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Study on a Construction of Information Database for the Safety and Efficiency of Marine Transportation by Practical Use of AIS Data

(AIS データの活用による海上交通の安全性向上及び効率化のための情報データベース構築に関する研究)

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CONTENTS

CHAPTER 1　Introduction

1.1　Background

Maritime domain awareness (MDA) is to achieve an effective understanding of maritime activities that can impact the security, safety, economy or environment [1]. MDA is used to establish the foundation for the successful recognition of potential and actual maritime threats and challenges by promoting favorable conditions for integrating and sharing information, including intelligence, to inform decision-makers. MDA has been pursued by the United States. In recent years, MDA has been spreading around the world. Now, MDA applies to not only the areas of maritime security but also the various artificial or natural threats from the ocean. In Japan, MDA contributes in the areas of maritime security, maritime safety, natural disaster prevention, marine industry promotion, and the development of technology [2].

As sea transport is responsible for 90% of goods and materials transportation in the world [3], securing the safety and increasing the efficiency of ship transportation is an important target for MDA. In order to understand the maritime domain, various types of information have been provided, for e.g., the Marine Cadastre provides information on ocean surface-water temperature, ocean currents, and fishing areas that have been created by Japan Coastal Grade [4]. As another example, Japan-Marine Accident Risk and Safety Information System (J-MARISIS) is proposed by the Japan Transport Safety Board (JTSB) [5]. The system presents information regarding the history of ship accidents and plenty of navigational environment information, such as traffic route, weather, and sea information. Accurate information on weather and sea conditions can avoid accidents, and information of accident-prone locations can improve the safety of ship navigation. These information systems can be used for MDA to promote maritime safety. However, these systems are not concerned with the information of ship transportation. The ship traffic information has only been provided through distribution on a large scale, like one year. For the effective understanding of potential and actual maritime risk and challenges, it is necessary to present detailed information of ship

navigation.

On the other hand, with the rapid development of the global economy in recent years, ships are increasing in number and size [6]. Especially, as the Chinese economy has rapidly grown, maritime transportation between Asian countries has increased significantly. However, ship navigation involves high-risk scenarios as maritime transportation has intensified. Moreover, owing to the characteristic of the ship is the one of the main reasons that makes navigation even more dangerous. Ship navigation is different with respect to the maneuvering of other vehicles. For instance, in cars, brakes can be applied to stop the vehicle when an obstacle is detected. Unfortunately, brake systems do not exist in ships. In contrast, ships avoid obstacles by deceleration and veering, using a propeller. Therefore, the maneuvers for avoiding obstacles and returning to the original route are time consuming and incur high risk. Furthermore, ship navigation is sensitive to external forces such as wind and currents, as well as visibility conditions and traffic conditions. Most of the main traffic routes and coastal areas experience congestion. Therefore, ships navigate under risky conditions, and thus maritime accidents, such as ship collisions and groundings, have occurred frequently. The damage due to these accidents has not only threatened maritime safety, but also caused significant environmental pollution and economic loss. Therefore, preventing the occurrence of ship accidents is an important issue. Consequently, MDA in ship navigation safety needs effective information to prevent the ship accidents.

According to the maritime accident report in 2014, the number of ship accidents in the coastal areas account for 40% of all ship accidents [7]. Moreover, there has been an increase in shipping as the cheapest means of transport, which has produced congestion in busy ports. As ships cannot sail smoothly into a port, they are usually crowded together offshore. This causes numerous maritime accidents, including collisions and grounding offshore, especially when ships anchor at a stormy weather. These waiting ships are one of the main reasons causing ship congestion and accidents in coastal areas. Additionally, several coastal facilities have incurred damage owing to natural disasters. During the 2011 Great East Japan Earthquake, 28,612 marine vessels, 319 ports, and approximately 1,725 facilities were damaged according to a report published by the Ministry of Agriculture, Forestry and Fisheries [8]. The accident not only damaged the

ships but also resulted in serious disasters. These waiting ships produce negative effects far beyond their influence on maritime safety. Such waiting ships have also created economic and environmental problems. For example, a waiting ship incurs expenses from the demurrage, fuel, and crew freight. Moreover, most ships anchor offshore without stopping their engines. Thus, hazardous substances are discharged from these ships, just as in the case of sailing ships. In order to secure the safety of ship transportation, it is important to ease the ship congestion in coastal areas and reduce the ship anchorage before entering the ports. Information on MDA in ship navigation needs to be available on time for the ships arriving at the destination, to achieve efficient ship navigation.

1.2 Objective

The purpose of this study is to understand the actual conditions prevalent in maritime transport and construct an information database for MDA on ship navigation, in order to promote the safety and efficiency of ship navigation. Specifically, the objective of this study is to provide the information for the following:

(1). Preventing the occurrence of ship accidents.

(2). Achieving efficient ship navigation.

1.3 Structure of the Dissertation

This thesis is organized into six chapters. The following chapter describes the methodology adopted in this study based on Geographic Information System (GIS). Moreover, the relevant previous studies on understanding the ship navigation and the benefits of using Automatic Identification System (AIS) data are explained. According to the application of AIS data, the ship traffic in the research area —Seto Inland Sea, Japan— is presented. Based on the objectives of this study, strengthening the ability of MDA for the safety and efficiency of marine transportation are discussed from Chapter 3 and Chapter 5.

Chapter 3 presents the information for preventing the occurrence of ship accidents through the practical use of AIS data. Chapter 4 presents information for achieving efficient ship navigation, and Chapter 5 presents the examples of the application of the information. Finally, the study concludes with Chapter 6.

In order to prevent ship accidents, this study provides the ship congestion areas in the Seto Inland Sea. As the congestion areas are crowded in narrow routes and port areas, the study analyzed the actual conditions of ship navigation in narrow routes and coastal areas in Section 3.3 and Section 3.4, respectively. In Section 3.3, the risk assessment essentially included the ship drift due to the current and the encounter situation of ships navigation in the narrow routes. Additionally, the risk-areas are presented based on Kernel Density Estimation (KDE) distribution. As these waiting ships are one of the main reasons causing ship congestion and accidents in coastal areas, this study analyzed the case in which the waiting ships were anchoring offshore, and how these ships influenced the safety of ship traffic in Section 3.4. The obtained information based on the analysis of AIS data can deepened the understanding of MDA in ship navigation. The effective information can be used to make a navigation plan for the avoidance of the risk areas and congestion time.

In order to ensure ship navigation safety in the coastal, it is important to ease the ship congestion in coastal areas and reduce the waiting ships. Therefore, this study understands the actual ship behavior for improving transport efficiency, to achieve efficient ship navigation. Especially, this study has focused on the waiting situation of ships. In Section 4.1, the behavior of a ship entering a port and the corresponding waiting time are analyzed. If the waiting time can be shortened, efficient ship navigation can be realized. For instance, if the ships devote the original waiting time to sailing instead, there is a reduction in fuel cost due to the reduction in waiting time. In order to achieve on-time navigation, it is necessary to understand the navigation behavior for the entire voyage of the ship at sea. In the Section 4.2, the ship navigation for the entire ship voyage in Seto Inland Sea is analyzed. Container shipping is the one of principal means of ship transportation in this area. The safety and efficiency of the container ship navigation has been deeply involved in the economic development between Japan, China, and South Korea. Therefore, the chapter describes the navigation conditions of

container ships in detail, including the ship trajectory, speed, and veering. In order to achieve non-waiting navigation, this study analyzed the behavior of a ferry that had no waiting time in the Seto Inland Sea. The distribution of speed and time was analyzed. This information aids operators in making informed decisions and preparing an effective navigation plan for efficient maritime transportation.

In Chapter 5, this paper presents the examples of the application of the information. Firstly, this paper presents the information utilized for the efficiency of ship navigation. The study provides the information that helps the operators to navigate more safely and efficiently. The ship navigation in the open sea was analyzed. A comparison with ship navigation in the open sea was performed, and the navigation risk was presented. Considering the safety and efficiency of ship traffic, the appropriate route was recommended based on the comparison.

Another example presents the information utilization for the safety of ship evacuation in a stormy weather. This study analyzed the ship traffic and congestion conditions of the evacuation areas based on the anchoring ships. This support information assists the operators in efficiently making a decision regarding which areas should be evacuated. Moreover, the risk-areas during ship evacuation were obtained; this information can be used to reduce risk and provide an evacuation route. Moreover, this study performed that an evacuation route was simulated based on a real ship.

This study analyzes the ships' navigation in the Seto Inland Sea via the practical use of AIS data. According to the analysis of the ships' behavior, the actual conditions of ship navigation were understood, and the information that was relevant to the implementation of maritime transport safety and efficiency was extracted. Moreover, the extracted information was integrated into the information database based on GIS. By presenting the information obtained in an effective and easy to understand form, this study aims to construct the information system that can be utilized by the ships for improved navigation safety and efficiency.

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CHAPTER 2   Methodology and Application of AIS in Seto Inland Sea

2.1 Application of GIS in Marine

In this study, the information database was constructed by geographic information system (GIS) techniques. The GIS is a technology that integrates hardware, software, and data for capturing, managing, analyzing, and displaying all forms of geographically referenced information [1], which presents navigational information in a particularly effective manner. The key word to this technology is Geography- this means that some portion of the data is spatial. In other words, any data can present referenced to locations on the earth. Coupled with this data is usually tabular data known as attribute data.

GIS has widely been used in different kinds of fields, such as urban regional plan, civil engineers, spatial economy, sociology, environmental science, civil engineering technology, and so on [2]. In the last decade many researchers from GIS interested in marine applications have been trying to describe and provide a prototype of a suitable GIS for marine purposes – a Marine GIS [3][4]. GIS plays an essential role to help people collect, analyze the related spatial data and display data in different formats, which have proven to be a useful tool in marine agencies' efforts. Nowadays, GIS technologies have been applied to diverse marine fields to assist experts and professionals in analyzing various types of geospatial data and dealing with complex situations. For example, benthic habitat mapping, mapping and visualization for coastal/marine applications, spatial analysis of marine animal movements, habitat modeling and mapping of marine protected areas.

This study has the insight to analyze through vast amounts of data, capture complex situation which result in the understanding of MDA, especially for the effective understanding of actual ship navigation situation and risk, in order to present the most accurate and sensible information to understand the situation in the area for ship operators and the parties.

Fig. 2-1 shows the block diagram of the construction of information database in this
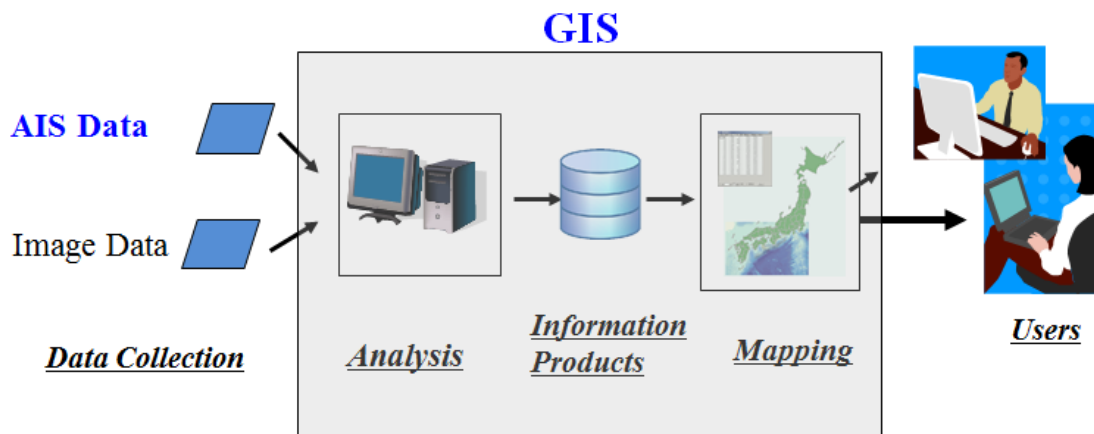
Fig. 2-1 Block diagram of the construction of information database

study. The information of obtaining form AIS data analysis and other data source were integrating, such as satellite photos and charts were layered in the GIS, in order to provide easy-to-understand information. This study used the ArcGIS software developed by ESRI, Japan, which is very effective tool to construct an information system.

2.2 Introduction of AIS Data

This study extract the information based on the analysis of Automatic Identification System (AIS) data. The AIS technology automatically provides information that can help avoid collisions. SOLAS (The International Convention for the Safety of Life At Sea) stipulates AIS technology automatically provides extensive information about the ship to other ships and coastal authorities, using very high frequency (VHF) radio waves. Fig. 2-2 shows AIS conceptual operation view. It is illustrated that the signals are transmitted and received between of the ships, and between the ships and coastal authorities.

As the received information can be collected together, and AIS obtains the accurate data of ship navigation, it is possible to understand the ship movement in a wide ocean area. In this study, the AIS data was collected at the land-based, from the Kobe University, and was provided by the data service companies.

http://www.seanews.com.tr/article/HOTN/48258/Automatic-Identification-System-AIS/
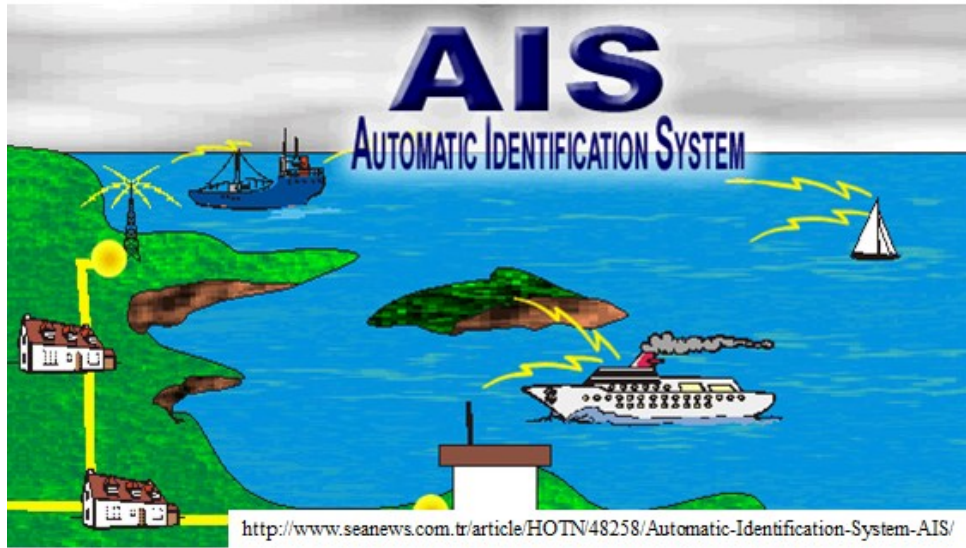
Fig. 2-2 AIS conceptual operation view

There are two classes of shipboard equipment: class A (mainly used by commercial vessels) and class B (mainly used by small ships such as fishing vessels and pleasure boats). Information transmission with class B equipment is simpler. AIS class A is compulsively installed aboard all international voyaging ships larger than 300 gross tonnage (GT), all non-international voyaging ships larger than 500 GT, and all passenger ships [5]. In recent years, with the development of AIS equipment, the ship navigation analysis by using AIS data is expected more reliability. This AIS data includes dynamic, static, and voyage-related data. The information supplied by AIS data is detailed in Table 2-1.

Table 2-1 Contents of AIS data

Dynamic data	Ship's position, UTM(Universal Time Coordinated), SOG(speed over ground), COG(course over ground; relative to true north to 0.1 degree), true heading(0 to 359 degrees from gyro compass), navigational status("at anchor", under way using engine" or "not under command), Longitude and Latitude(to 1/10,000 minute),time stamp, etc.

Static data	MMSI(Vessel's Maritime Mobile Service Identity), IMO(International Maritime Organization) number, call sign, Vessel name, type of ship/cargo, length and breadth of vessel, dimension of ship, type of positioning system(such GPS, DGPS, LORAN)., etc.
Voyage-related data	ETA (Estimated time of arrival), Draught of ship, hazardous, and destination, etc.

These data resource is automatically transmitted. Indeed, it is possible to obtain navigation information of ships using AIS in an accurate and quantitative manner. According to the practical use of these data, the ship navigation was understood.

The dynamic data of AIS transmission interval depends on the navigational status. The data transmitted was irregular due to the speed of the ship. The report interval of AIS data is listed in Table 2-2. For example, the data is transmitted long interval when a ship is at anchor, and transmitted frequently when the ship veering and acceleration. The static data and voyage-related data of AIS are transmitted by 6-minute interval.

Table 2-2 AIS reporting interval of dynamic data

Reporting interval of dynamic data	Reporting interval
Ship at anchor	3 min
Ship at anchor > 3 knots	10 sec
Ship 0 – 14 knots	10 sec
Ship 0 – 14 knots and changing course	3.33 sec

ship 14 –23 knots	6 sec
ship 14 - 23 knots and changing course	2 sec
ship > 23 knots	2 sec
ship > 23 knots and changing course	2 sec

2.3 Benefits of Using AIS Data

Usually, two methods are used to investigate navigational ships, visual observation and radar image observation [6]. However, it is impossible to obtain data over a long period using these methods, and accurately measuring the position, course, and speed of a vessel is difficult. Moreover, many studies have understood the ship movement by performing simulation models [7][8]. Although these models can describe the dynamic motion of the ship, majority of them can only be applied to a few specific ships. Currently, because of the development of the nautical equipment and advanced technology, it is possible to collect the ship navigational information easily. Such as the ship movements can be simulated with manned ship-handling simulators [9][10][11], but they require experts to operate it and the equipment is expensive. Table2-3 lists that the availability of the methods in ship navigation analysis.

