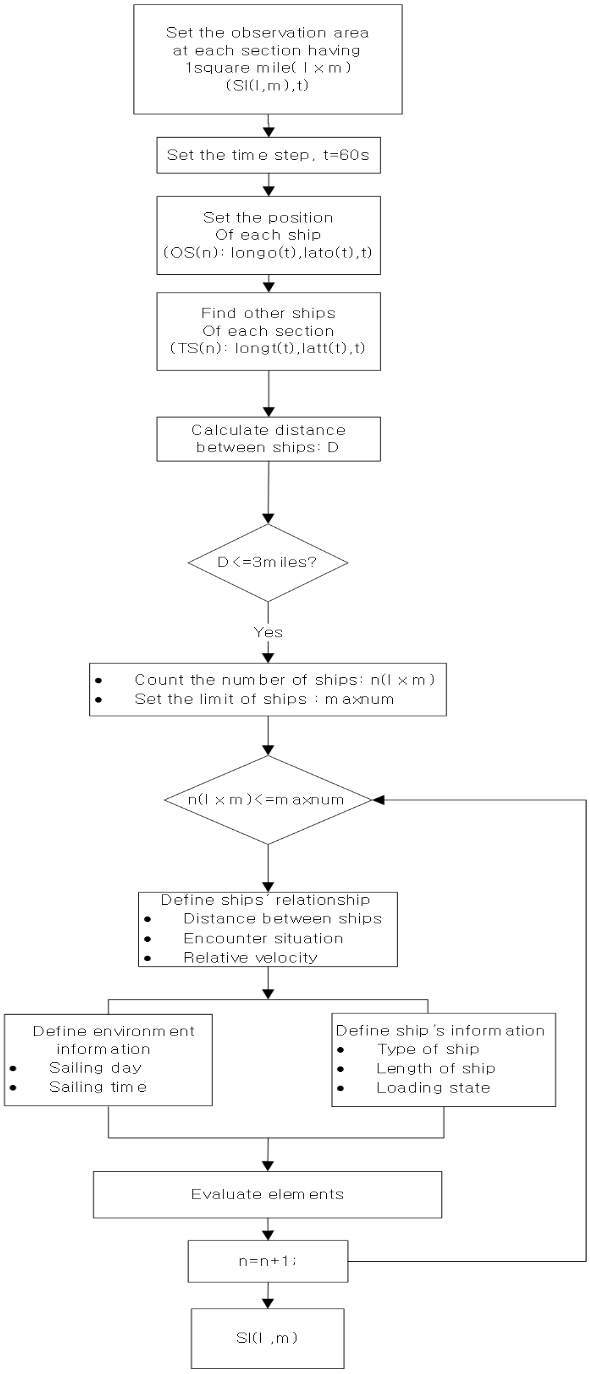


Figure 5-6 Algorithm flow to calculate safety index associated with navigation situation in each section l x m (l: l^{th} column number, m: m^{th} row number)

The safety level of each section is expressed by a representative value called a safety index. The safety index is calculated using equation (2):

$$SI_{l,m} = \sum_{1}^{n} \sum_{1}^{i} I_{ij} \qquad (2)$$

Where:

$SI_{l,m}$	:	Safety index of l^{th} x m^{th} section (l : column number, m: row number)
n	:	Number of ships within specified range of observation point
I_{ij}	:	Risk quantification of each element in question
i	:	item number of questionnaire (i =1-8)
j	:	element number of each item

5.3 Conclusions

This section proposes the algorithm that can be used to determine the navigational safety zone. This algorithm takes into consideration the analysis of ship navigation situation in real-time and estimates the risks of ship navigation situation in entire ship route area. It is proposed the ship route area is divided into several sections at regular distance. Each ship navigation situation at entire ship route area can be quantified in terms of safety index based on the ship data within a specified distance range. The safety level of each section is expressed by a representative value reflecting the navigation officers' perception. The results using this algorithm can be used to determine the navigational safety zone. The proposed algorithm is to be effective in quantifying navigation safety throughout an entire ship route area. It can be helpful to vessel traffic centers and port safety authorities in ship navigation safety management. To verify the effectiveness of the proposed algorithm, a simulation will carry out in chapter 5.

Chapter 6

Simulation Results

6.1 Introduction

A new model was described that can be used to evaluate the safety of an entire ship route area on the basis of navigation officers' perceptions. This section presents an assessment of the suitability of the proposed model for use as a safety evaluation method in assessing risk for an entire ship route area. A simulation was carried out to validate the proposed model for use as a safety evaluation model. It was conducted for Osaka Bay, as shown in Figure 4. Osaka bay is Japan's largest semi-enclosed sea, which is located at the eastern end of Seto Inland. This bay has two entrances for the Osaka/Kobe port areas, which are the Akashi Strait and the Tomogashima Channel. According to the Port Authority of Japan (2010), the area used is latitude N34° 14´ to N34° 46´ and longitude E134° 54´ to E135° 26´. This simulation was carried out using AIS data. In Figure 6-2, the receiving system of AIS is installed on the top floor of a building at Kobe University, and AIS data from Osaka Bay is acquired continuously.

6.2 Subjective Observation area in Osaka Bay

Figure 6-3 shows the trajectories of ships navigating in Osaka Bay based on AIS data beginning at 17:00 for a duration of one hour. It shows all ship navigating according to suggestion route from Port Authority of Japan. The trajectories are classified from two entrances such as Tomogashima channel and Akashi Strait for the Osaka/Kobe port areas. The number of ships passing in Osaka Bay is shown in Figure 6-4. In Figure 6-5 and Table 6-1, characteristics of passing ships are presented. For one hour from 17:00 in Osaka Bay, it shows that ships are passing this area from 12 ships to 27ships as shown in Figure 6-4. In Figure 6-5, the majority of ships are cargo ship and tanker. The length of ship in most common is that more than 50 m and less than 100 m as shown in Table 6-1.

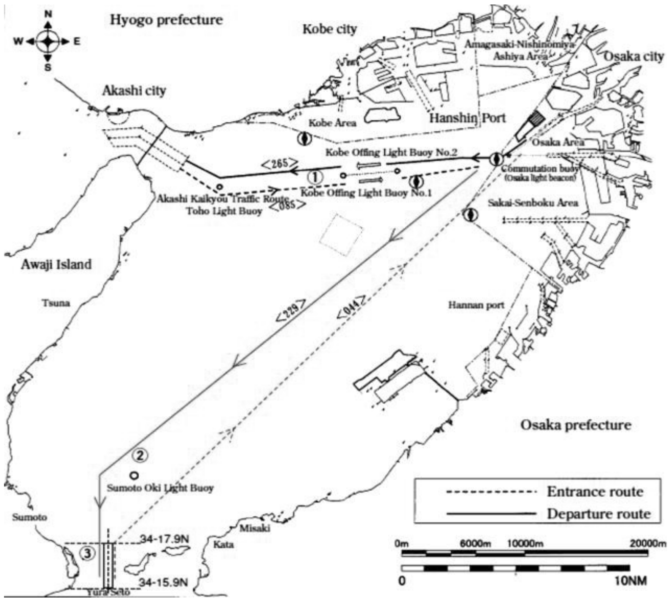


Figure 6-1 Traffic rules in Osaka Bay (From port authority in Japan, 2010)