Table 2-3 Availability comparison

Method	Accuracy	Data Collection	Long Period	Extensive	Dynamic Movement
Visual Observation	no	hard	no	no	no
Model & Simulation	hard	-	-	no	yes

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Ship Handling Simulator	hard	-	-	no	yes
AIS	yes	easy	yes	yes	yes

The advantage of using AIS data is the ability to obtain data over a long period and easily and accurately measure the position, course, and speed of ships. The data of ship navigation can be obtained accurately and quantitatively. These studies have shown that the analysis of historical ship navigation using AIS data is possible so as to unveil the characteristics of real ship movement. These studies were good use of the actual ship navigational data. Because a ship's navigational situation can generally be grasped in real time, it is expected that the AIS data will be applicable, not only to the maritime field, but also to research in other fields. Several studies have been made good use of it in the fields of traffic control, port administration, maritime traffic flow, and so on [12][13].

In this study, the characteristics of ship behavior were analyzed using a dynamic analysis technology, which is a novel method. A dynamic analysis based on real ship movement data was carried out in this study, and the latent risks in navigation were extracted. The transmission interval of AIS data differs depending on the navigational status. A dynamic analysis approach was followed, which involved tracking the position and navigational situation of this ship across different time series. Using this accurate and quantitative ship-navigation data, dynamic analysis is possible, and the ship behavior can be understood in detail. The application of AIS data is the most effective method for MDA in ship navigation to understand the situation of a wide area.

2.4 Investigation of Ship Traffic in Seto Inland Sea Using AIS Data

2.4.1 Research Area

Seto Inland Sea, Japan is the research area in this study. In recent years, as the Chinese economy has rapidly grown, maritime transportation centering on Asia has

increased. Seto Inland Sea, Japan is a primary traffic route for this transportation. Many ships move frequently through this area, especially those departing and arriving from China and South Korea. A Seto Inland Sea route has been developed and stabilized, and is now responsible for the trade between Japan, China, and South Korea, and thus, for their economies [14]. However, as ships have grown in size and quantity, ship congestion and maritime accidents have become frequent. The Seto Inland Sea is a particularly dangerous route for ship navigation [15], because of the large number of small islands scattered throughout it, and the relatively shallow water in most places. Moreover, many types of ships use this area, including fishing boats. The complex terrain and string currents make traveling through it even more dangerous. Considering the fact that ship transport will continue to increase in the future, ensuring and improving the safety of maritime traffic in the Seto Inland Sea have become important issues.

In previous years, studies on maritime traffic were performed by dividing the Seto Inland Sea into small areas [16]. There has been no study that tried to analyze the entire ocean area of the Seto Inland Sea. In order to improve maritime safety and efficiency, it is necessary to understand the navigation. Therefore, MDA in the ship navigation is necessary to prevent the ship accident and improve the ship transportation efficiency in this area. It is contributes to the stabilization and development of the Asian economy.

Fig 2-3 shows the location of Seto Inland Sea, Japan (32°31′N~ 34°57′12″N; 130°28′40″E~ 135°39′4″E). Four narrow waterways in the inland sea—Kanmon Strait, Kurushima Strait, BisanSeto, and Akashi Strait—are shown from west to east in the figure. The Seto Inland Sea also contains two Japanese international ports at Kobe and Osaka. Most voyaging ships stop at these ports; therefore, the area is frequently crowded with large ships.
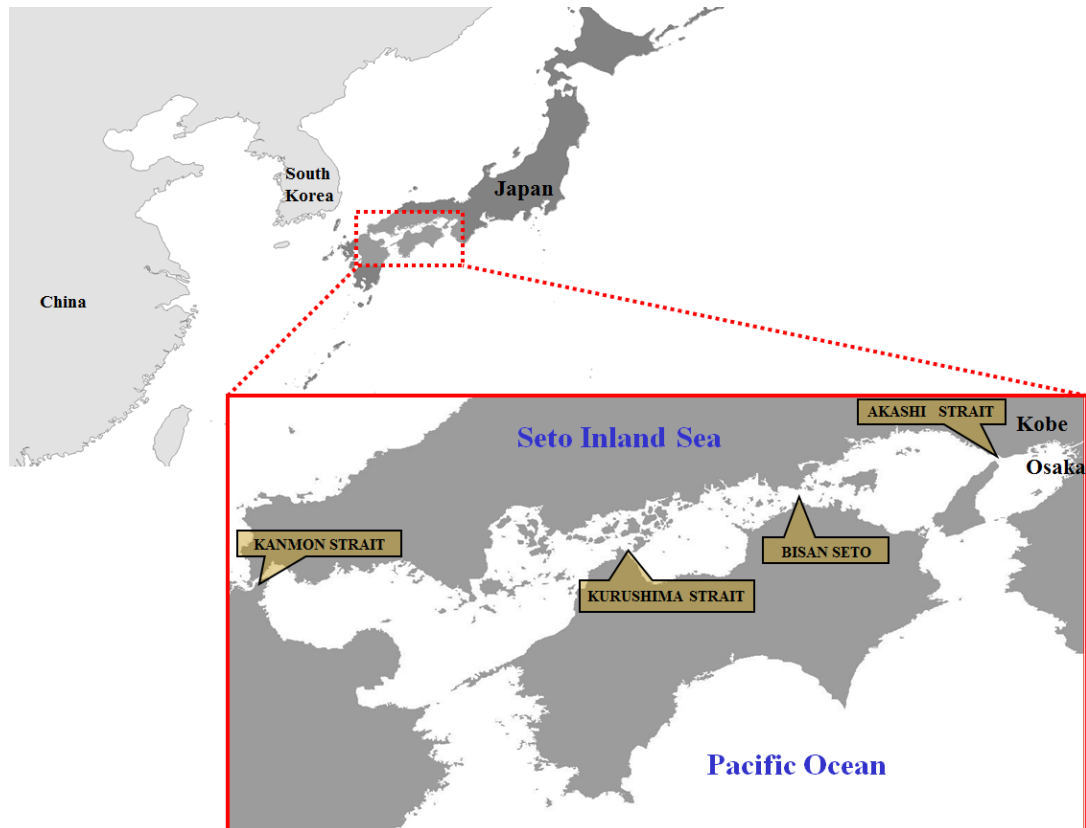
Fig. 2-3 A map of research area

2.4.2 Ship Traffic Flow in Seto Inland Sea

The research period was between March 1 and 7, 2012. This study analyzed by using AIS data, which were acquired by Kobe University, and also were provided by the related organizations. According to the data provided by the Japan Meteorological Agency, the weather conditions were zero visibility, little rainfall, and wind during the investigation period.

Fig. 2-4 shows the number and types of ships in the Seto Inland Sea according to the AIS data. There were more than 1400 ships each day, with the largest number of ships found on March 7 (Wednesday), with a slightly smaller number of ships on March 3 (Saturday). The main type of ship in this area was dry cargo and tanker. Thus, most of the ships voyaging in this inland sea transport goods, materials, and energy resources, which support the economy and daily life.

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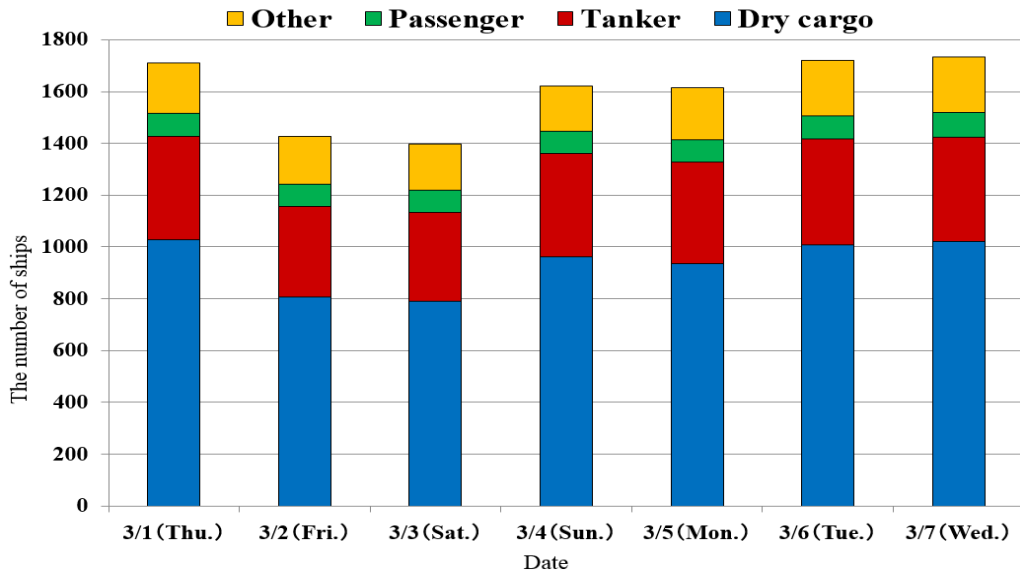
Fig. 2-4 The number and Types of vessels in the research area

Based on the position information included in the AIS data, the trajectories of ships in one day (March, 6) are shown in Fig. 2-5. The black dots indicate the exact positions of the ships. The trajectories were obtained from a geographic information system (GIS). The statistics on the vessel traffic and cargo type of every ship with an MMSI number were based on the AIS data. The total number of ships was 2610 passing ships during the research period.

Fig. 2-5 Trajectories of ship navigation (March 6, 2012)

Based on the ship trajectories in Fig. 2-5, it can clear that there are two general routes in the inland sea. The main route is used by ships navigating between the east and west, and is always congested by many large ships. The other route crosses the main route and is used by ships navigating between the south and north. The south-north route is used by many small ships, like ferries and fishing boats. According to the AIS data analysis, the navigation trend in the route was understood based on the type of ship.

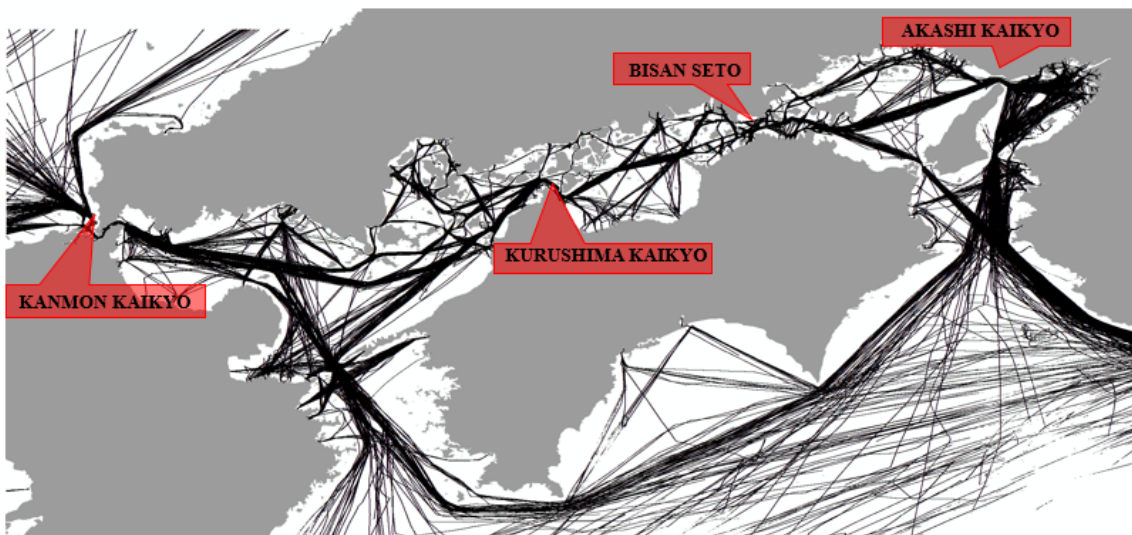Figs. 2-6 to Fig. 2-8 show the ship trajectories of cargo ships, tankers and passenger ships, respectively. Fig. 2-6 shows the ship trajectories of cargo ships in March 6, 2012. Blue dots indicate the trajectories of cargo ship, and gray dots the trajectories of other ships. A consideration by ship category is that 52% of the ships contributing to the traffic were cargo ship. The most ships were cargo ship navigation in Seto Inland Sea.

Fig. 2-7 shows the ship trajectories of tanker. The red dots indicate the trajectories of them. Tanker ships (24%) constituting the second highest category in the Seto Inland Sea. From the trajectories, it is understood that the most of tanker navigated in Seto Inland sea route, and few ships sailed the open sea route.

Fig. 2-8 shows the ship trajectories of passenger ships in March 6, 2012. Green dots indicate the trajectories of passenger ship, and gray dots the trajectories of other ships.

Fig. 2-6 Trajectories of cargo ship (March 6, 2012)

The contributing of passenger to the traffic were 4%. The passenger ship is the regular service in the area, thus most of ferries navigated in the islands route. Especially, many ships cross through the Seto Inland Sea sailing the south-north routes.
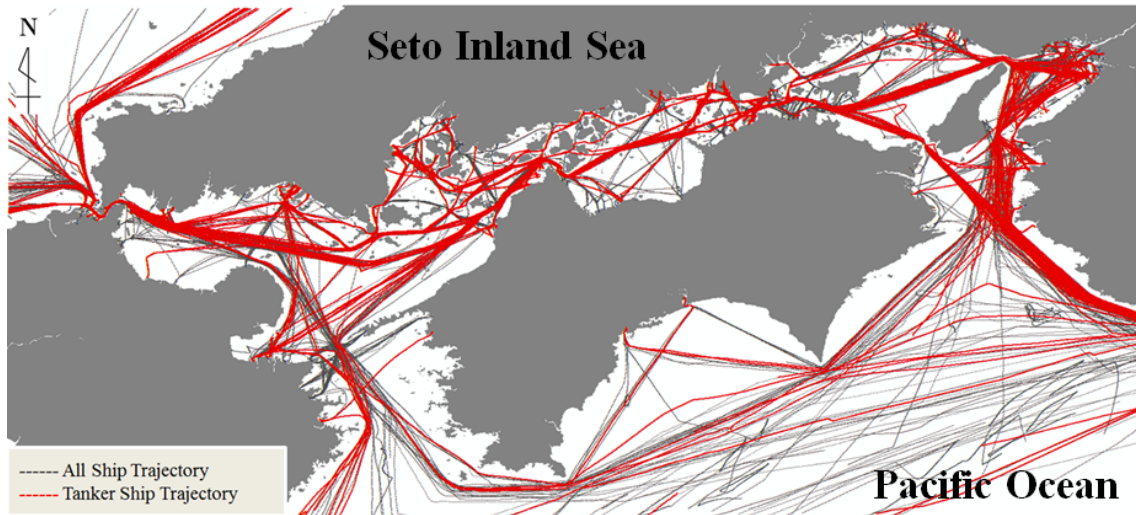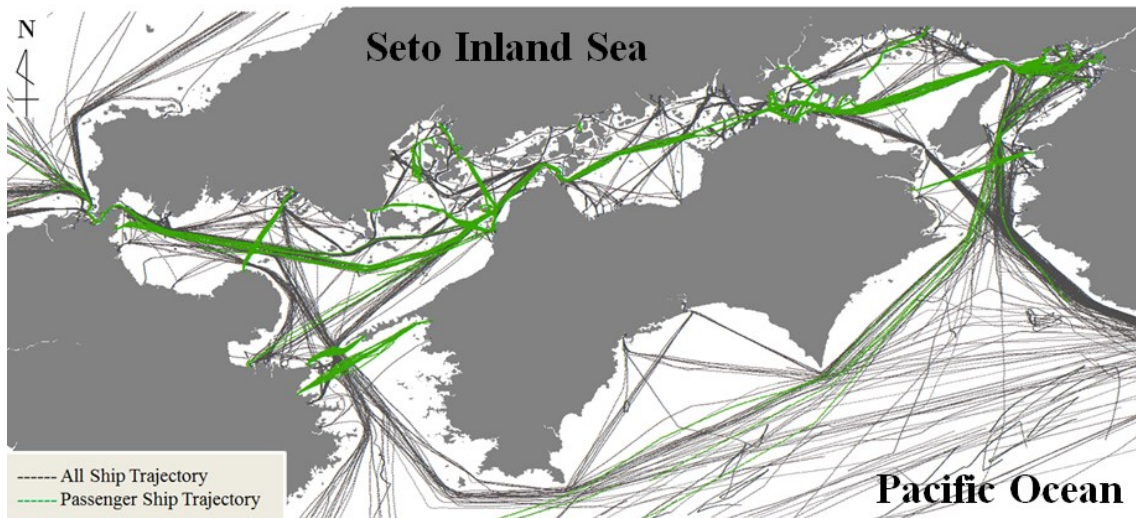
Fig. 2-7 Trajectories of tanker ship (March 6, 2012)

Fig. 2-8 Trajectories of passenger ship (March 6, 2012)

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CHAPTER 3   Analysis of the Actual Ship Navigation for Preventing the Occurrence of Ship Accidents via Practical Use of AIS Data

In connection with the rapid increase in population and economic development in the world, the amount of domestic and international maritime transport is increasing rapidly. This has led to a global increase in shipbuilding. As a result, the number of accidents at sea, such as collisions, groundings, rollovers, and engine failures is also increasing. This increase is troubling. The main causes of marine disasters are collision and stranding [1]. Therefore, the prevention of ship accidents is an important issue for maritime safety.

In order to the prevention of ship accidents, this study understood the actual situation of ship navigation in Seto Inland Sea based on the analysis of AIS data. Firstly, this study has obtained the congestion areas, the extraction method and the results are described in Section 3.1. As the congestion areas are crowded in narrow routes and port areas, the study analyzed the actual conditions of ship navigation in narrow routes and coastal areas in Section 3.2 and Section 3.3, respectively. According to the dynamic analysis of ship movement, the potential risks were understood. In order to present the risk quantitative, the risk-areas were obtained based on Kernel Density Estimation (KDE) distribution. Additionally, the actual ship this study analyzed the case in which the waiting ships were anchoring offshore, and how these ships influenced the safety of ship traffic. The obtained information based on the analysis of AIS data can deepened the understanding of MDA in ship navigation. The effective information can be used to make a navigation plan for the avoidance of the risk areas and congestion time.

3.1 Congestion Areas in Seto Inland Sea Using AIS Data

This section analyzes the ship congestion and presents the risk areas for a ship sailing in the Seto Inland Sea, in order to help operators understand the navigational situation before their voyage, and avoid maritime accidents. Moreover, the navigating

schedule can be designed to avoid times of heavy traffic congestion based on the analysis results.

Here, this study analyzed the congestion situation of ships based on their density distribution. The research area was divided into grid areas of 5 km × 5 km. Then, according to the ship positions, a sea area was divided into different regions, each of which was individually studied. In the study, the analysis method analyzed and evaluated the congestion density not only by considering the ship positions, but also by calculating the influence of the ship's length on the traffic [2]. The standard length of a ship was set at 90 m, because 90 m is the average length of the ships navigating the inland sea. Thus, if the length of a ship was 45 m, it would be converted to 0.5 ship, and the length of a ship was 180 m, the converted value is 2 ships.

The study was carried out the extraction of the congestion areas every day, during the research period. As an example of the results, Fig. 3-1 shows the distribution of ships navigating the Seto Inland Sea at 0:00, 6:00 12:00 and 18:00 on March 7 (Wed.). High and low traffic densities are coded in red and yellow colors, respectively. Fig. 3-1(a) shows the density of the ship traffic at 0:00, where ships are shown to be crowded around the routes, except for the Akashi Strait. In addition, there was an increase in the number of ships anchoring outside Kobe and Osaka during this time in order to wait for a berth. From 6:00 to 9:00, when the ships began to enter the ports and prepared to unload their cargo, the traffic density near the ports increased further.
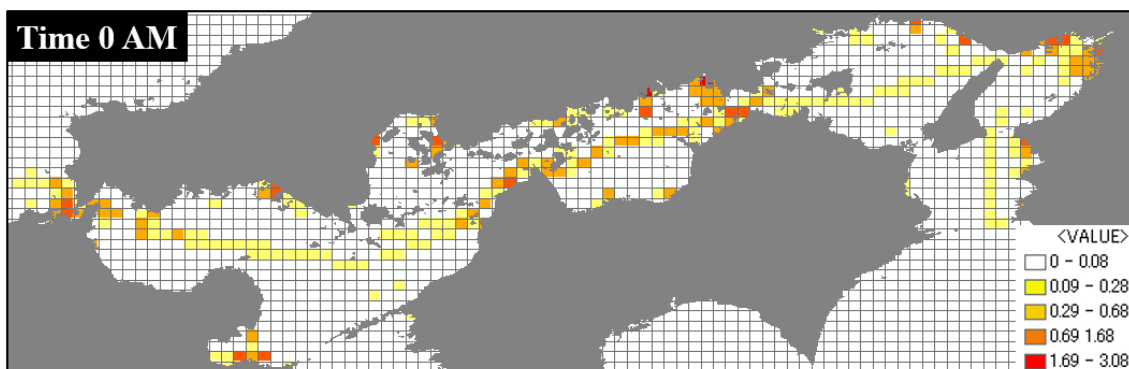
(a) Time 0:00
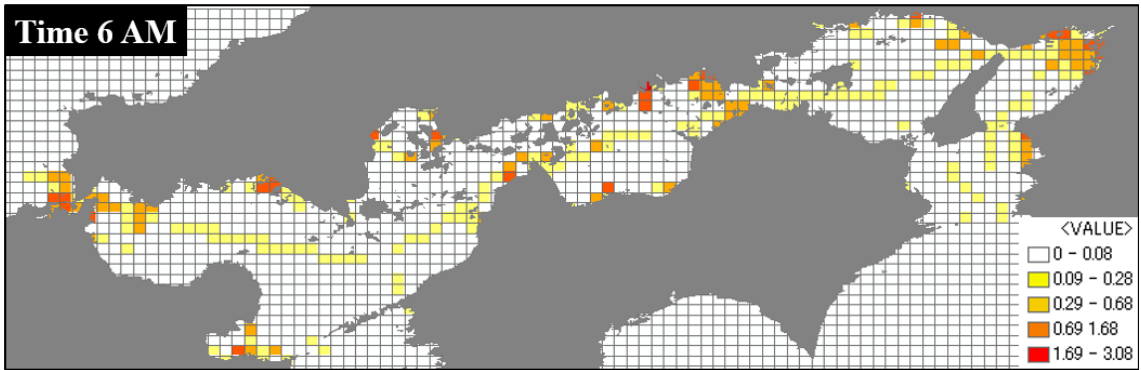
(b) Time 6:00
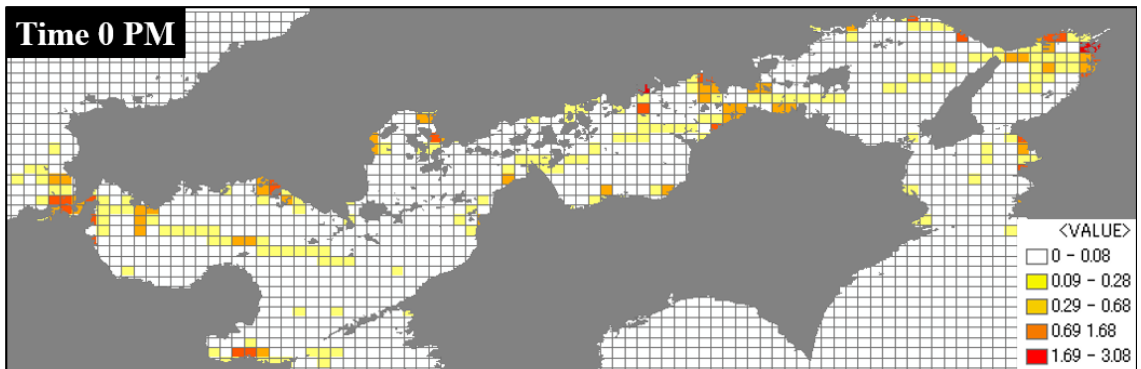
(c) Time 12:00

(d) Time 18:00

Fig. 3-1 Density distributions of ships in Seto Inland Sea (March 7, 2012)

In accordance with economic actions, the congested areas altered from the main traffic route to both ports throughout the morning. Fig.3-1(d) shows the traffic density distribution at 18:00. As can be seen, the traffic flow through the route increased again.

Based on the above vessel traffic analysis, we can elucidate the navigational situation of ships in Osaka Bay. In particular, the operating trend of various ship c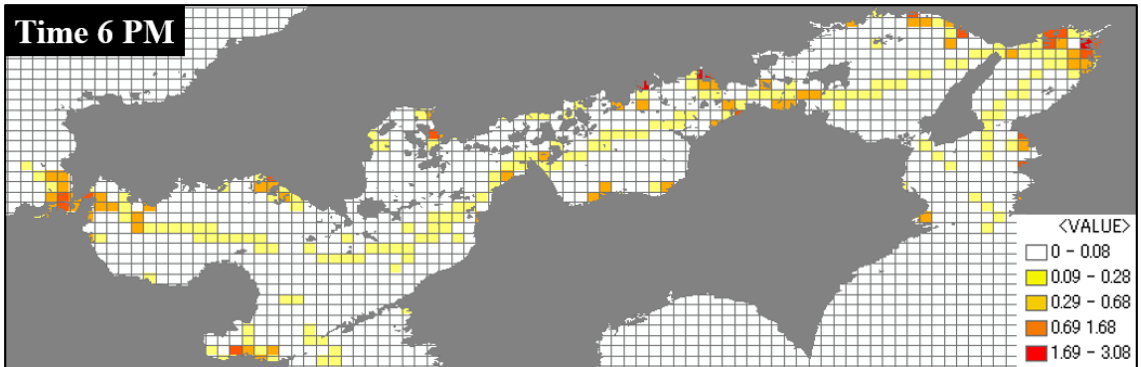ategories becomes clear. Moreover, we analyzed the congestion situation in the wide ocean area in terms of the density distribution. The congestion area is temporally dynamic and reflects the business hours of the harbor facilities. If ship operators understand the congestion situation beforehand, they can perform operations in a safer manner.

In this section, this study presented the results of an important reference investigation on ship navigation in the Seto Inland Sea. According to the analysis of AIS data, the congestion areas were obtained based on the ship density and the real situation of ship traffic was understood. The density distribution has a free mesh size and time interval, which can assist the operator to understand the traffic situation of navigation area in detail, based on their voyage plan. The analysis results can help operators avoid congestion, and navigate more safely and efficiently in the inland sea. This information has deepened understanding of ship navigation in Seto Inland Sea. Based on the analysis of the density distribution, this study determined the risk areas at specific times in the Seto Inland Sea. It is found that the ship congestion is commonly in the narrow routes and the coastal areas.

3.2 Analysis of Latent Risk of Ship Navigation in Seto Inland Sea

Seto Inland Sea is a very dangerous route for ship navigation, because the large number of small islands scattered throughout it, and relatively narrow and shallow water in most places. Plus, the ships are commonly congested. Due to ships avoid obstacles by deceleration and veering, using a propeller. The maneuvers of avoidance and returning to original route are time consuming and in high risk, especially for ship navigating in a restricted water. In contrast, if the shipping operator understands the latent risk during the ship voyage. It is possible to make an ideal navigation plan for ensuring the ship navigation more safety and efficiency. Therefore, the study focused on unveiling the characteristics and latent risk of the ship navigation in the narrow route in this chapter. This information is very important for MDA to prevent ship accidents.

In the study, the latent risk was understood by the analysis of the actual ship behavior. Related studies to this research have shown that the application of behavior analyses to land transport vehicles is possible [3][4][5]. Precisely, these studies analyzed the vehicle behavior to understand the driving features of the drivers and the effect of road infrastructures. For instance, Yokoyama et al. [6] used recorded data from drivers to analyze the real driving behavior to reduce the number of traffic accidents in the future. In the maritime transport field, most studies on ship behavior analysis have been carried out with simulation models [7][8][9]. Although these models can describe the dynamic motion of the ship, most of them can be only applied to a few specific ships. In this study, the characteristics of ship behavior were analyzed based on the dynamic data (including speed, course, heading and position of ships) of AIS data with time series. A dynamic analysis based on real ship movement data was carried out in this study, and the applied method was the analysis of the density distribution of risk using a KDE (kernel density estimation) approach. The latent risks in navigation were success successfully extracted.

3.2.1 Analysis of Ship Navigation in a Narrow Strait

Since the navigable waters are narrow and congested by many ships, sailing ships have difficulty passing through the narrow route. According to the statistics of the Marine Accident Inquiry Agency, Japan, there were 676 accidents in the main narrow routes of Japan from 2002 to 2007 [10]. In particular, when the ships are sailing in the narrow and shallow water, they are easy to be affected by external forces, such as the strong currents and winds. Therefore, collision and grounding accidents frequently occur. The damage of these accidents has caused significant environmental pollution and economical loss. It is necessary to understand the navigational situation of ships, especially for the behavior of ship drift to ensure maritime traffic safety in a narrow channel [11].

Tada has investigated the traffic volume of the Kurushima Strait by visual observation that took a great amount of effort and manpower [12]. After that, Tanaka et al. [13] analyzed the ship traffic in the Kurushima Strait using AIS data in 2004, and the

study indicated that AIS is able to obtain the ship navigation data accurately, and evaluate the maritime traffic quantitatively. Therefore, it can be said that currently it is possible to understand ship movement with high accuracy. The advantages of using AIS data includes the ability to obtain data about the properties of an ocean area based on the analysis of a group of ships, and understanding a ship sailing behavior in detail. Therefore, AIS data is an optimal approach to understanding ship drifts.

Fig. 3-2 shows the traffic volume of ships passing through the Kurushima Strait route. During the investigation, 1427 passing ships were checked from March 1-7, 2012. The highest number of ships was 229 ships on March 1 (Thu.), and the lowest number of ships was 181 ships on March 3 (Sat.). It was found that 58% of all ships that passed through the Kurushima Strait traffic route were cargo ships. The other types of ships were tanker ships (30%), passenger liners (7%), and others (4%).
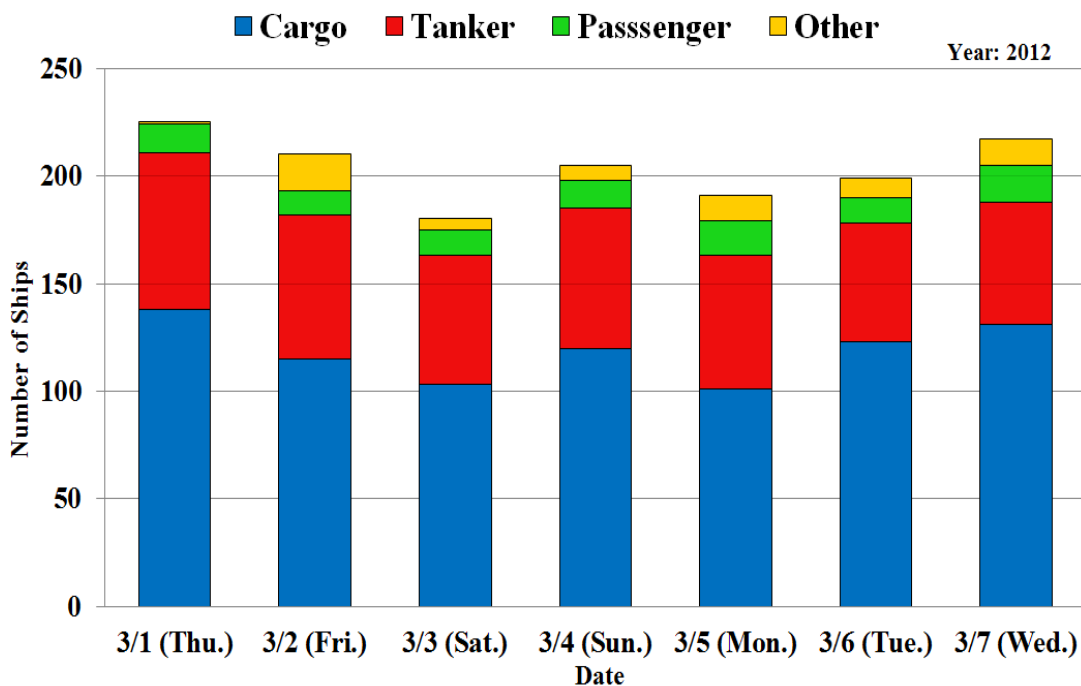

Fig. 3-2 Number and type of passing ships in Kurushima Strait

The ship traffic data in the Kurushima Strait were obtained using AIS data. The AIS data were acquired between March 1 and March 7, 2012. Fig. 3-3 tracks the movement of

all AIS-equipped ships in the Kurushima Strait during the research period. The black dots indicate the trajectory of ships by their positions, and the green line shows the limit of the Kurushima Strait route. From the trend of ships navigating, it is observed that most ships via this strait sailed eastward and westward. There were very few ships that sailed across the route northward or southward. This study extracted the ships sailing within the route as the research target.

From the trend of ships navigating, it is observed that the main route was used by ships sailing between eastward and westward, which is the Kurushima Strait traffic route. There were very few ships cross the main route sailing between northward and southward. The Kurushima Strait is the one of the most difficult route in Seto Inland Sea, which is consistently congested because of the ship traffic. Moreover, the route implements a rule that is rare and unique in the world.
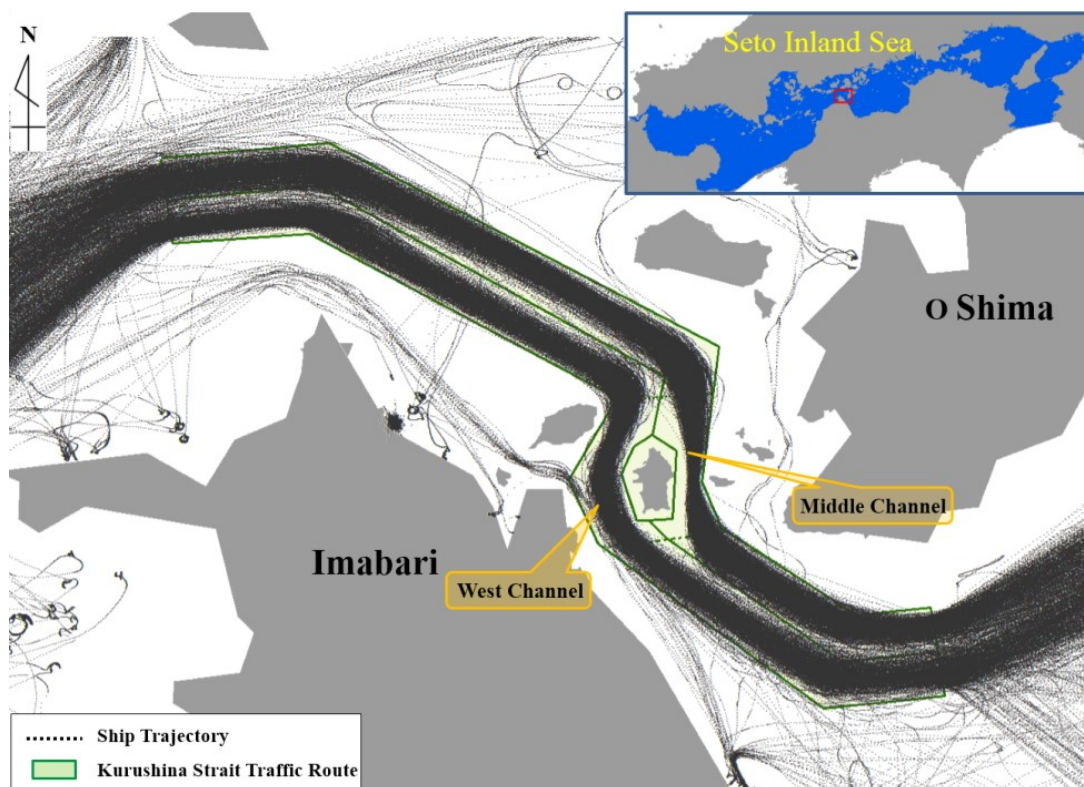

Fig. 3-3 Ship trajectories in Kurshima Strait

The main essential navigation rule of this route is; when current is favorable, a ship shall navigate through the Middle Channel. When current is adverse, a vessel shall navigate through the West Channel, and a ground speed of 4 knots and upwards.