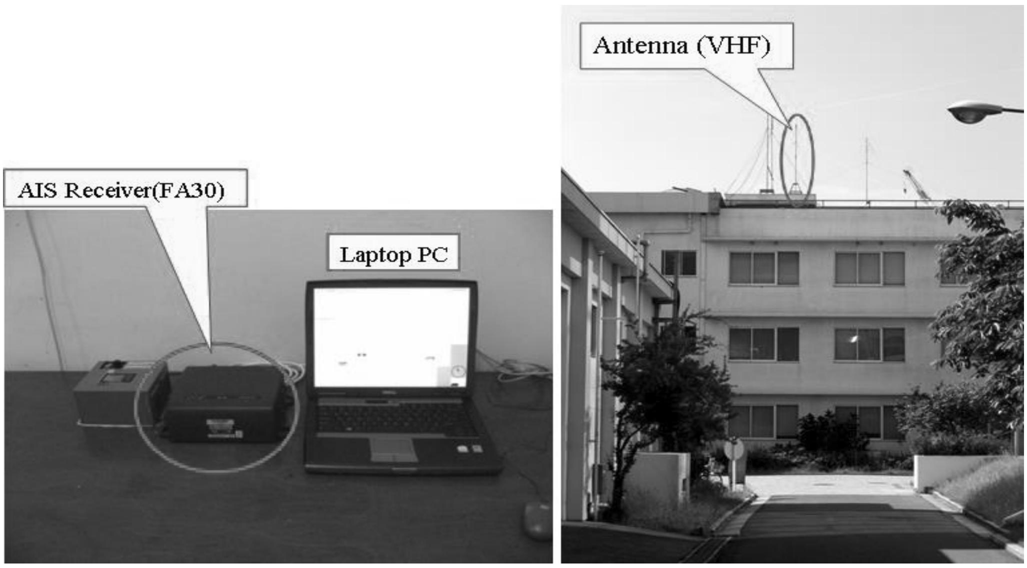


Figure 6-2 Photographs of AIS equipment installed in Kobe University

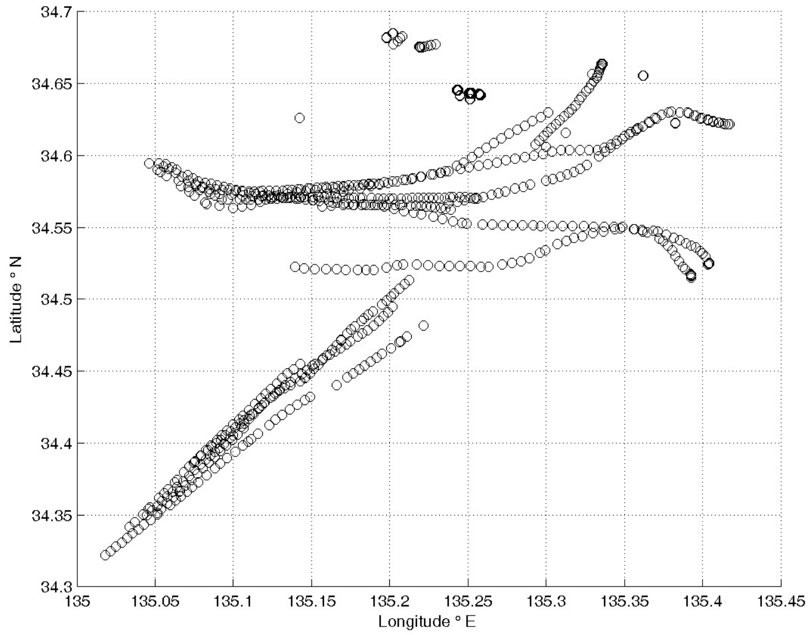


Figure 6-3 Trajectories of ship passing Osaka Bay from 17:00 to 18:00 on March 1, 2013

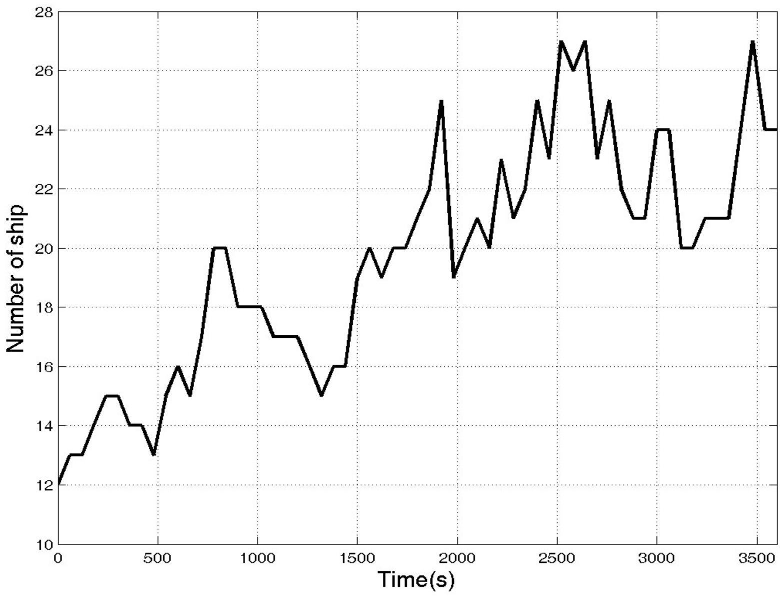


Figure 6-4 Trend of number of ships according to time changed based on beginning at 17:00 for a duration of one hour.

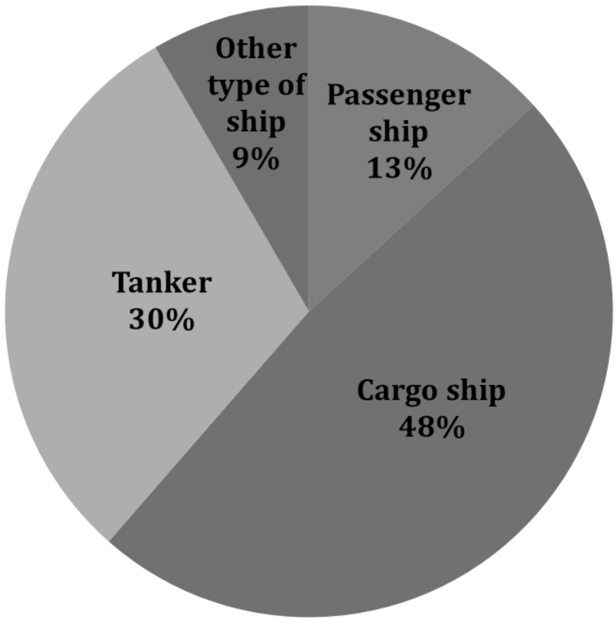


Figure 6-5 Distribution of type of ship for one hour from 17:00 in Osaka Bay

Table 6-1 Distribution of length of ship passing Osaka Bay for one hour from 17:00 in Osaka Bay

Rank	Proportion (%)
less than 50 m	8
more than 50 m ~ less than 100 m	40
more than 100 m ~ less than 150 m	28
more than 150 m ~ less than 200 m	21
more than 250 m ~ less than 300 m	0
more than 300 m ~ less than 350 m	2
more than 350 m ~	1
Total	100

Figure 6-6 shows where ships are at 19980sec in Osaka Bay. The average number of ship encounters within a 3-mile radius is shown in Figure 6-7. The average number of ship encounters at 19980 sec is about 3ships.

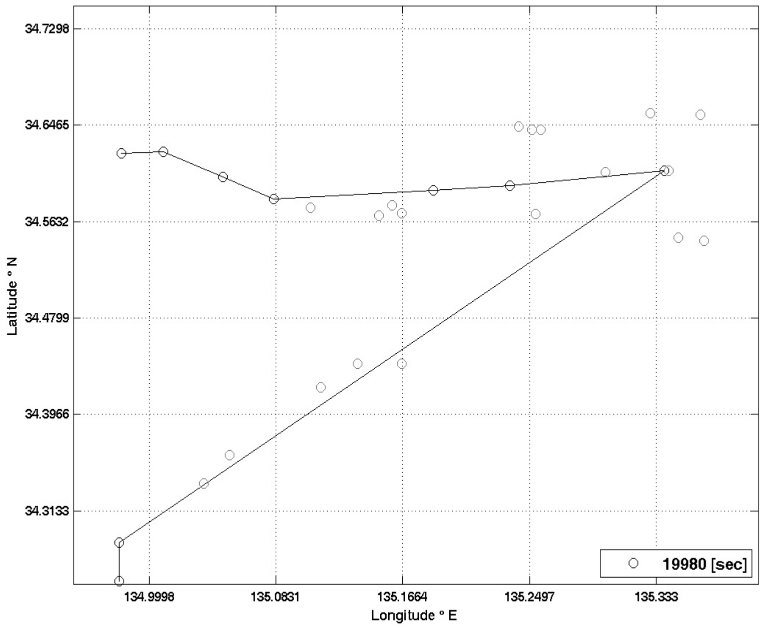


Figure 6-6 Distribution of ship at 19980 sec in Osaka Bay

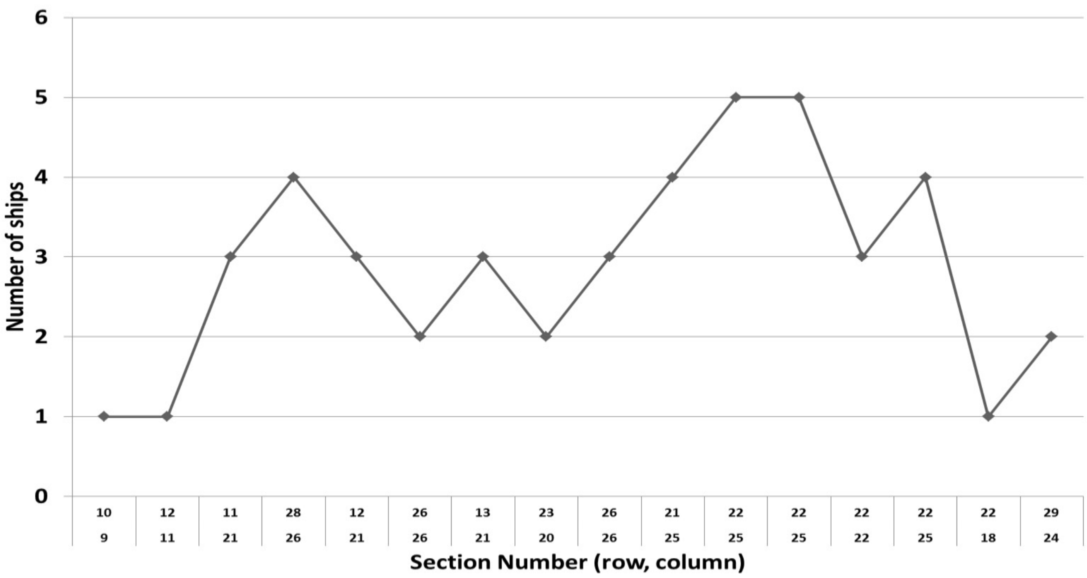


Figure 6-7 The average number of ships encounters with respect to an individual ship in each section at 19980 sec in Osaka Bay

6.3 Evaluation Risk in Osaka Bay

The distribution based on ship position and the number of ships in each section at 19080sec to 19200 sec in Osaka Bay as shown in Figure 6-8 as (a), (b), (c) and (d).

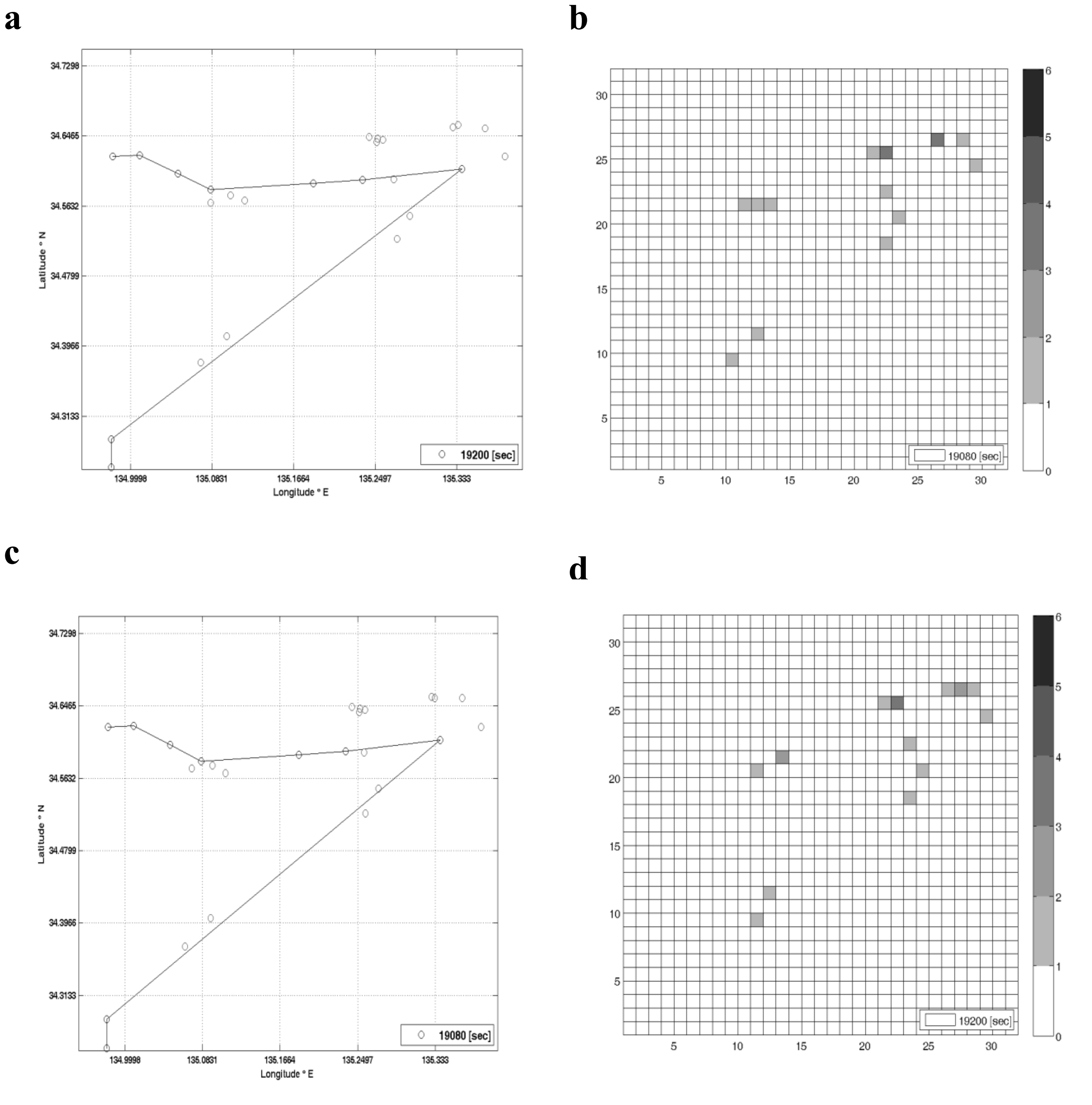


Figure 6-8 Ships position in Osaka Bay (a) distribution of ship at 19080 sec (b) the number of ships in each section at 19080 sec (c) distribution of ship at 19200 sec (d) the number of ships in each section at 19200 sec

Figure 6-9 shows the ship positon in Osaka Bay at 19080sec. At that time, safety index associated with navigation situation in real-time as shown in figure 6-10. The risk calculation results using the proposed safety index model. A section (22, 25) is the highest level of safety index in this time. These results are plotted in color with respect to the level of the safety index as shown in Figure 6-11. The result is called a hazard map in this. It has much information in each section at the specific time, which is at 19080 sec. At this time, according to this hazard map, section (22, 25) and section (22, 26) indicate the highest level of safety index in dark red. Results in detail are shown in Figure 6-12 (a). Each safety index between section (28, 26) and (29, 24) indicates significant different as shown in Figure 6-12(b). But, there is only one ship in each section, which are (28, 26) and (29, 24). It is shown that the safety index in a section is affected by the number of other ship to meet and also the results of safety index are reflected.