Due to the special rule, it is difficult for the foreign ships pass through this route. In addition, the Kurushima Strait route has unfavorable geographical conditions such as scattered islands and curved route, and the route has strong current, the maximum current is over 10 knots. These situations are dangerous for ship navigation, and many latent risks are present during navigation. The ship operator is required a high techniques to passing through the route. For these reasons, understanding the unexpected movement of one's own ship and other ships becomes a very important factor for avoiding marine accident. Normally, it is considered that currents and wind are a main factor affecting ship drifts. According to the information of Japan Meteorological Agency, the weather during the research period was zero visibility, little rainfall, and low wind speed. Therefore, wind had less influence on the ship navigation. For this reason, it was assumed that the ship drifts were influenced by currents only. Table 3-1 gives the current data in the Kurushima Strait for the sample time frame.

Table 3-1 Current data

Date	Slack time	Maximum time	Direction (S/N)	Speed (Kt)
March 1	—	00:59	S	4.1
	04:21	07:11	N	2.5
	10:10	13:03	S	2.8
	15:48	19:21	N	3.4
	22:51	—	—	—
March 2	—	01:59	S	3.3
	05:41	08:36	N	1.8
	11:30	14:13	S	1.8
	16:56	20:48	N	2.8
March 3	00:09	03:34	S	3.0
	07:29	10:27	N	2.0
	13:29	16:10	S	1.6
	18:49	22:23	N	2.9
March 4	01:41	05:16	S	3.7
	08:50	11:52	N	2.9
	15:01	17:48	S	2.5
	20:28	23:52	N	3.8
March 5	02:56	06:23	S	5.0
	09:43	12:49	N	4.2
	15:56	18:46	S	3.9
	21:32	—	—	—
March 6	—	00:50	N	5.1
	03:53	07:11	S	6.3
	10:26	13:32	N	5.5

	16:38	19:30	S	5.3
	22:21	—	—	—
March 7	—	01:36	N	6.3
	04:41	07:52	S	7.5
	11:04	14:10	N	6.7
	17:14	20:10	S	6.7
	23:04	—	—	—

In the study, the drifting analysis was based on the deviation of the course over ground (COG) and ship heading information, which are stored in AIS data. The COG is the true course of a ship navigating under the influence of external forces such wind and tidal currents. The direction of heading is the intended direction when a ship operator takes the helm. Especially when current is adverse, a ship stems the current to improve the steering effectiveness and prevent the ship drift. Therefore, the ship drift can be described by the COG and heading. The image of ship drift is shown in Fig.3-4. The drifting angle was extracted from the difference between COG and ship heading.

It is a customary maneuver for a ship operator to take the helm in order to resist external forces when a ship is drifting laterally. In the advanced research, Makino [14][15] has illuminated that the deviation is less than 5° in usual navigation, when a ship is sailing forward. If the deviation is 5° or more, the ship may become unstable.
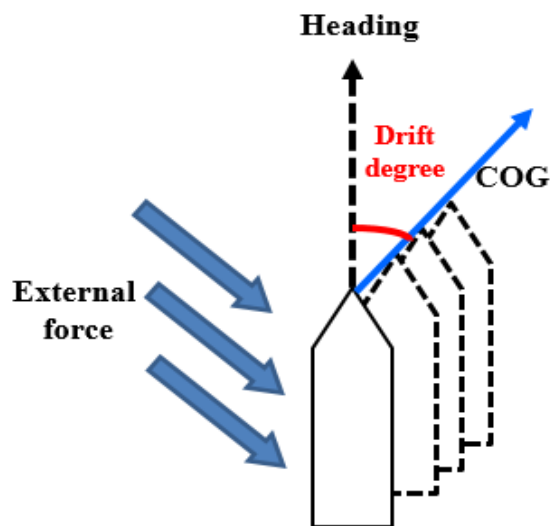

Fig. 3-4 Image of ship drift

Especially for the Kurushima Strait, the route consists of twists and turns, and the currents are swift and complex. The Kurushima Strait is known as a difficult route. The author interviewed ship captains who had substantial experience passing through the Kurushima Strait. They proposed that, in general the operator should keep the drifting angles less than 15°. If this degree is exceeded, the original course of the ship will be significantly difficult to maintain. That is, when a navigational ship deviates to an angle exceeding 15°, ship operators cannot control it, and this is an indication that the navigation of a ship is in a dangerous condition. Kose et al. [16] adopted a maximum permissible drifting degree of below 14.3° to evaluate the difficulty of ship maneuvering in the Kurushima Strait. Generally, 15° is recommended as the maximum drifting degree when sailing in the Kurushima Strait.

During the research period, a total of 1427 ships passed through the Kurushima Strait route, and 53 were excluded because, the information of ship heading were in error. Because the AIS data transmission interval depends on the navigational status, the data transmitted was irregular due to the speed of the ship. Therefore, the dynamic information including in the position, SOG, COG, and heading of ship were interpolated at a rate of once every second using the linear interpolation, and the data was analyzed at intervals of 10 seconds. In this study, a dynamic analysis used to analyze the drift behavior. The approach was followed, which involved tracking the position and navigational situation (including in the COG, Heading and SOG) of this ship across different time series. According to MMSI number of ships, the drift situation of individual ship was obtained. Moreover, it is possible to understand the process of the ship drift behavior in a detailed.

Fig. 3-5 and Fig. 3-6 indicate the results of ship drifts. Fig. 3-5 shows a graph of the maximum drifting degrees of each ship passing through the western channel of the Kurushima Strait route. In this figure, blue bars indicate ships sailing westward and red bars indicate ships sailing eastward. Fig. 3-6 shows a graph of the maximum drifting degrees of ships passing through the middle channel, in the same way as Fig. 3-5.
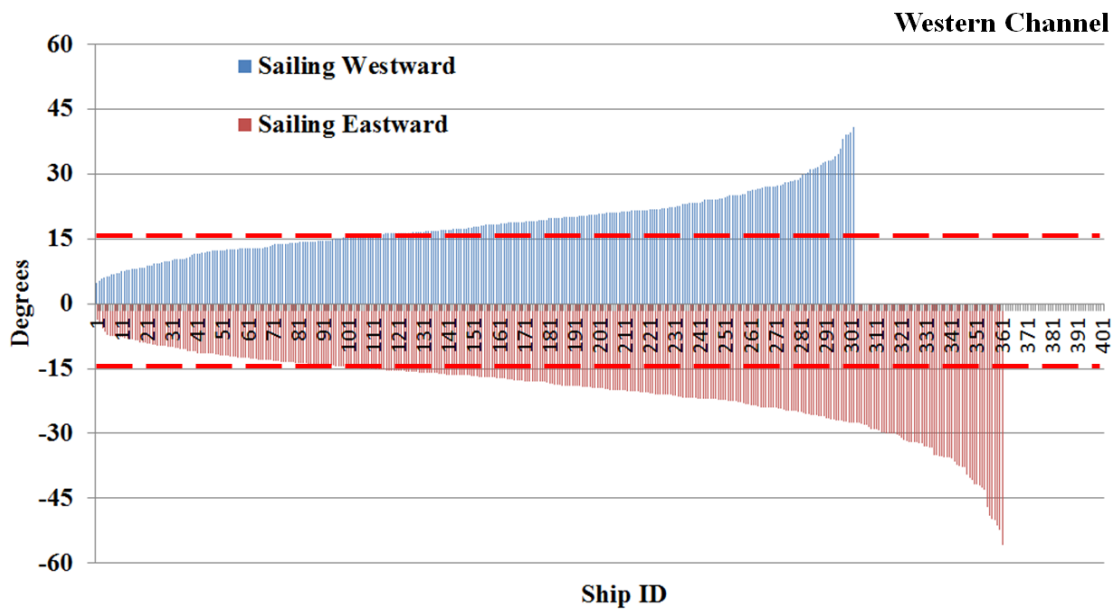
Fig. 3-5 Degree of drifting of ships in Western Channel
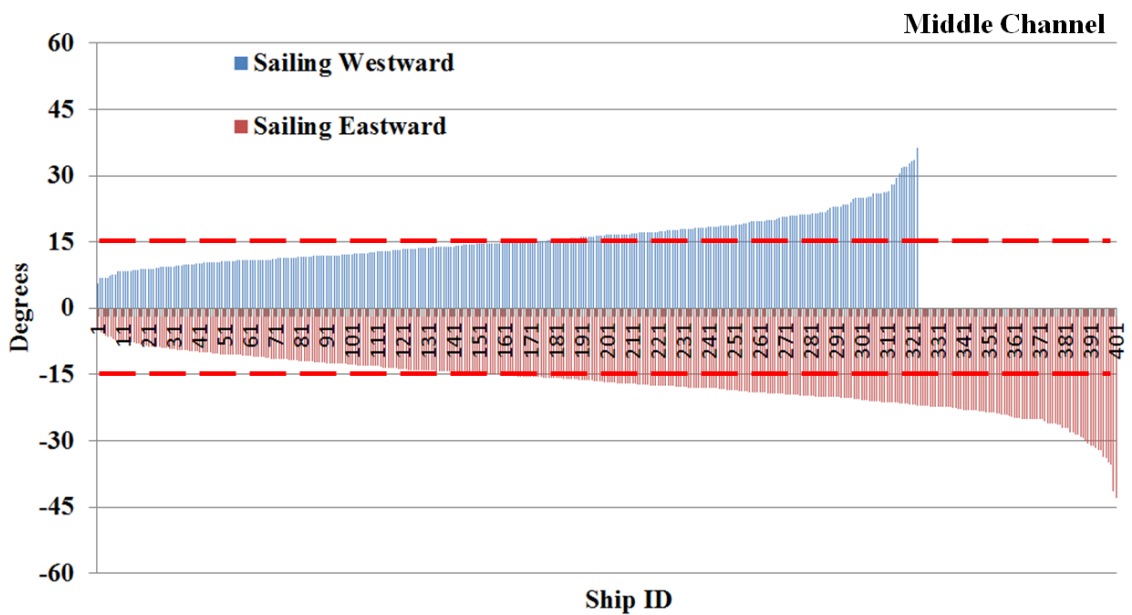

Fig. 3-6 Degree of drifting of ships in Middle Channel

From these results, it was found that many sailing ships significantly exceeded the drifting degree of 15° in both channels, which surpasses the recommended value found through advanced research and the operators' recognition. A total of 663 ships passed through the western channel, and 451 of them, corresponding to approximately 68% of

the total number, that exceeded 15° for sailing. The ships that passed through western channel were easy to drift, especially when sailing eastward, and the maximum angle was 55.8°. As for the middle channel, a total of 663 ships passed through, and approximately 55% exceeded 15°. The maximum drifting was 43°. From the statistical results of ship drifting, it is understood that out of the total number of AIS-equipped ships that passed through the Kurushima Strait, about 61% exceeded 15° for sailing. According to the above results, most passing ships drift more than 15°, which is outside of the safe range indicated by operators. This means that the navigation of the ships was in a dangerous condition. Using the AIS data to analyze real navigation history of ships, the results of the actual navigational situations confirm that many ships passing through the Kurushima Strait route operate in a dangerous drift outside the recommended safe range.

According the analysis, it is checked that during one day (March 1, 2012), of total 225 ships passed through Kurushima Strait route and 135 ships of them corresponding to about 60% exceeds the maximum permissible deviation angle to sailing. As the analysis, it is grasped that at least 43% passing ships were in a dangerous navigational situation. For another, with regard to the special features of the change of tides in Kurushima Strait route, based on the tidal tables, the tidal current changes the opposite direction at 04:00, 10:00, 15:00, and 22:00. However, it is found from this result that many ships drift even though the tidal current is slack in these time periods. To analyze the categories and length of ships deviate angle above 15 degrees, in order to grasp their detail situation.

Fig. 3-7 shows the the number of sailing ships drifted in Kurushima Strait based on the type of ships on March 1, 2012. From the graph, most of cargo ships drifted when passing the strait, in contrast, there no passenger drifted during the day. It is grasped that 69% and 31% were cargo and tanker ships, respectively, and the other kinds of ship were not existed. Many small and medium-sized ships between 50m and 99m were in peril of their sailing, and compared with the coastal vessels, the international vessel is easy to drift in the area.
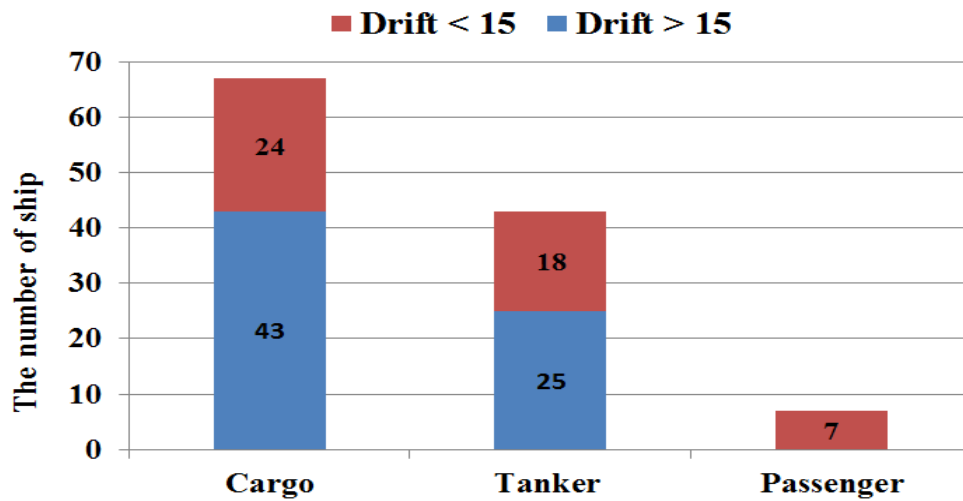
Fig. 3-7 Ship drift in Kurushima Strait based on the type of ships (March 1, 2012)

An example of drifting is given according to an actual navigational ship. The drifting situation was analyzed based on the ship's trajectory. According to the positions of ship, the trajectory was mapped by GIS. The sample ship is a domestic LPG tanker, and the overall length is 52 m. Due to the current was northward, this ship passed through the western channel of the Kurushima Strait sailing eastward from 1 AM to 3 AM on March 6 (Tues.). The current speed was over than 4 knots at this time. Fig. 3-8 tracks the movement of the ship. Black dots show the trajectory of the ship, and red triangle symbols indicate that the ship drift exceeded 15°. From the tracking, it is found that the ship drifted near the western channel and the entrance of the route. Under the tracking figure, the ship trajectory of ship drift before entering the western channel is enlarged. The direction of red triangle symbols shows the heading of the ship. The enlarged figure indicates the drifting situation. The ship drifted to the north because of the effect of strong currents. The moving distance with drift was 482 m, and taking 3 mins was significantly difficult to operate. The green line in the enlarged figure indicates the drifting route. Consequently, the ship performed a wide turn, and was very close to the opposite route. The situation not only was dangerous for the specific ship but also posed a risk of collision with the westbound ships. Moreover, the maneuvers of returning to original route are time consuming. The drifting can be resulted a negative influence in the efficiency and fuel costs.
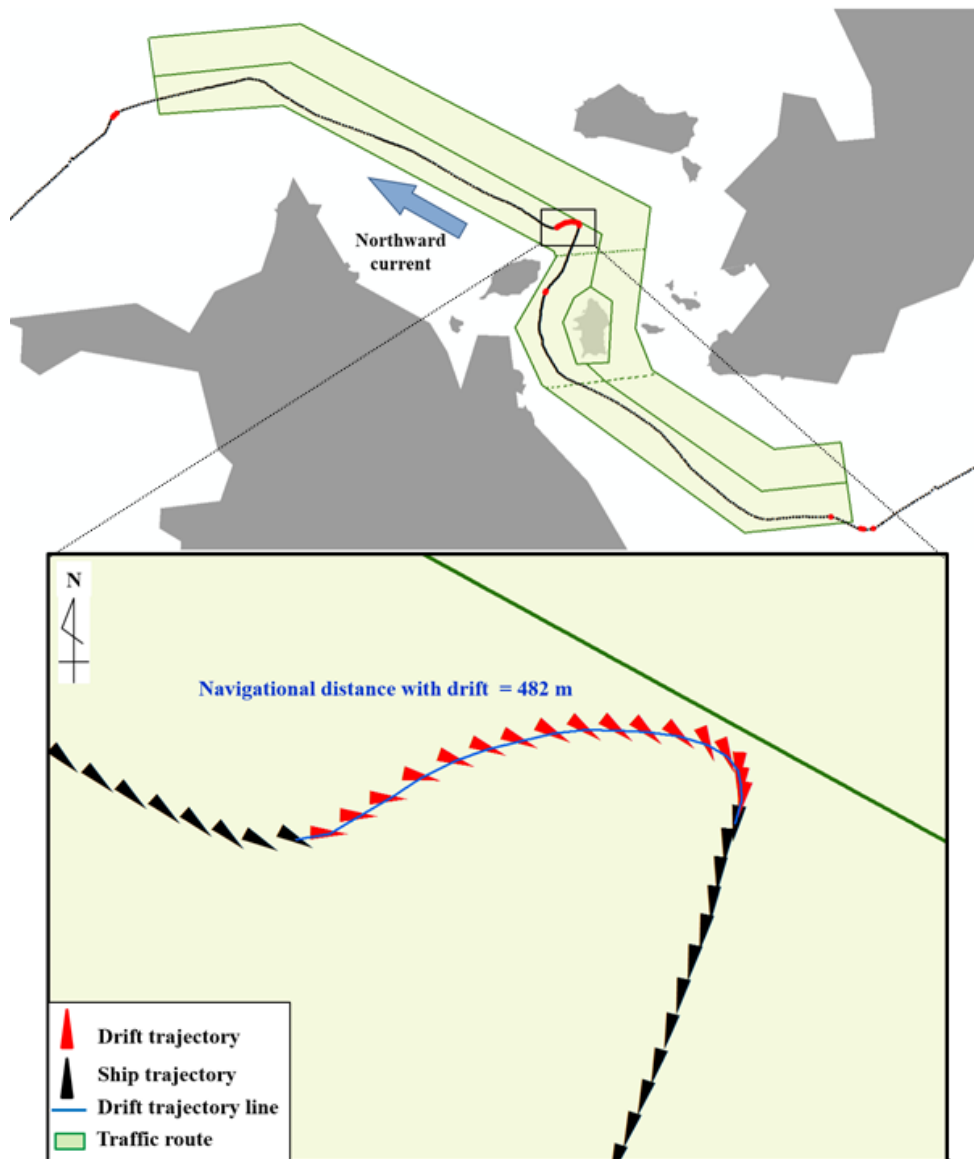
Fig. 3-8 Tracking of sample ship sailing eastward

The situation not only was dangerous for the specific ship but also posed a risk of collision with the westbound ships. Moreover, the maneuvers of returning to original route are time consuming. The drifting can be resulted a negative influence in the efficiency and fuel costs.