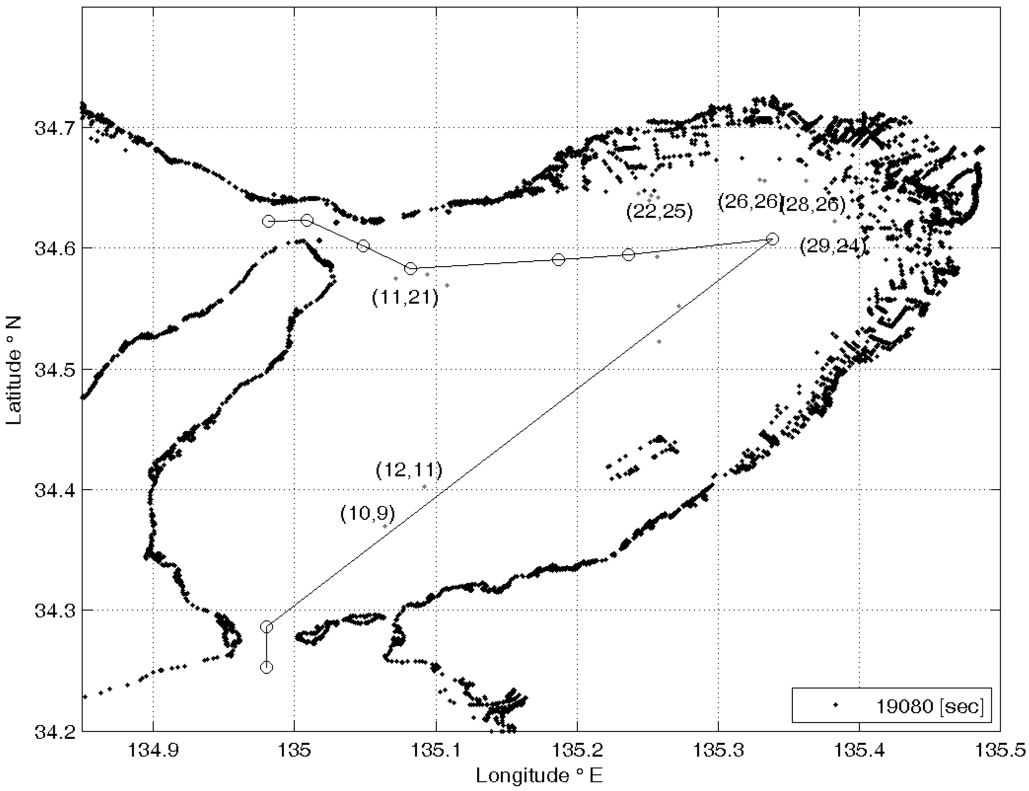


Figure 6-9 Distribution of ships at 19080 sec in Osaka Bay

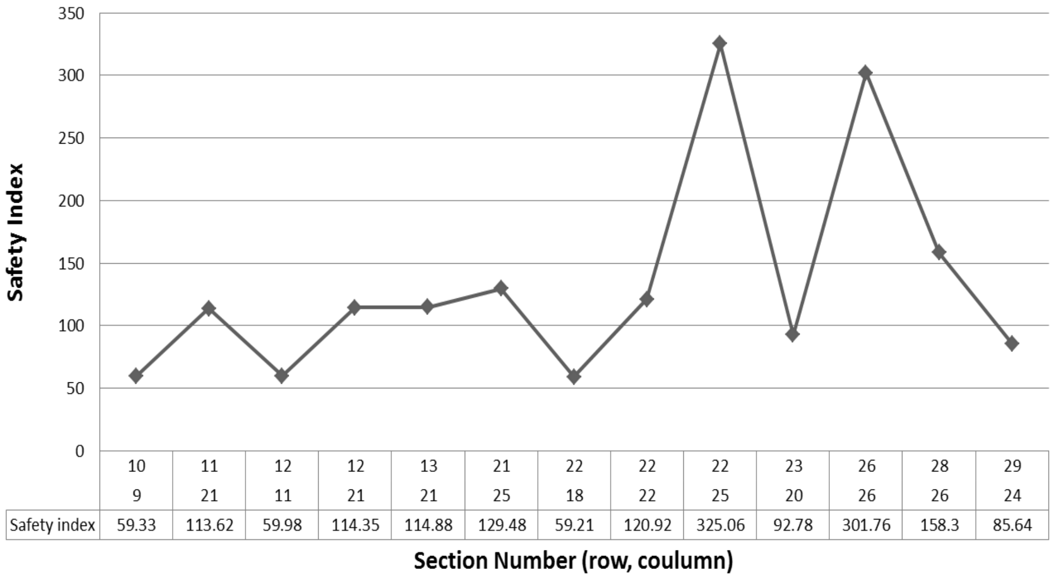


Figure 6-10 Calculation result of Safety index associated with navigation situation of each section in Osaka bay at 19080 sec

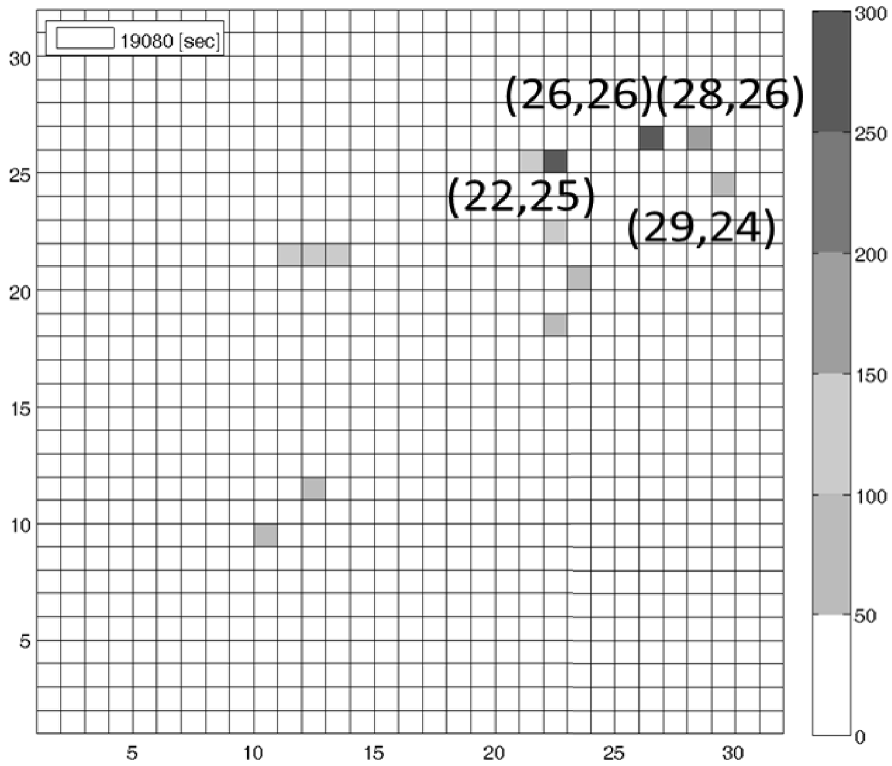
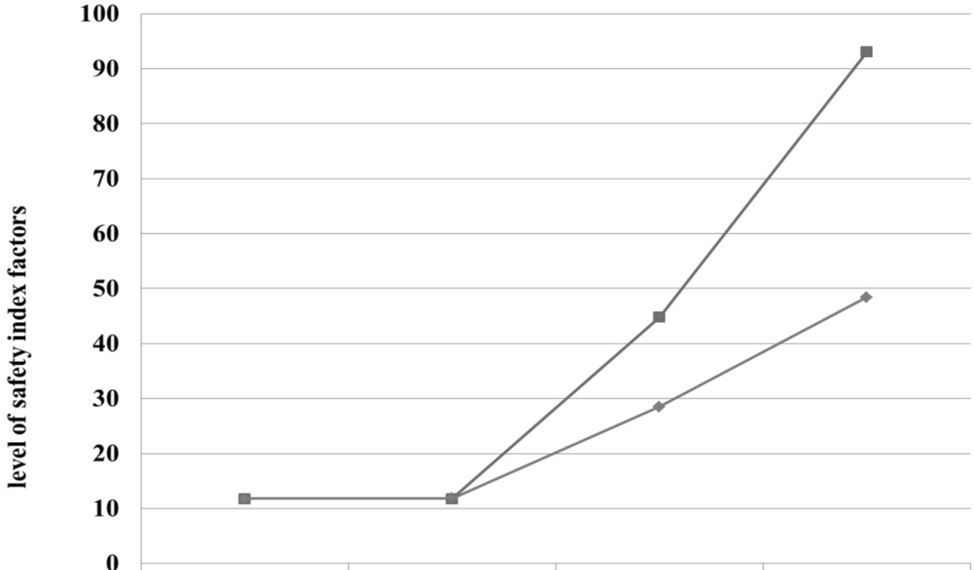


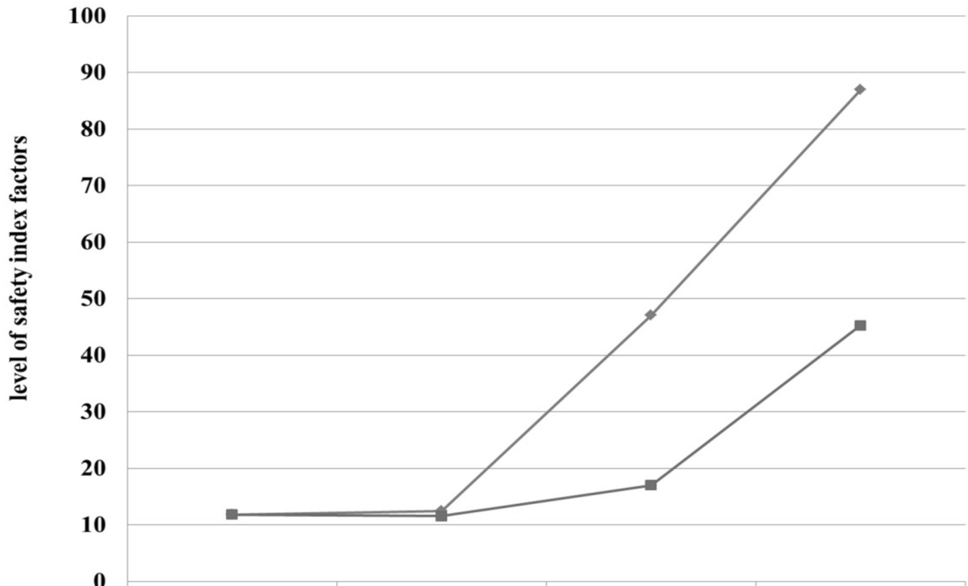
Figure 6-11 Hazard map according to level of the safety index at 19080 sec

a



	Enviornmental situations	Own ship infromation	Other ship information	Relationship between ships
section(22,25)	11.81	11.82	44.83	93.04
section(26,26)	11.81	11.85	28.49	48.44

b



	Enviornmental situations	Own ship infromation	Other ship information	Relationship between ships
section(28,26)	11.81	12.48	47.07	86.94
section(29,24)	11.81	11.53	17	45.3

Figure 6-12 A comparison of level of safety factors between sections as (a) and (b)

Figure 6-13 shows the influences factors on safety index, which are safety index, number of ships and other ships to meet in each section as shown Figure 6-13 (a), (b) and (c). In these results shown in Figure 6-13, safety index and average number of other ship to meet are in inversely proportional to each other. The influences of number of ship in each section are relatively low. Figure 6-14 shows the safety index changes depending on ship movements in real-time. In addition, it describes changes according to the speed and number of ships in these figures. It illustrates that the navigational safety zone and hazard zone can be determined easily and quickly.

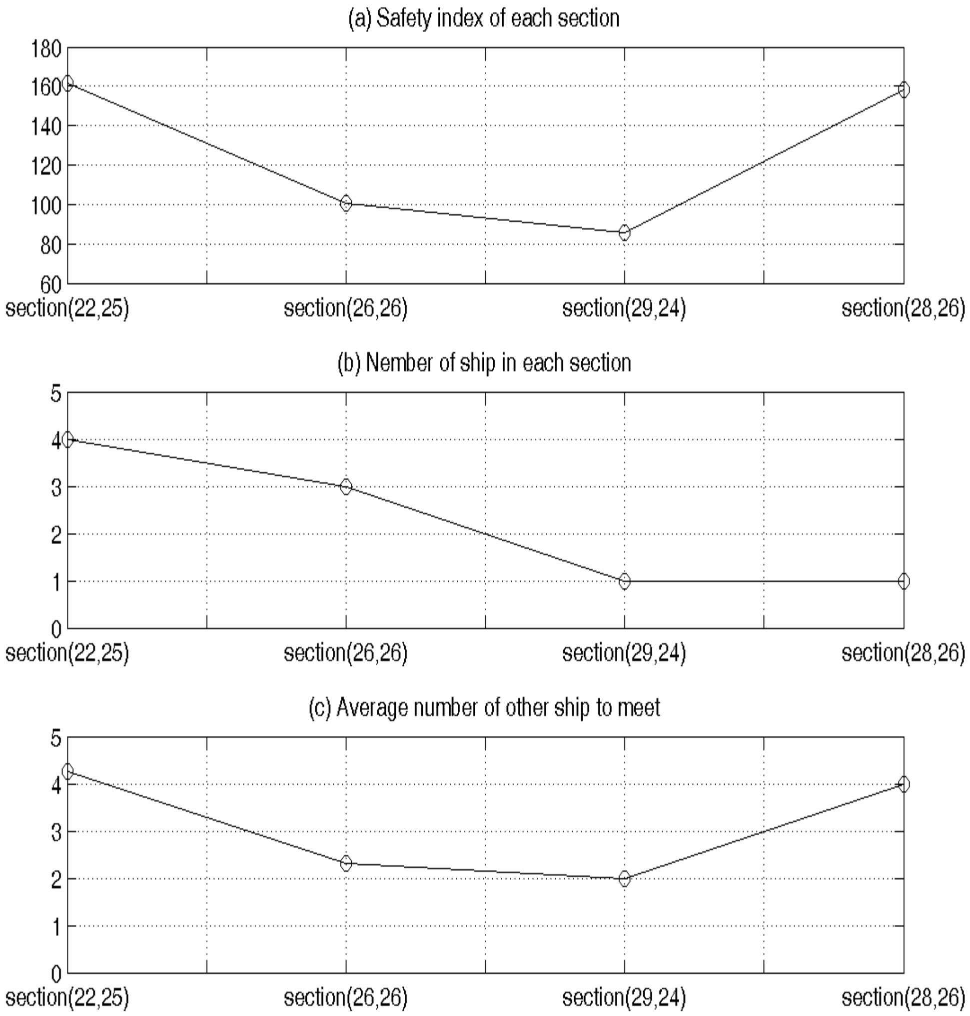


Figure 6-13 A comparison between sections (a) average number of other ship to meet, (b) safety index in each section

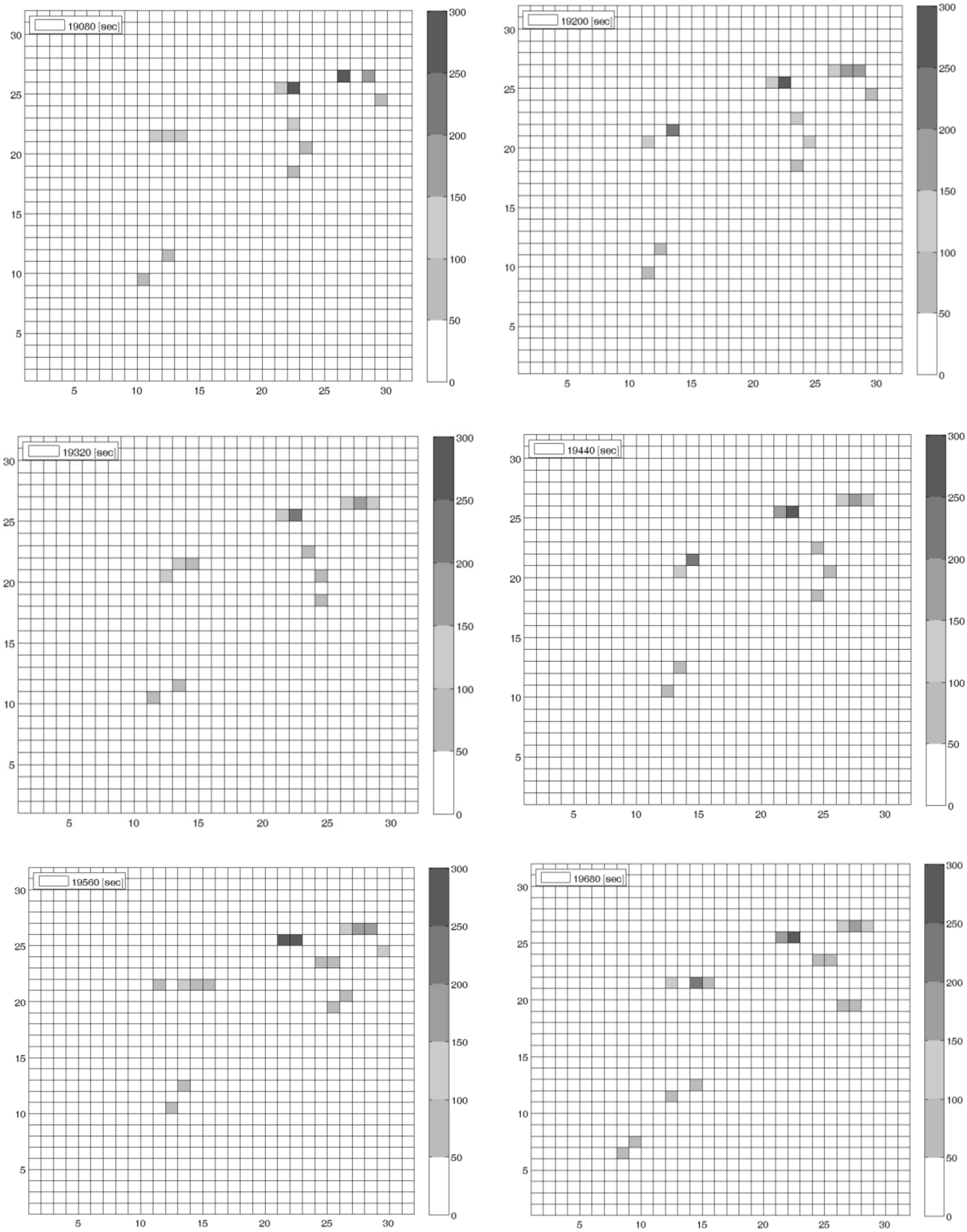


Figure 6-14 Hazard map according to safety index changes depending on ship movements in real-time (interval time: 120 sec, beginning at 19080 sec)

Safety index model is also useful to evaluate the risk of the specific section not only specific time but also a period of time. Figures 6-15 and 6-18 show the position of specific section to estimate the risk associated with navigation situation depending on the time. Section (27, 23) is near Osaka light buy. There are many ships entering or leaving the Osaka area. The safety index in this section (27, 23) is shown as in Figure 6-16. The safety index is affected by the changes in both the number of other ships encountered and their speeds, as shown in Figure 6-16 as (a), (b) and (c). In these results shown in Figure 6-16, the number of ships and speed are in inversely proportional to each other. On average, for one-hour duration and with respect to an individual ship navigating through the section, there is one passing ship and about two other ships being encountered. In addition, it is essential to analyze the distribution of safety index factors, as shown in Figure 6-16. Figure 6-17 shows the proportion of safety index factors in section (27, 23) for one hour beginning 17:00. It is shown the majority factor is relationship between ships, followed by type of ship and environmental situations.