Fig. 3-9 shows a graph of the ship drifting degree and speed over ground (SOG) according to time. Red parts in the graph indicate drifting exceeding 15°, similar to the

red trajectory in Fig. 3-8. The zones in which this ship navigated the entrances and western channel are indicated with green strips on the graph. From the graph, it is understood that the ship drifted near the entrance of the route at approximately 20° of drift; however, the speed of the ship was maintained. The maximum drifting occurred before entering the westernchannel, when the drifting was 55.8°, and the speed dropped sharply to less than 4 knots. As the rule of the Kurushima Strait, the speed of a ship must be more than 4 knots during the passage. Thus it is inferred that the ship was uncontrollable at that moment because of the drifting.

Moreover, it was confirmed that there were seven other ships passing through the route at the same time and they also drifted like the sample ship. The results of analysis prove that ship drifting can very easily cause a collision or grounding accident, especially in this type of narrow channel.
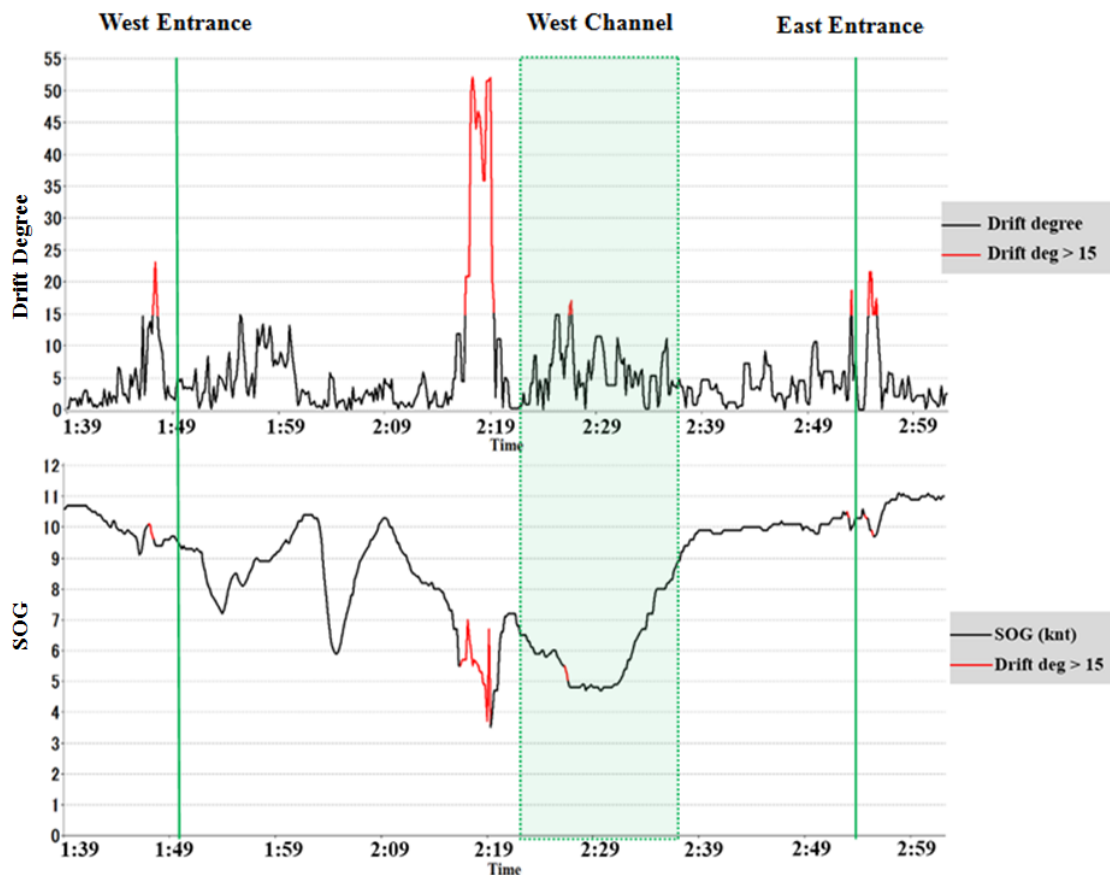

Fig. 3-9 Graph of drifting degree and speed of sample ship

The drifting ship was in danger, and there was also the possibility of becoming a potential threat for other ships. It can be presumed that the officer operated under extremely dangerous conditions.

In this study, the drift behavior of a group ship passing through the Kurushima Strait was understood using AIS data. According to the ship drift analysis, the characteristics of an ocean area were obtained. The risk areas of the Kurushima Strait route were extracted based on the distribution of drifting ships. The results were visualized by GIS techniques. Using the AIS data, the areas where drifting occurs frequently can be extracted. The method was to analyze the density distribution of drifting using Kernel Density Estimation (KDE), which is one of the most popular methods for analyzing the properties of a partial point event distribution [17], as it is simple to understand and implement.

$$\lambda(s) = \sum_{i=1}^{n} \frac{1}{nr} k\left(\frac{d_{is}}{r}\right) \tag{1}$$

where $\lambda(s)$ is the density at location s, r is the search radius (band width) of the KDE, and k is the weight of point i at distance d_{is} to location s. k is usually modeled as a function of the ratio between d_{is} and r.

In the space, the KDE uses a model function through which "distance decay effect" can be taken into account [18]. A point at a longer distance from a location is weighted lower for calculating the overall density. Setting the function of KDE in our analysis, the point location of the trajectory of ships was recorded as a pair of longitude and latitude obtained from the drifting degrees more than 15°, and the search radius was 300 m.

As an example of the results, Fig. 3-10 shows the distribution of ship drifting per hour on March 1. High and low densities are color coded red and blue, respectively. From the results, it is found that the ships drifted in each time period. Currents changed their directions at 4:00, 9:00, and 15:00 on March 1, 2012; thus, currents were lowest
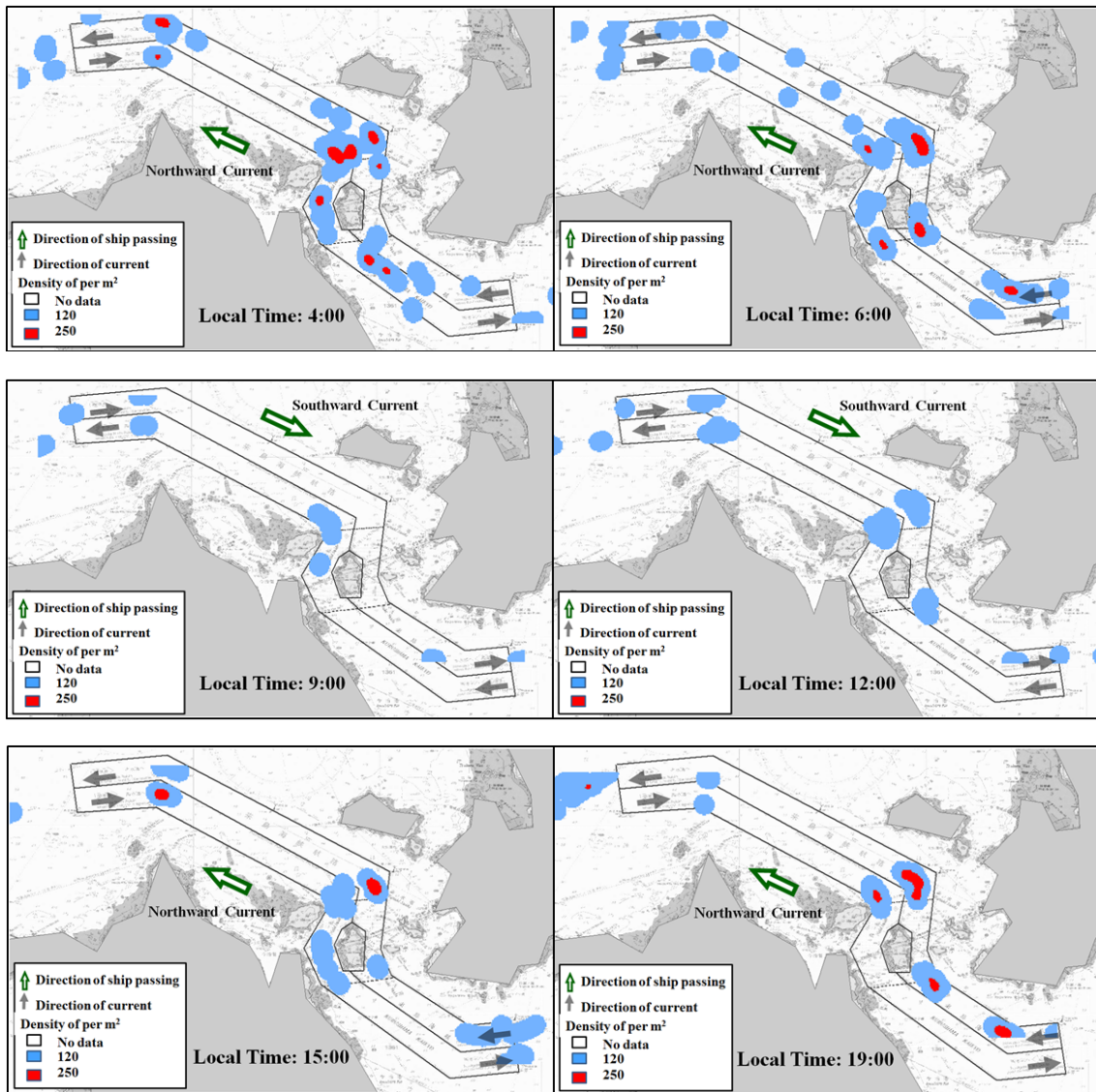
Fig. 3-10 Density distribution of drifting (March 1, 2012)

around these times. However, there was a high density of drifting in the Kurushima Strait route at 4:00 and 15:00.

From the density distribution, we can see that ship drifting was frequent at the veering position. Moreover, there were other water areas in addition to the veering positions where drifting occurred, at 4:00, 6:00, and 19:00 as currents were strong around these times. From the analysis, the risk areas of ship drifting are presented, which can help ship operators understand the risk in advance before their voyage in order to operate with more safety. According to the ship behavior analysis in the section,

the main results are as follows:

1. The situation of ships drift in the narrow strait was understood.

2. Many ships passing the through the Kurushima Strait route operate under potential danger, with drifting surpassing the safe range of ±15°.

3. Approximately 61% of all AIS-equipped ships exceeded the drifting degree of 15°. The latent risk situation was understood. The drifting ship not only endangers herself, but also other sailing ships.

4. The risk areas of ship drift were obtained by analyzing the kernel density distribution. The risk areas with big drift are clearly.

5. Understanding the ship drift can prevent the occurrence of grounding and collision in narrow route. The information is valuable for the MDA in ship navigation, especially for the foreign operators. If the operates can understand the risk areas before their voyage, it is more attention to safe navigation.

6. According to understand the ship drift of each ship, the traffic management side can apply the information to support the ship navigation safety in narrow straits.

3.2.2 Extraction of Latent Risk Based on Encounter Situation of Ships

Since the ships are increasing in number and size, the ship navigation involves high-risk scenarios as maritime transportation has intensified. On the other hand, the characteristic of the ship is the one main reason that makes navigation even more dangerous. Ship navigation is different with respect to the maneuvering of other vehicles. For instance, in cars, brakes can be applied to stop the vehicle when an obstacle is found. Unfortunately, brake systems do not exist for ships. In contrast, ships avoid obstacles by deceleration and veering, using a propeller. Therefore, the maneuvers of avoidance and returning to original route are time consuming and in high risk. In addition, they have the negative influence in the efficiency and fuel costs. Navigation with large ships is thus more difficult. Furthermore, ship navigation is sensitive to external forces such as wind and currents, as well as the visibility conditions and traffic situation. Weather conditions can be checked before the voyage. However, it is difficult to reliably predict the traffic situation. For these reasons, many latent risks are present during navigation. The results of this study can effectively avoid the risk.

Fig. 3-11 shows the ship trajectories based on the routes in Seto Inland Sea. The route connects the traffic exits in the Kamon Straits (on the westernmost side of Japan) and the Osaka Bay (in the center of Japan). This area also harbors two main ports, Kobe and Osaka. Most voyaging ships stop at these ports; therefore, the route is always congestion. On the other hand, there is a route crossing the Seto Inland Sea, it is used by ship navigating between the south and north. These crossing routes in the inland sea area were evidenced by analyzing the AIS data on the course over ground (COG) of the ships. The blue and red dots in Fig. 3-11 indicate the trajectories of ships navigating the east-west route and the south-north route, respectively. There were a large number of cargos and tankers following the east-west route. These ships transport goods, materials and energy resources, supporting the economy and logistics of the region.

Fig. 3-12 indicates the traffic volume of these routes derived based on the ship voyages. It was obtained by each ship sailing on the return voyage between the routes, using AIS data analysis. In contrast to the number of ships in the east- west route, the number of ships in the south-north route was lower, but the traffic was very busy. Most of these ships were ferries, which frequently sail across the Seto Inland Sea route.
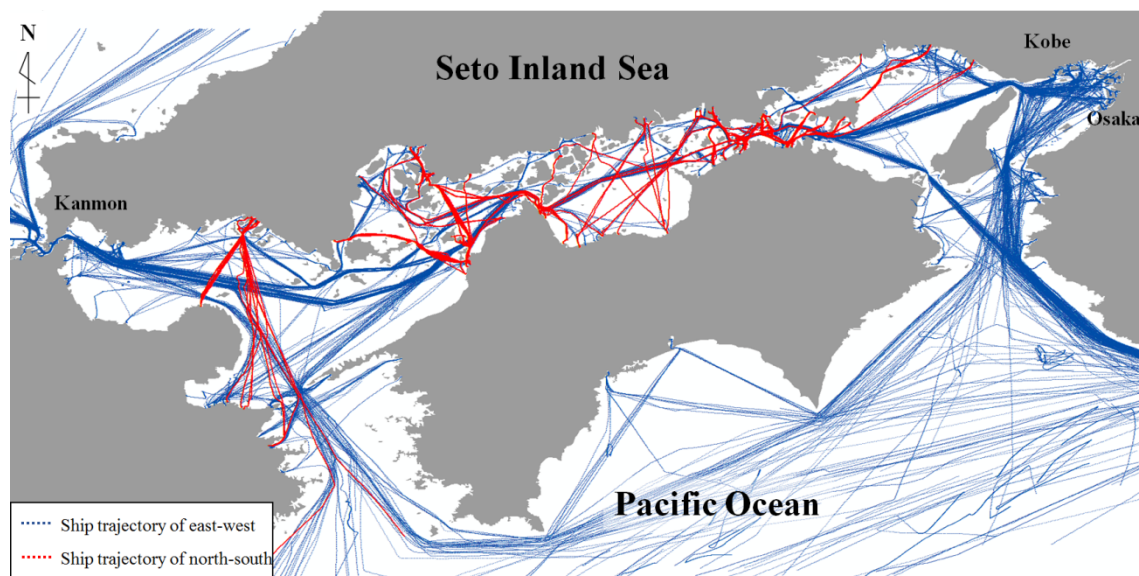

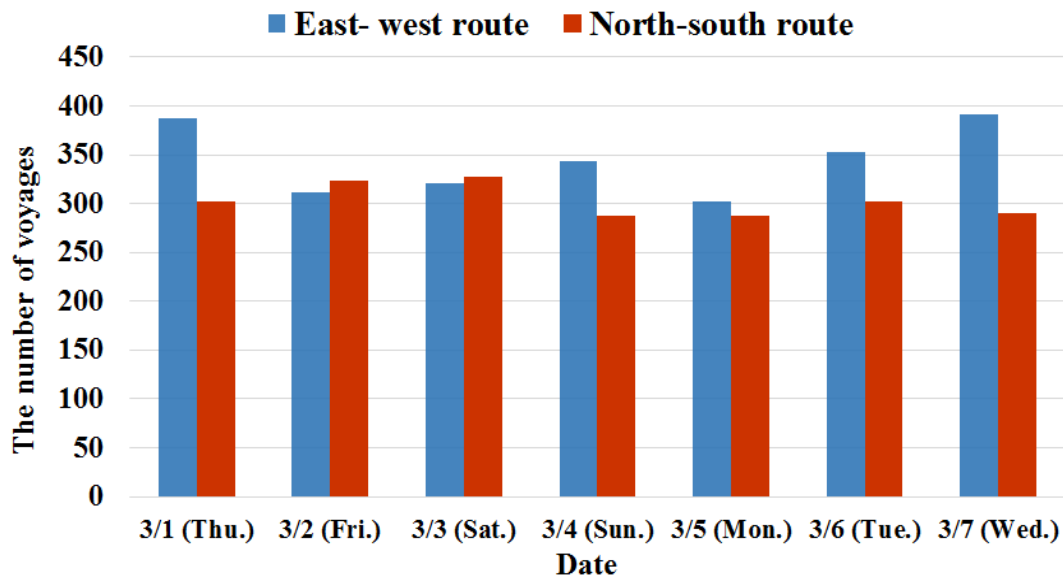Fig. 3-11 Ship trajectories based on the routes in Seto Inland Sea

Fig. 3-12 Traffic volume by the ship voyages in the east- west and north- south route

These ships are responsible for the local transportation of people moving between the islands. Thus, the number of ships crossing is high, and as a result, the traffic situation is complex, showing the latent risk of navigation in this inland area. To understand in detail the reasons for ship deceleration and the subjacent latent risk during navigation, the authors analyzed the encounter situation and the approaching distance between the ships.