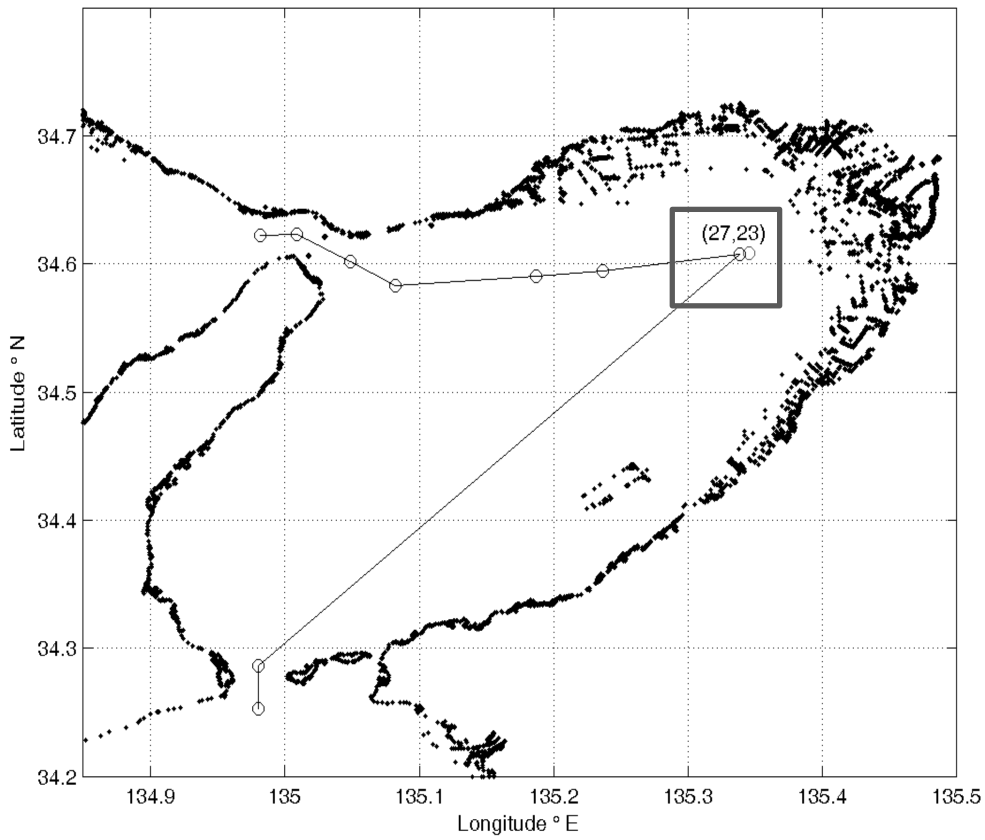


Figure 6-15 Specific section (27, 23) to observe navigation situation in Osaka bay

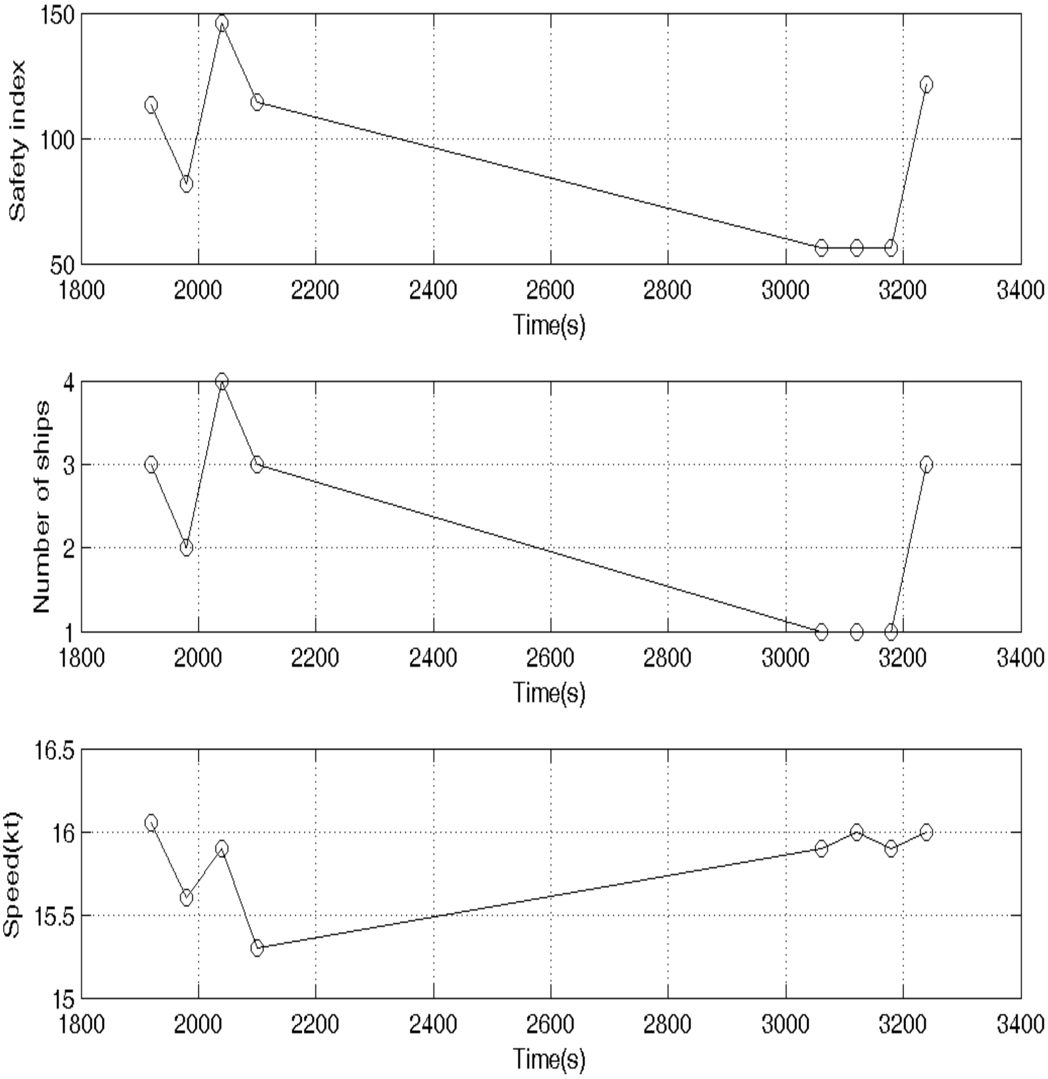


Figure 6-16 The results for evaluating navigation situation of section (27, 23) using safety index (a) safety index (b) Number of ships encountering other ships (c) Average speed of ships passing through this section

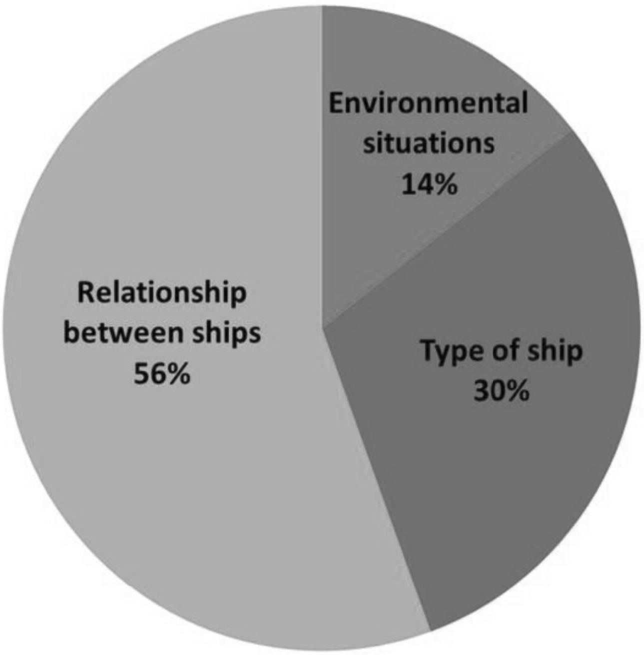


Figure 6-17 Distribution of safety index factors in section (27, 23)

Figure 6-18 shows the position of specific section (16, 21) to estimate the risk associated with navigation situation depending on the time. Section (16, 21) is between Akashi Kaikyou Traffic Route Toho Light Buoy and Kobe offing Light Buoy No.1. Figure 6-19 shows the safety index observed in section 16 x 21. The average safety index in this section is approximately 91.2 as shown in figure 6-19(a). It shows that the lowest and highest level of safety index is 55.14 and 125.44, respectively. In figure 6-19 (b), there are 2 ships passing through this section on average. It shows that the heaviest traffic occurs at 20100 sec, while the highest level of safety index occurs at 20220 sec. In this case, the speed is not affected by the number of ship as shown in figure 6-19 (c). In addition, it is essential to analyze the distribution of safety index factors, as shown in Figure 6-20. Figure 6-20 shows the proportion of safety index factors in section (16, 21) for one hour beginning 17:00. It is shown the majority factor is relationship between ships, followed by environmental situations and type ship. These results in Figures 6-16 and 6-19 are that the common impact factors indicate relationship between ships.