The AIS data transmission interval depends on the navigational status. Therefore, the transmitted data is irregular such as the speed of the ship. The position was interpolated at a rate of one second to calculate the distance between ships. According to the dynamic calculation and analysis, the navigation situation was understood on the basis of the closest distance and the encounter situation with an approaching ship. These factors are often used to evaluate the collision risk [19].

To determine the closest distance and the encounter situation, the distance was calculated using Hubeny's formula, which considers the curve of the earth in order to determine the distance between two positions. The formula is given as follows:

38

$$d = \sqrt{(d_y R)^2 + (d_x N \cos \mu_y)^2} \qquad (1)$$

where dy is the latitude difference between two ship positions, dx is the longitude difference, μy is the average latitude of the two positions, R is the radius of curvature of the meridian, and N is the transverse radius of curvature. The data were projected onto the WGS 84 datum. Thus, the following ellipsoid parameters were obtained: 6,378,137m for the semi-major a and 6,356,752 m for the minor b.

$$R = \frac{a(1-e^2)}{W^3} \qquad (2)$$

$$N = \frac{a}{W} \qquad (3)$$

$$W = \sqrt{1 - e^2 \sin^2 \mu_y} \qquad (4)$$

$$e = \sqrt{\frac{a^2 - b^2}{a^2}} \qquad (5)$$

Generally, a sailing ship performs an evading action when a target ship within two nautical miles ahead is detected. If a ship enters the domain of one nautical mile, there is a high risk of collision. We developed a program to count the number of ships when a ship approaches within a radius of one nautical mile, and the distance between these ships was calculated simultaneously. The types of encounter situations were based on the Prevention of Collision at Sea Act (1972), which specifies three types according to the angle between the two ships: crossing, head-on, and overtaking. These ship-encounter situations are illustrated in Fig.3-13.
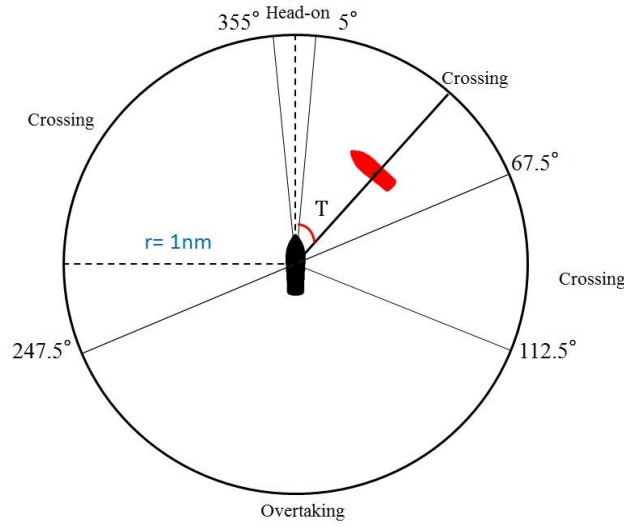
Fig. 3-13 Ship domain and encounter situation

The angle between the two ships is indicated by T and was calculated using the ship positions, as follows:

$$T = t - (t - T) \tag{6}$$

$$t = \text{Arctan}\frac{d_y}{d_x} \tag{7}$$

$$(t - T) = -\frac{1}{4m^2R^2}(y_2 + y_1)d_x + \frac{1}{12m^2R^2}(x_2 - x_1)d_y \tag{8}$$

Here, the research area was divided into seven zones, accounting for the straits in the Seto Inland Sea, to compare the characteristics of the ship behavior in each area and identify their changes throughout the inland sea. The defined zones are shown in Fig. 3-14.

The Kurushima Strait, Bisan Seto and Akashi Strait correspond to Zones 2, 4 and 6, respectively. The red dots in the Fig. 3-14 show the trajectories of the ship in these three cases. During the voyages, it took approximately 12.5 h to complete 245 nautical miles.
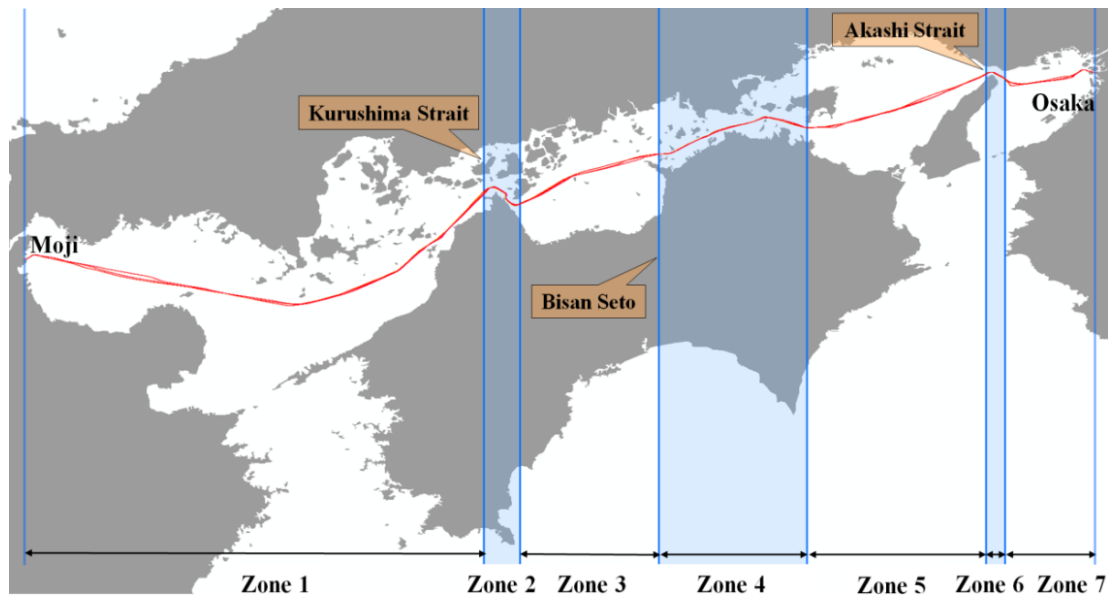
Fig. 3-14 Zone areas and trajectories of the ferry ship

The analysis results of encounter situation in the cases are indicated in Table 3-2. The number of ships in overtaking and head-on positions was larger than those in crossing positions. Since the inland sea is narrow and the speed of ferry ships is greater than that of any other types of ships, the authors focused on discussing the encounter situation of crossing.

Table 3-2 The encounter situation of Cruisings 1, 2, and 3

Study cases	Overtaking	Head-on	Crossing
	(The number of ships)		
Cruising 1	39	73	7
Cruising 2	43	62	13
Cruising 3	34	77	5

The results obtained from the analysis were used to evaluate the navigation risk, and GIS techniques were used for this purpose. The applied method was the analysis of the density distribution of risk using a KDE approach. The point event in the analysis used risk labels related to the encounter situation and approaching distance. The catalog of risk labels are listed in Table 3-3, with n taken as the number of ships in a given situation.

Crossings were considered as high-risk situations and the risk label depended on the approaching distance (d), being the most dangerous situation when entering within 0.5 nautical miles.

Table 3-3 Risk labels depending on the encounter situation

Risk label	Encounter situation		
	Overtaking	Head-on	Crossing
$d > 0.5$ n.m. and $d < 1$ n.m.	$n \times 1$	$n \times 1$	$n \times 5$
$d < 0.5$ n.m.	$n \times 1$	$n \times 1$	$n \times 10$

Fig. 3-15 to Fig. 3-17 show the distribution of ship navigation risks. High and low densities are colored in red and yellow, respectively. From the results, it is possible to determine the risk areas for each zone, in particular for Zones 1, 3 and 4. As explained above, the ship experiences different traveling times across Zone 1. The risk distribution demonstrates this ship sailed Zone 1 in a complex traffic situation, and thus the risk of collision was high. As the strength and direction of currents change with time in the Kurushima Strait, the route demands a rare and unique rule. To fit the current and meet the rules of the route, many ships change their course before entering the route. Therefore, a high-risk area in Zone 3 is present due to a sudden change in the course of the other ships, leading to multiple ship crossings. Zone 4 corresponds to Besen Seto. In this zone, a large number of ship crossings take place. This zone should be carefully sailed. Finally, the results from this analysis can be used to avoid collision accidents.

This study presents a method for the analysis of actual ship navigation. Moreover, a dynamic analysis was performed to understand the real behavior of ships in detail. Therefore, it can be considered as an innovative study in the sense that provides insights into ship traffic and unveils the latent risk in ship navigation. Although the results presented in the paper are for a particular ferry ship, the analysis can be applied to any regular ship to better understand the traffic situation within the research area. Future work will be devoted to the analysis of the navigational behavior of the other types of ships.

Certainly, a quantitative and detail analysis of the actual ships behavior will result in a sensible and appropriate simulation traffic model for the safety and efficiency of ship navigation.
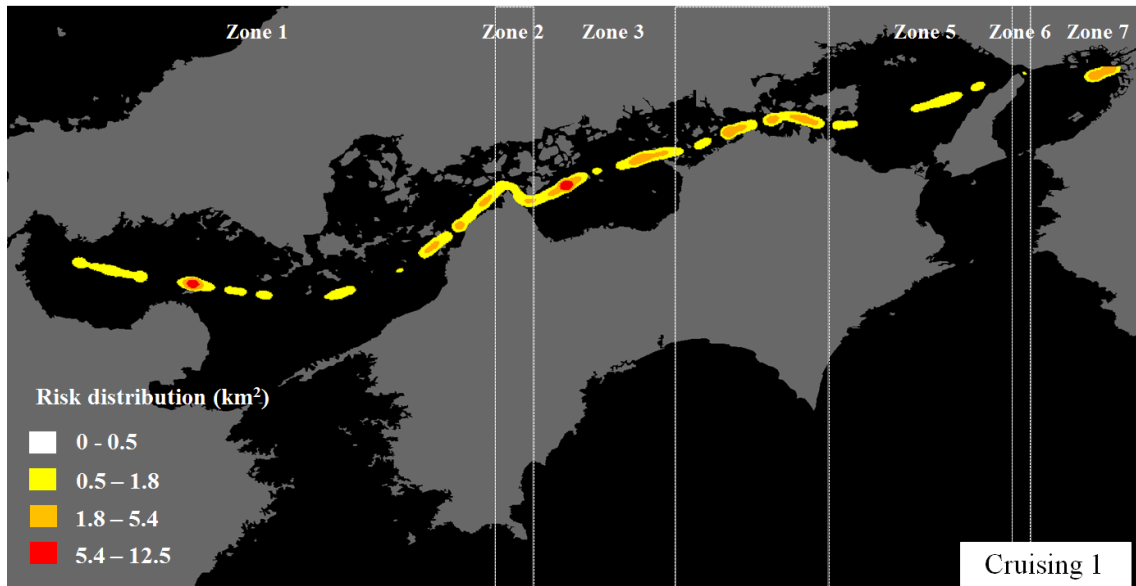

Fig. 3-15 Risk distributions of Cruising 1 in Seto Inland Sea
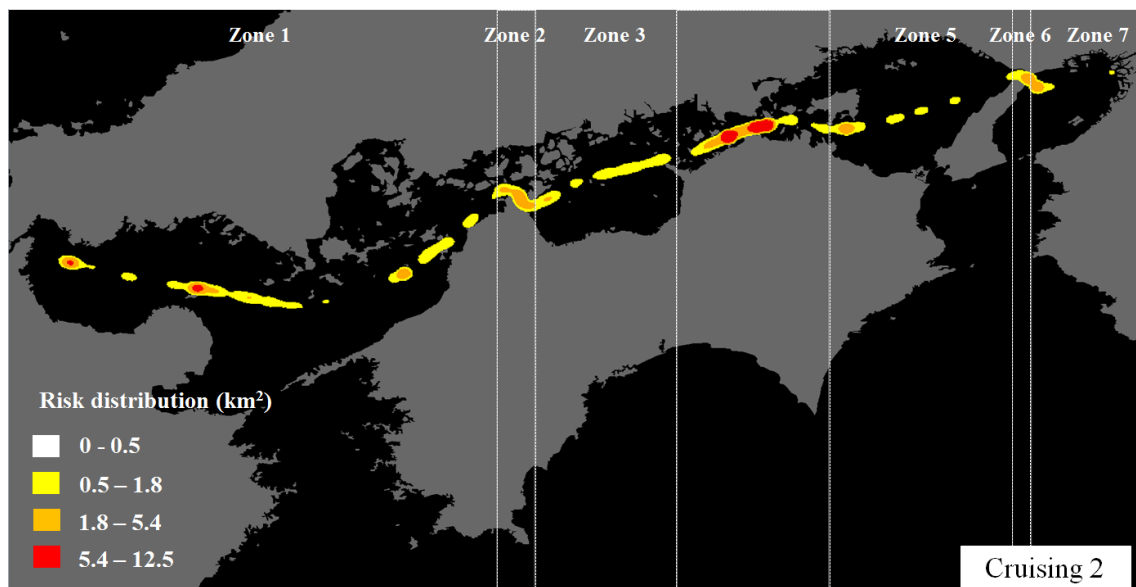

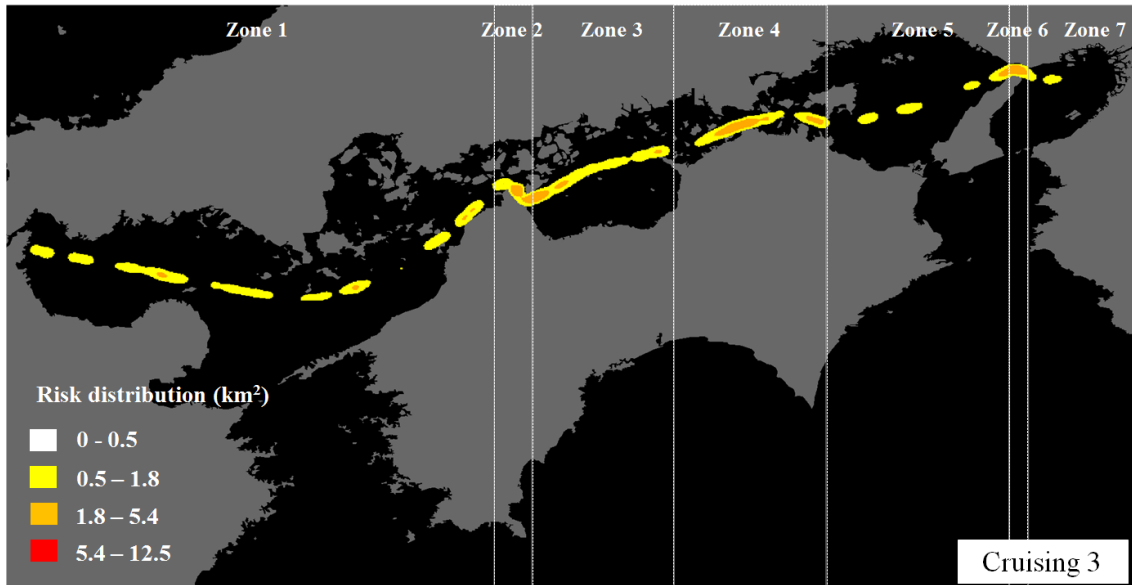Fig. 3-16 Risk distributions of Cruising 2 in Seto Inland Sea

Fig. 3-17 Risk distributions of Cruising 3 in Seto Inland Sea

This study presented an analysis on ship behavior using the real ship movement from AIS data. The encounter situation of ship navigation in Seto Inland Sea was understood. According to the encounter situation and approaching distance of ships navigating, the latent risk areas were extracted. Moreover, it is found that there is high risk not only occurring in the narrow straits. These information resources can help the ship to avoid the risk, especially for the foreign operators. The information is very valuable information for MDA to contribute in the prevention of ship accidents.

3.3 Analysis of Actual Situation of Waiting Ships by Practical Use of AIS Data

The high risk of ship navigation not only is in the narrow routes but also occurs in the coastal areas. The number of ship accidents in the coastal areas account for 40% of all ship accidents [20]. Therefore, there has been an increase in shipping as the cheapest means of transport, which has produced congestion in busy ports. Because ships cannot sail smoothly into a port, they are commonly crowded together offshore. This not only causes the ship congestion around ports, also results in the numerous maritime accidents, including collisions and grounding offshore. Especially in a stormy weather, the ships are susceptible to external forces such as the winds and currents, the risk is high.

The target area was Osaka Bay, because the most sailing ship in the Seto Inland Sea entered the ports of Osaka Bay. Osaka and Kobe port are one of the most important ports in Japan. Osaka Bay also contains two traffic exits the Akashi Strait and Tomogashima Channel, which are located in the western and southern parts of Osaka Bay, respectively.

Fig. 3-18 tracks the movement of all AIS-quipped ships in Osaka Bay during the research period (between March 1 and March 7, 2012). The black dots indicate ships tracked by ships' position, and the red arrows show the general trend of ships in Osaka Bay. From the trend of ships, it is observed that most ships residing in Osaka Bay pass through Akashi Strait route or Tomogashima Channel, entering Kobe and Osaka. Because of the development of the East Asian economy in recent years, most large and medium-sized vessels come into Osaka Bay, Japan. Consequently, vessel congestion and maritime accidents in these ocean areas are common.
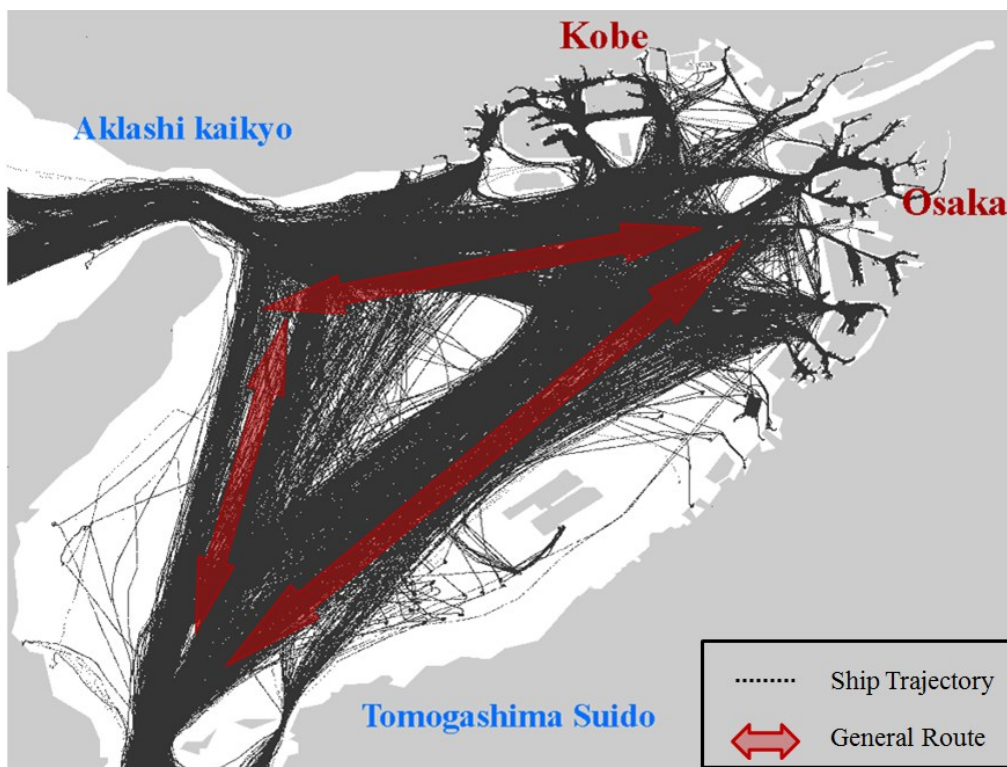

Fig. 3-18 Tracking of ships in Osaka Bay during the research period

This study extracted the waiting ships using AIS data. The information of navigation status included in the dynamic AIS data could have been used to indicate whether a ship was at anchor or sailing. However, there may have been some errors because this information is manually recorded, and most ships drift in an area without anchoring during a temporary stay. Therefore, using only the navigation status would make it difficult to determine the target data. In this study, the extraction of the waiting ships was carried out using the position and speed data of the ships. The extraction process is shown in Fig. 3-19. According to the weather information during the research period, the weather did not have a significant effect on the ships. Consequently, the study established whether a ship was at anchor or sailing based on its speed over ground (SOG) and sailing distance. The study conducted the computations when the branch condition was satisfied. Finally, ships during cargo handling and waiting offshore were concentrated based on the ship position within and without berths. The target ships were obtained that were the ships entering the port. At the same time, the positions of waiting ship were recorded.
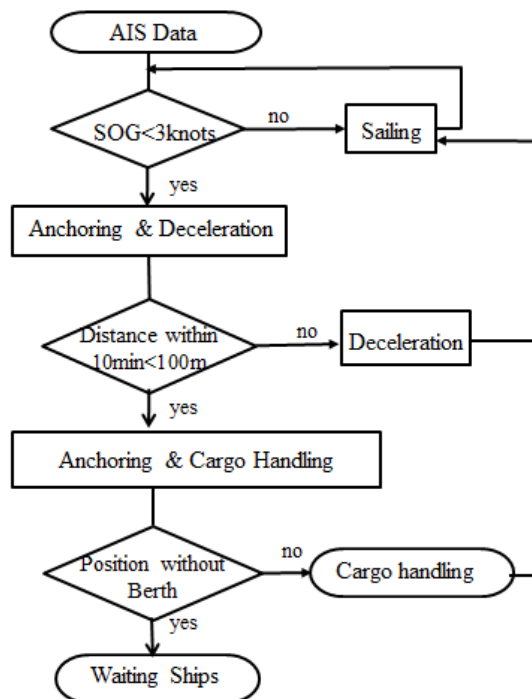

Fig. 3-19 Flowchart of extraction of waiting ship

The locations of waiting ship were extracted during the research period, is shown in Fig. 3-20. This figure shows the positional distribution of the waiting ships in Osaka Bay. The gray areas surrounded by black lines show the limits of the port area. Red and blue triangles indicate the waiting ships. The blue triangles in port areas mean the designated anchorage areas, in which ships can anchor properly. Even so, there are many waiting ships anchoring outside the port, the red triangles show them. These anchorage areas are permitted for special ships carrying dangerous goods. A general cargo ship must pay a demurrage charge for anchoring in one of these areas. Therefore, many ships anchored near the port at the very limit of what is not permissible. This could have a bad influence on sailing ships. Therefore, the following analysis focused on the no permitted ships.
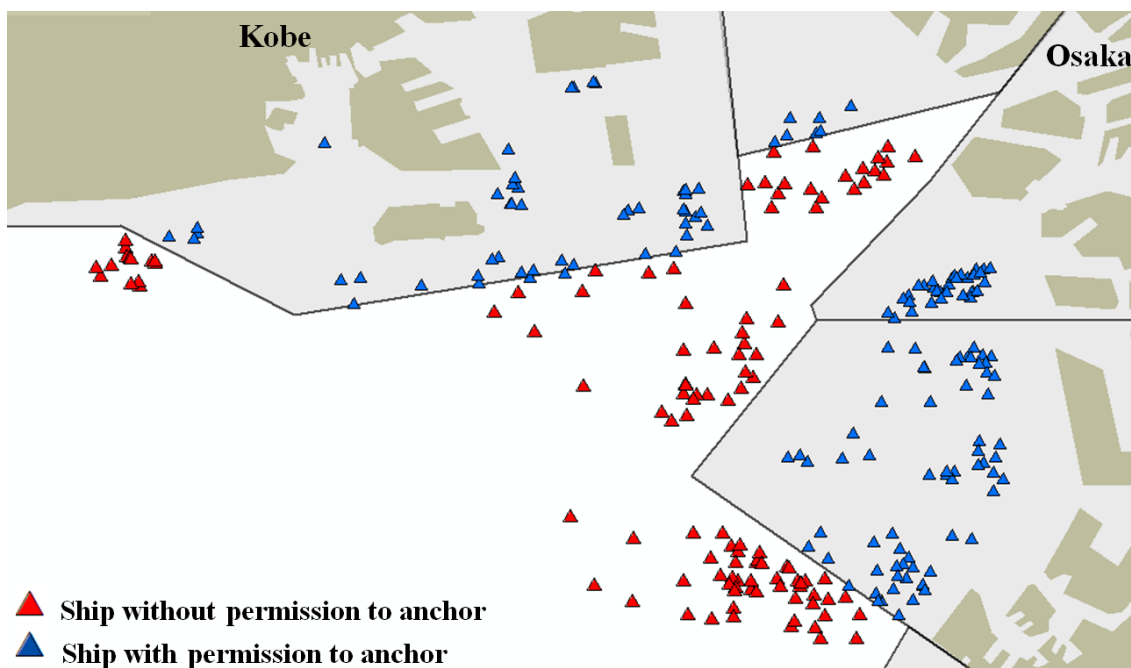

▲ Ship without permission to anchor
▲ Ship with permission to anchor

Fig. 3-20 Locations of waiting ships (March 1- March 7, 2012)

3.3.1 Bad Influence of Anchoring Ships in Maritime Traffic

To put it more concretely, a waiting ship that is anchored for a long waiting period is the same as a large piece of floating wreckage, and is especially at the mercy of the wind and waves. In addition, because there is a high traffic flow around a port, a waiting

ship would affect sailing ships. Here, this study presented how the navigational conditions of a waiting ship influence a sailing ship.

The distance between the anchoring ships and sailing ships was calculated. General speaking, sailing ship makes an evading action when find a ship of end-on or across two nautical miles ahead. Because the waiting ships anchored around the ports where always crowd with many ships, the analysis calculated the distance between waiting ship and sailing ship within one nautical mile. The distance calculation was based on Hubeny's distance formula, which considers the curve of the earth to calculate the distance between two places on a grid [21].

This study obtained the proximity for each sailing ship entering an area within one nautical mile of a waiting ship. Each waiting ship was given a count when a ship entered their area, and the minimum distance between the sailing ship and waiting ship was calculated. In order to represent the relationship of them, this calculation was not made between waiting ships. In the distance analysis, the minimum distances of the sailing ships from each waiting ship were recorded. As an example, the result for a sample ship is given by Fig. 3-21. This sample ship is a large cargo ship, and her length is 225 m. According to the analysis of waiting time, we understood that this ship anchored for about 18 h, and was destined for Osaka. This figure shows the distance results for each sailing ship entering the one nautical mile area around the sample ship. During her waiting time, there were 51 sailing ships that came close to this ship. The vertical axis in the figure shows the number of ships and their ID numbers. The minimum distance was 135 m. A waiting ship that is anchored for a long waiting period is the same as a large piece of floating wreckage because anchoring ship swings, and is especially at the mercy of the wind and waves. Therefore, the swing area of ship is very dangerous. The sample ship swung about 350m. From the figure, we can know that 17 sailing ships entered her swing range. This could have a high risk to cause a collision. According to the distance of swing, it is grasped that the proximity for the sailing ships entering a swing area within 350m of the waiting ships. The dangerous anchoring for waiting ships on March 7, 2012 is shown in Fig. 3-22.
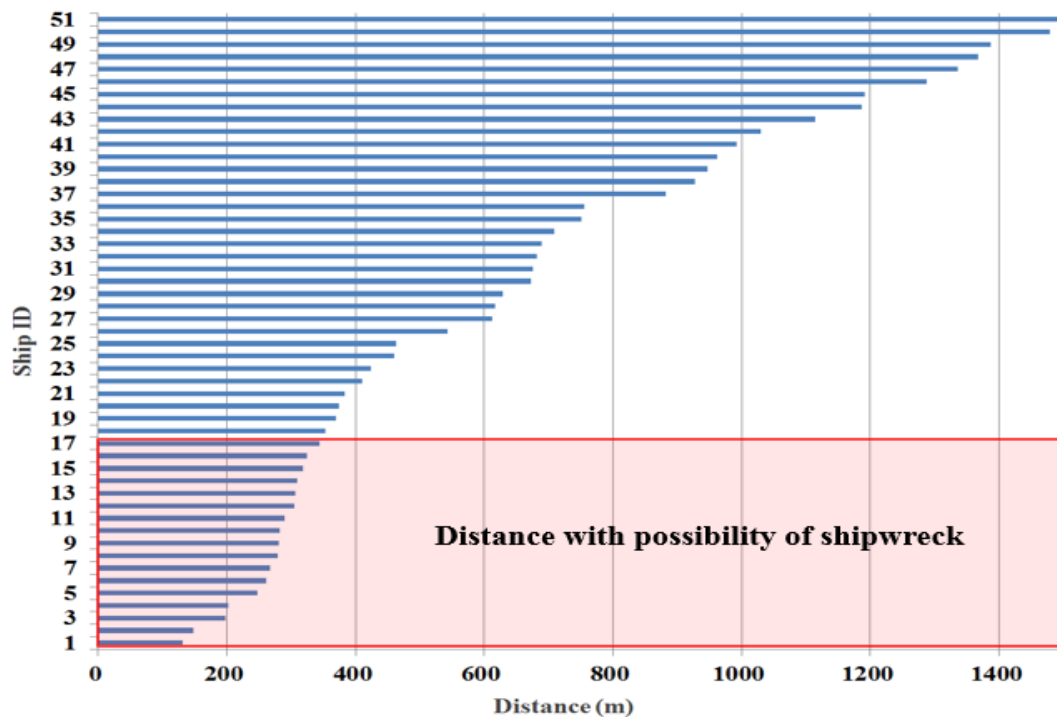
Fig. 3-21 Distance between waiting ship and sailing ships

The triangle markers show the waiting ships, and their count value was labeled. Red triangle markers indicate the objective ship, where ships without permission to anchor. The swing ship and her swing area within 350m are indicated in the bottom left corner of the figure. Of 21 waiting ships without permission, the high count value of the proximity for sailing ships are checked near the entrance of the port.

The ship situation was clarified by tracking the sailing ships during real navigation in order to understand how the waiting ships affect sailing ships. Fig. 2-23 and Fig. 2-24 show the cases of waiting ship without permission to illustrate the influence of a waiting ship on the vessel traffic. She anchored around the Osaka port. The black dots show ships tracked by AIS data, the arrows indicate the ships and their headings, and the speed of ship is labeled. The circle markers indicate the waiting ships within 350m. The blue areas surrounded by black lines show the target of this analysis. The anchor ship A is the sample ship in the example of the last section.
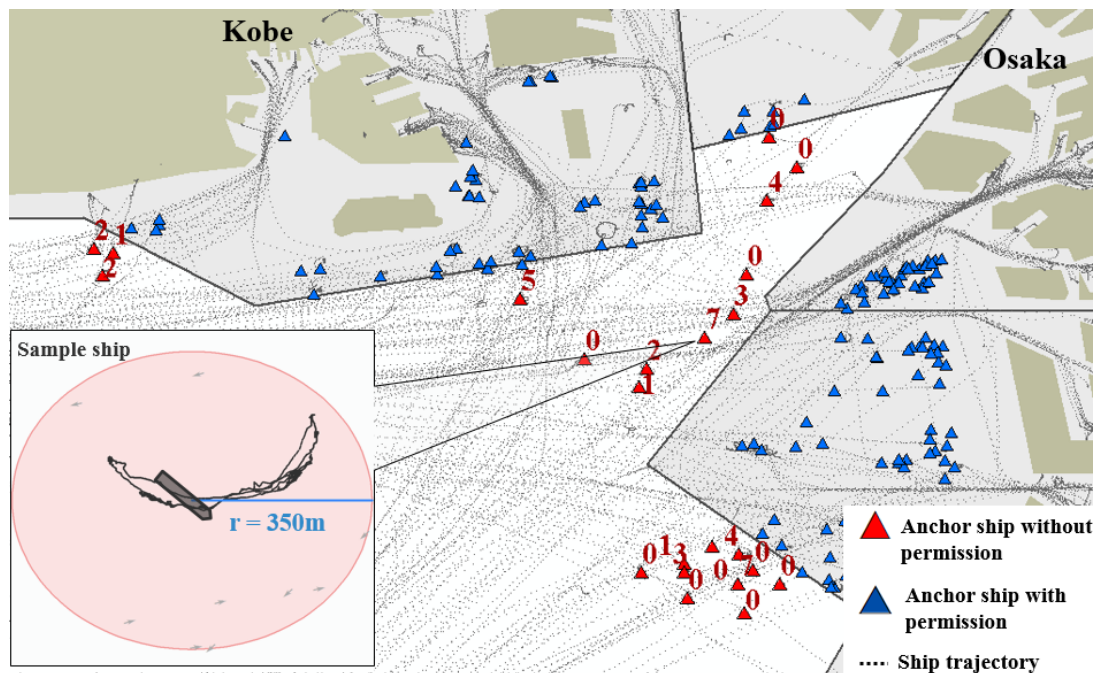
Fig. 3-22 Result of area count on March 7, 2012