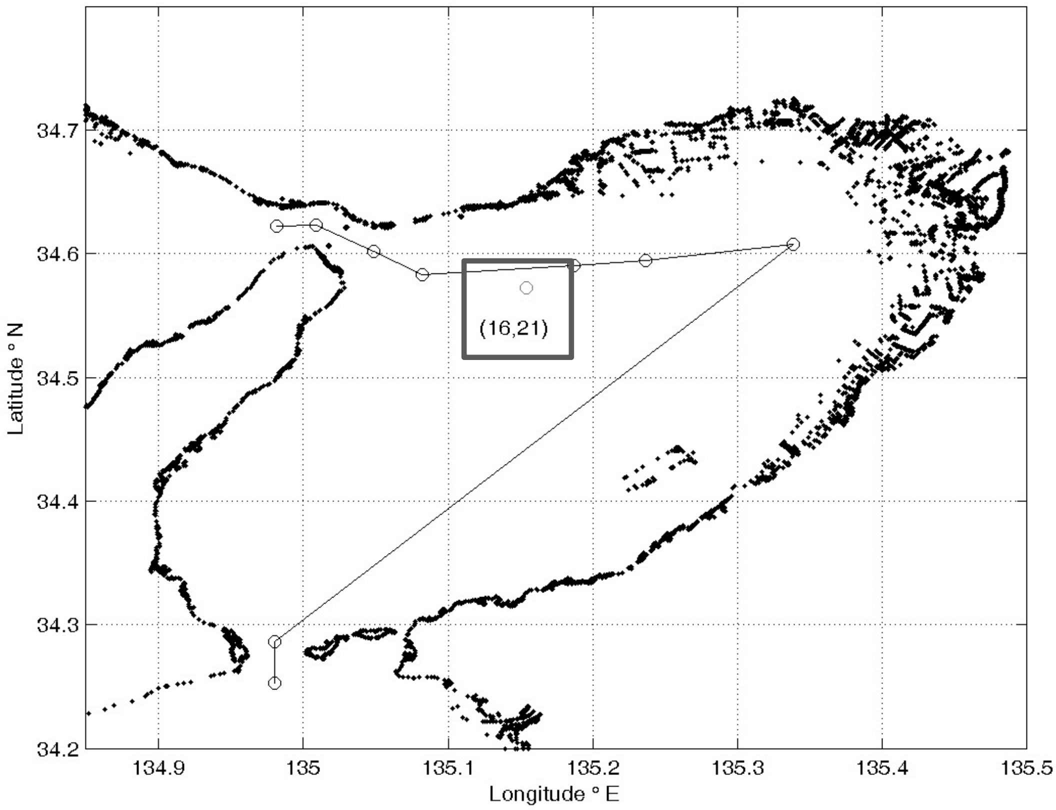


Figure 6-18 Specific section (16, 21) to observe navigation situation in Osaka bay

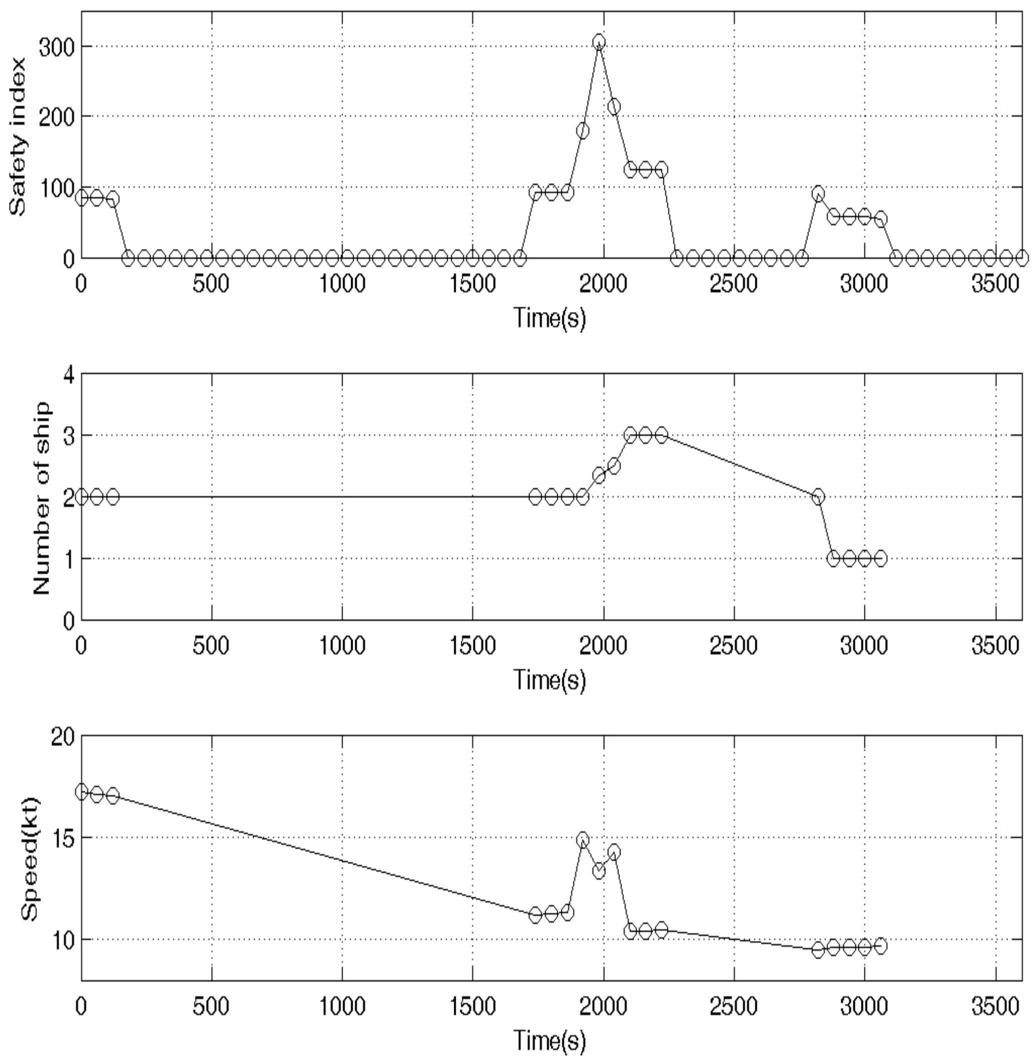


Figure 6-19 The results for evaluating navigation situation of section (16, 21) using safety index (a) safety index (b) Number of ships encountering other ships (c) Average speed of ships passing through this section

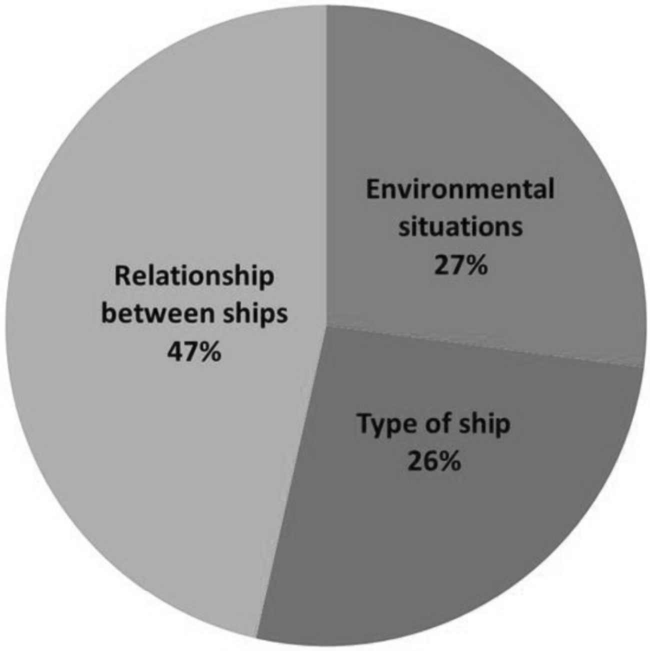


Figure 6-20 Distribution of safety index factors in section (16, 21)

6.4 Conclusions

This new safety evaluation model is proposed as a method to estimate risk throughout an entire ship route area in real-time. In order to verify the usefulness of the proposed model, a risk evaluation was implemented for Osaka Bay. The safety index in each section is illustrated in color according to level of risk, which is called a hazard map in this study. This approach allows for visualization of the risk. This model is expected to be able to serve as a new tool for determining hazard zones more quickly and easily than is currently possible with other navigation safety evaluation methods through the centralized management of an entire ship route in real-time,.

Chapter 7

Conclusions

7.1 Conclusion

Some Conclusions regarding to proposed safety evaluation model have been performed as follows:

1. Development of Safety Evaluation Model as Port Safety Management

Development of safety evaluation model in port safety management is important in order to manage the potential risks of ship navigation situation. The safety evaluation models consist of two major parts. One is to develop the risk quantification in order to estimate the risks of ship navigation situation. The other is to propose the algorithm to evaluate the ship navigation situation. In this research, the risk quantification was developed based on several elements affecting the navigation officer's perception in ship navigation situation. The algorithm was proposed to evaluate the risks along entire ship route area.

2. Development of Safety Index reflecting navigation officers' perception

A large proportion of marine accidents are ship collisions caused by human error. As one of the major sources of human error, navigators play an important role in navigating ships. In the proposed model, safety index is proposed as a risk quantification how to estimate the risks of ship navigation situation based on navigation officer's perception. This index consists of several elements affecting navigation officers' perception while navigating. Questionnaire was carried out and each element was quantified. The safety index indicates the ship navigation situation reflecting the navigation officers' perception. However, in order to evaluate the complicated ship navigation situation, it considers a variety of factors that affect a navigation officer's perception while navigating such as wind, ship maneuverability to handling and so on. It also needs to consider the definition of encounter situations more specifically, it is very impact factor that affects the risk level reflecting the navigation officer's perception. In this study, the definition of head-on is defined as 30 degree from side to side focusing on the heading of own ship. However, it needs to redefine the definition because navigation officers consider the head-on situation when they can see the side lights both starboard and port of target ships in actual navigation situation. And it is also to be consider how to distinguish the boundary between head-on and crossing situation. Likewise, the questionnaire is designed to include and express the complex navigation situation.

3. Development of Algorithm to estimate the risks of ship navigation situation

In the proposed model, it is established in algorithm for evaluation of the navigation safety zone throughout an entire ship route for use by a port safety authority or vessel traffic service center. In previous studies, a safe navigational zone can be determined. However, the safety level determined using historical data. It is not possible to evaluate the safety level of a ship route using navigational situation in real time. In research, this algorithm is designed to consider both AIS data to monitor ship navigation situation in real time and safety index reflecting the navigation officers' perception. This algorithm to solve this problem is that ship route area is divided into several section. Each section is evaluated by safety index. The level of safety can be compared. It is helpful to determine the navigational safety zone in real time. However, it considers the base line to determine the navigation safety zone individually in order to manage safety in port area for establishing a long-term measure.

4. Proposed a New Safety Evaluation Model

This research describes a new safety evaluation model that can be used to support a port safety authority or vessel traffic service center. This model takes into consideration the perceptions of navigational officers in the risk evaluation algorithm, which was developed using a questionnaire to obtain input from navigators. A numerical simulation was conducted to verify the usefulness of the proposed model, using Osaka Bay. A new approach was employed to monitor the level of navigation safety along an entire ship route. Using the numerical results, the safety index along the ship route was plotted to illustrate the level of risk in each area along the route. This type of plot is called a hazard map.

This model is expected to be able to serve as a new tool for determining the level of navigation risk throughout a ship's entire route area in real time, more quickly and more easily than is possible using other navigation safety evaluation methods. The procedure developed in this study can be used by vessel traffic service centers and port safety authorities to evaluate the navigation safety level of a ship route in real time.

7.2 Future Works

By considering some discussions and results of assessment, the some further researches that could be performed in order to improve the safety evaluation model are presented as follows:

1. Improvement of safety index that considers a variety of elements reflecting navigation officers' perceptions while navigating such as wind, ship maneuverability to handling and so on.
2. Improvement of the questionnaire that is designed to include and express the complex navigation situation.
3. Development of base line to determine the navigation safety zone based on historical data to manage safety in port area for establishing a long-term measures

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Reference

Fujii, Y. & Shiobara, R. (1971). The analysis of traffic accidents, *Journal of Navigation,* vol. 24, no. 04, pp. 534-543.

Fujii, Y. & Tanaka, K. (1971). Traffic capacity, *Journal of Navigation,* vol. 24, no. 04, pp. 543-552.

Goerlandt, F. & Kujala, P. (2011). Traffic simulation based ship collision probability modeling, *Reliability Engineering & System Safety,* vol. 96, no. 1, pp. 91-107.

Goodwin, E.M. (1975), A statistical study of ship domains, *Journal of Navigation,* vol. 28, no. 03, pp. 328-344.

Grech, M.R., Horberry, T., & Smith, A. (2002). Human error in maritime operations: Analyses of accident reports using the leximancer tool. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting,* vol. 46, no. 19, pp. 1718-1721.

Hara, K. & Nakamura, S. (1995). A comprehensive assessment system for the maritime traffic environment, *Safety Science,* vol. 19, no. 2, pp. 203-215.

Hasegawa, K and Kouzuku, A. (1987). Automatic Collision Avoidance System for Ships Using Fuzzy Control, *Journal of the Kansai Society of Naval Architects, Japan,* (205), pp. 1-10.

Hasegawa, K. (1997). Reconfiguration of Ship Autonavigation Fuzzy Expert System (SAFES), *The Kansai Society of Naval Architects of Japan (KSNAJ)(8),* , pp. 191-196.

Hetherington, C., Flin, R. & Mearns, K. (2006), Safety in shipping: The human element, *Journal of Safety Research,* vol. 37, no. 4, pp. 401-411

IMO (1997). Resolution A.857(20), Guidelines for vessel traffic services

IMO (2000). Resolution A.884(221), Amendments to the code for the investigation of marine casualties and incidents

Inoue, K., Usami, S. & Shibata, T. (1994). Modelling of Mariners' Senses on Minimum Passing Distance between Ships in Harbour, *JIN (125),* pp. 63-71.

Inoue, K., Hara, K., Kaneko, M. & Masuda, K. (1996). Assessment of the Correlation of Safety between Ship Handling and Environment, *The Kansai Society of Naval architects of Japan*, no. 95, pp. 147-153.

Inoue K., Masuda K., Hara K. & Miyasaka M. (1997). Aggregate Evaluation of Environmental Stress due to Water Restriction and Traffic Congestion, *The Kansai Society of Naval architects of Japan* , no. 97, pp. 191-199.

Inoue, K., Kubono, M., Miyasaka, M. & Hara, D. (1998). Modeling of Mariners' Perception of Safety when Being Faced with Imminent Danger, *Journal of Japan Institute of Navigation,* pp. 235-245.

Inoue, K. (2000). Evaluation method of ship-handling difficulty for navigation in restricted and congested waterways, *Journal of Navigation,* vol. 53, no. 01, pp. 167-180.

Japan Port Authority 2010, http://www.osakaharbor-info.com/PDF/nyusyukkou_e.pdf

Kujala, P., Hänninen, M., Arola, T. & Ylitalo, J. (2009). Analysis of the marine traffic safety in the Gulf of Finland, *Reliability Engineering & System Safety,* vol. 94, no. 8, pp. 1349-1357.

Macduff, T. (1974). The probability of vessel collisions, *Ocean Industry,* vol. 9, no. 9. pp. 144-148.

Montewka, J., Hinz, T., Kujala, P. & Matusiak, J. (2010). Probability modelling of vessel collisions, *Reliability Engineering & System Safety,* vol. 95, no. 5, pp. 573-589.

Montewka, J., Goerlandt, F. & Kujala, P. (2012). Determination of collision criteria and causation factors appropriate to a model for estimating the probability of maritime accidents, *Ocean Engineering,* vol. 40, pp. 50-61.

Nagasawa, A., Hara, K. & Inoue, K. (1988). The Subjective Difficulties of the Situation of Collision Avoidance-I: Toward the Rating by Simulation, *The Kansai Society of Naval architects of Japan,* no. 79, pp. 91-100.

Nagasawa, A., Hara, K., Inoue, K. & Kose, K. (1993). The Subjective Difficulties of the Situation of Collision Avoidance-II : Toward the Rating by Simulation, *The Kansai Society of Naval architects of Japan,* , no. 88, pp. 137-144.

Nakamura, S., Fukuo, Y. & Hara, K. (1990). Evaluation of the Difficulty of Berthing Maneuver by Fuzzy Regression Analysis, *The Kansai Society of Naval architects of Japan* , no. 82, pp. 25-31.

O'Neil, W.A. (2003). The human element in shipping, *WMU Journal of Maritime Affairs,* vol. 2, no. 2, pp. 95-97.

Otto, S., Pedersen, P.T., Samuelides, M. & Sames, P.C. (2002). Elements of risk analysis for collision and grounding of a RoRo passenger ferry, *Marine Structures,* vol. 15, no. 4, pp. 461-474.

Pedersen, P.T. (2010). Review and application of ship collision and grounding analysis procedures, *Marine Structures,* vol. 23, no. 3, pp. 241-262.

Pietrzykowski, Z. (2008). Ship's Fuzzy Domain–a Criterion for Navigational Safety in Narrow Fairways, *Journal of Navigation,* vol. 61, no. 03, pp. 499-514.

Pietrzykowski, Z. & Uriasz, J. (2009). The ship domain-a criterion of navigational safety assessment in an open sea area, *Journal of Navigation,* vol. 62, no. 1, pp. 93-108.

Szlapczynski, R. (2006). A unified measure of collision risk derived from the concept of a ship domain, *Journal of Navigation,* vol. 59, no. 03, pp. 477-490.

Vanem, E., Antão, P., Østvik, I. & de Comas, Francisco Del Castillo (2008). Analysing the risk of LNG carrier operations, *Reliability Engineering & System Safety,* vol. 93, no. 9, pp. 1328-1344.

Wang, N., Meng, X., Xu, Q. & Wang, Z. (2009). A unified analytical framework for ship domains, *Journal of Navigation,* vol. 62, no. 04, pp. 643-655.

Wang, N. (2010). An intelligent spatial collision risk based on the quaternion ship domain, *Journal of Navigation,* vol. 63, no. 04, pp. 733-749.