In the case of Fig. 3-23, sailing ship A navigated from Akashi Strait and scheduled to enter the Osaka at 8:30. The tracking of ship A at 8:05 is shown in the left side of Fig. 3-23(a). Based on the tracking, we can image that the ship can keep the scheduled course and directly enter the port. Her scheduled course is indicated by an arrow in the figure. However, the ship A was forced to change her course due to the waiting ship. The tracking of ship changed her course is shown in Fig. 3-23(b). We can imagine that if it is not for the waiting ship, ship A can enter the port by proceeding along a straight line. In fact, the ship A took a devious rout to avoid the anchor ship A. The avoiding movement is not efficiency and safety for the traffic. This situation is of particular concern because ship sailed at about 19 knots to catch the arriving time. The sudden change of course is possible to interfere with other ship sailing from behind, like ship B in this case. In addition, many ships enter the port between 7:00 and 8:00, the traffic is congestion around the port. This could produce a ship collision risk.
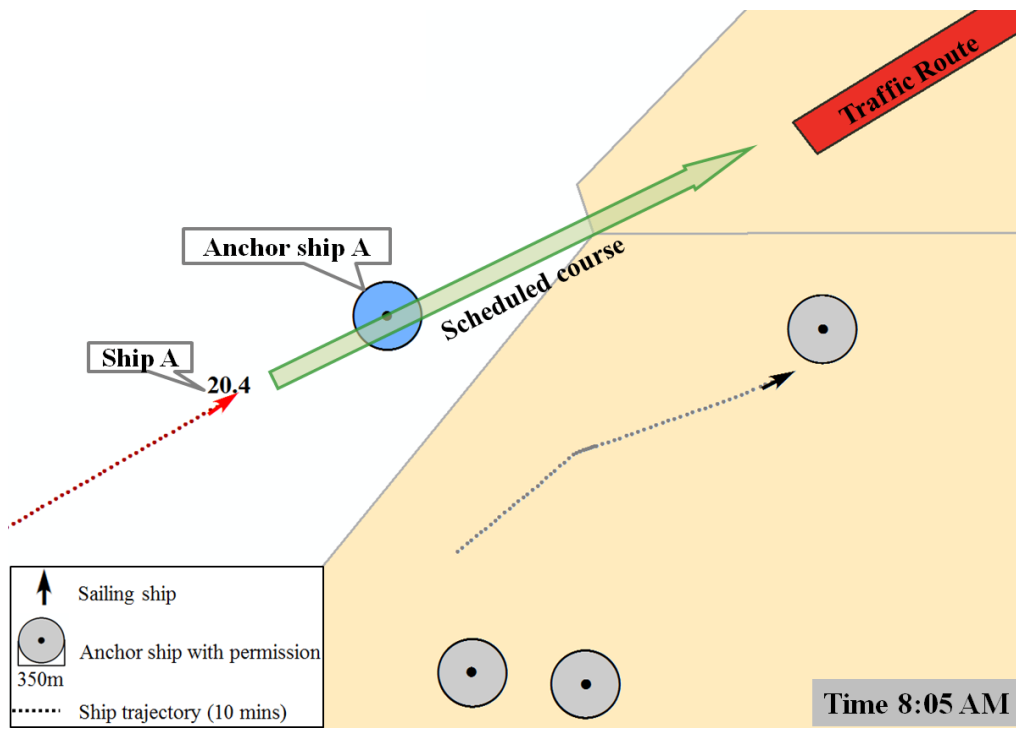
(a)
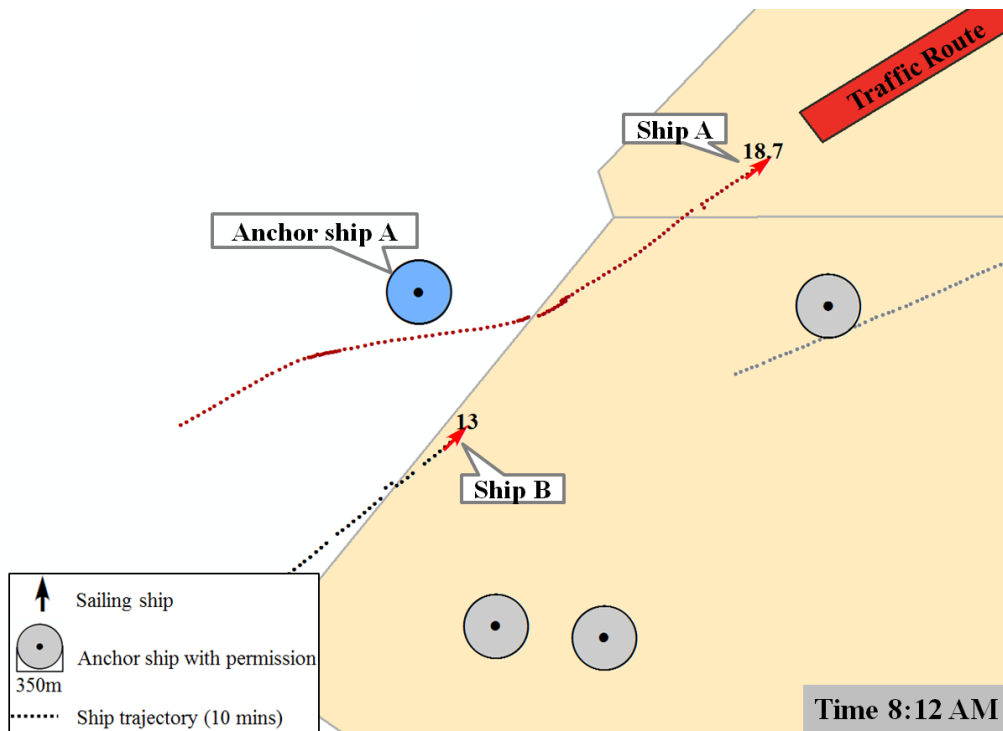
(b)

Fig. 3-23 Navigation obstruction by anchor ship without permission

The case of Fig. 3-24 shows that the sailing ship was disturbed by more than one waiting ship. The tracking of ships at 5:55 is indicated in Fig. 3-24(a). Ship C navigated from Akashi Strait toward the Osaka port, and ship D ended her waiting to enter the Osaka port. At the same time, ship E sailed to the Akashi Strait and directly across from ship C and ship D. From the tracking, we can see that their distance was very close, only about 600m. According to the traffic role, ship C and ship D must take avoidance action to sail right side. Just because the navigational relationship of three ships could give tension to the operators, the situation was more complicated by the waiting ships. Based on the Fig. 3-24(b), we can see that two waiting ships anchored around the entrance of port. Their distance was only about 900m. Due to the waiting ships, ship C had not enough space and distance to avoid, thus she passed between two waiting ships.
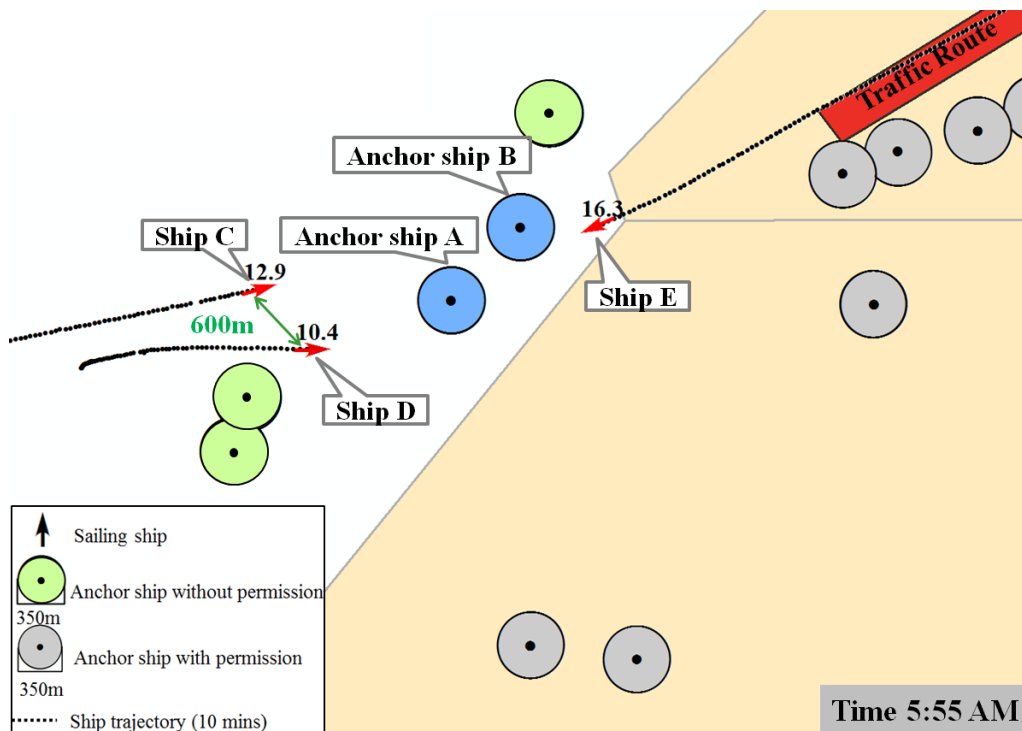
(a)
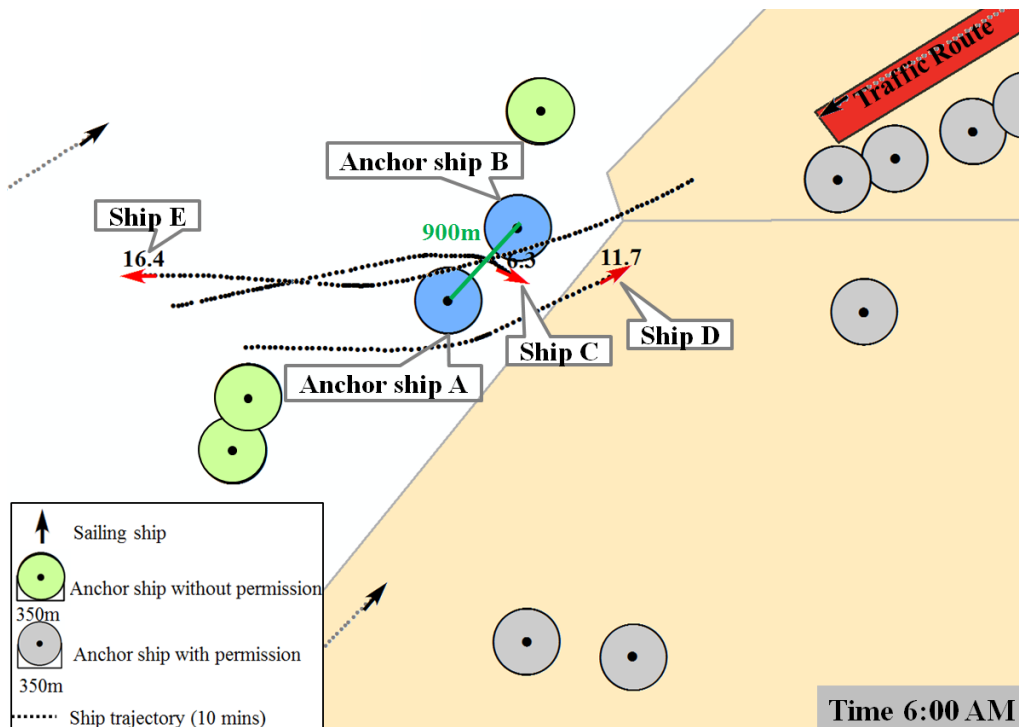
(b)

Fig. 3-24 Risk of maritime accident cause by waiting ships

For this reason, the sailing ship was very close to a waiting ship. Moreover, her speed decreased from 12 knots to 6 knots when she was passed between the two waiting ships. Such this kind of situation is easy to drift when ship sails at the mercy of the wind and waves. Especially, the waiting ships make a dangerous situation for ship operators because the danger is compounded by stress. If there are not the waiting ships, ship C could sail more space, and the three sailing could keep their course to entering the port. Therefore, the crowded waiting ships anchor around the entrance of port is possible to interfere with the sailing ships and other anchoring ship. Based on the above analysis of examples, we found that sailing ships were obstructed by waiting ships, and taking action to avoid them increased the amount of energy consumed.

Ship waiting for berth before entering the ports is an important problem for maritime safety and economy. In this study, the waiting ships were extracted. The positional distribution of the waiting ships was obtained. According to the statistical analysis, the main results for the actual situation of waiting ships are as follows:

53

1. Approximately 25% of all AIS-equipped ships waited in Osaka Bay.

2. It is confirmed that the waiting ships inhibit the sailing ships entering the ports.

3. Due to the waiting ships anchored around the entrance of ports, most sailing ships navigated close to the waiting ships.

4. In real navigation examples, it was found that the waiting ships interfered with a sailing ship's navigation, and the sailing ship changed her course and took a devious route in order to avoid the waiting ships.

5. The waiting ships have a negative influence on maritime traffic, in relation to both safety and the economy. It is important to reduce the quantity and laytime of waiting ships.

6. According to this information, the operators can understand the situation of anchoring ships before the voyage. This information is expected to prevent the ship accidents in the coastal areas.

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CHAPTER 4 　Analysis of Actual Ship Behaviors for Promoting Efficient Navigation through Practical Use of AIS Data

The development of a world economy has driven a surge in the demand for transportation, particularly maritime transport. Therefore, there has been an increase in shipping as the cheapest means of transport, which has produced congestion in busy ports. Because ships cannot sail smoothly into a port, they are commonly crowded together offshore [1]. This causes numerous maritime accidents, including collisions and grounding offshore, especially when ships anchor at a stormy weather. The damage of these accidents has caused significant environmental pollution and economical loss. Therefore, it is important to solve the problem of waiting ships for maritime transportation. In order to ease the situation of ship waiting and achieve the on-time navigation, it is necessary to understand the navigation situation for the entire voyage.

In order to ensure ship navigation safety in the coastal, it is important to ease the ship congestion in coastal areas and reduce the waiting ships. This study understands the actual ship behavior for improving transport efficiency, to achieve efficient ship navigation. Especially, this study has focused on the ships waiting berth before entering the ports. If the waiting time can be shortened, efficient ship navigation can be realized. For instance, if the ships devote the original waiting time to sailing instead, there is a reduction in fuel cost due to the reduction in waiting time. In order to achieve on-time navigation, it is necessary to understand the navigation behavior for the entire voyage of the ship at sea. Therefore, this study analyzed the ship navigation for the entire ship voyage in Seto Inland Sea. Especially, the navigation conditions of container ships were understood in detail. Moreover, the behaviors of a ferry that had no waiting time in the Seto Inland Sea were analyzed, in order to achieve non-waiting navigation.

4.1 Analysis of Actual Behavior of Waiting Ships

4.1.1 Behavior of Entering the Ports based on the Waiting Ships

The concern over ship demurrage has been growing for the past few years. In response to the growth in demand, many ports are planning expansions. In addition, several studies have been conducted on increasing the utilization rate of a port to reduce the waiting time. However, most of these studies have been concerned with improving the port management and have been conducted using economic models and simulations [2]. Little attention has been given to ship navigation. Okuyama, 1975 has developed a simulation program to extract the waiting ships. Moreover, Statistical methods have also been applied to AIS data in a study on waiting ships [3]. However, that study did not mention the behaviors of navigational ships. To solve the maritime traffic problem of waiting ships, it is necessary to grasp the stationary and dynamic conditions of ships. Makino (2012) focused on an analysis of ship behavior during a disaster using AIS data [4]. That study referred to the importance of understanding the situation of anchored ships. Therefore, the activities of waiting ships will be grasped in detail if their AIS data can be obtained. Understanding the situation of a waiting ship is the key to solving the ship congestion problem.

In the above chapter, the waiting ships were successfully extracted. At the same time, waiting times were calculated and recorded. The transmission interval of AIS data differs depending on the navigational status. The data for a sailing ship are transmitted at 2–10-s intervals based on the speed of the ship, and the data for an anchored ship are transmitted at 3-min intervals. There is a possibility that the data will be interrupted if the reception conditions are poor. Therefore, this study interpolated the position data on a per-second basis using a linear interpolation method. By calculating the number of ships over time, the start and end times of the waiting activity were determined.

Based on the statistics for the extracted waiting ships, it is found that a total of 902 ships passed through this area, with 228 ships of them, or approximately 25% of the total, having to wait for a berth before entering the port. A follow up survey of waiting

ships conducted using MMSI number, the number of 269 sailings had to wait. The bar graph in Fig. 4-1 shows the numbers of all passing ships, entering ships and waiting ships. As can be seen from this graph, the numbers of entering ships and waiting ships were the largest on March 7 (Wed.), with a slightly smaller number of entering ships on March 4 (Sun.). However, the number of waiting ships was greater on Sunday compared with Saturday. It could be inferred that this was because most ships arrived at Osaka Bay on Sunday when scheduled to enter port on Monday. The average number of waiting ships during the investigation was about 31% of the total number entering.

Fig. 4-2 shows a line graph displaying the number of waiting ships for each day of this week. These results confirmed that the flow of waiting ships sharply decreased from 6:00, and the number of waiting ships was on the rise again from 14:00. We know that most ships ended their waiting to start entering the port from 6:00, because most docks in Kobe and Osaka are opened at 8:00 or 9:00. The activity of ships entering the port caused a heavy traffic flow. We also presumed that the waiting ships were congested at midnight, and most ships anchored offshore overnight. It is explained that most ships arrived early and then passed the night waiting for a berth.
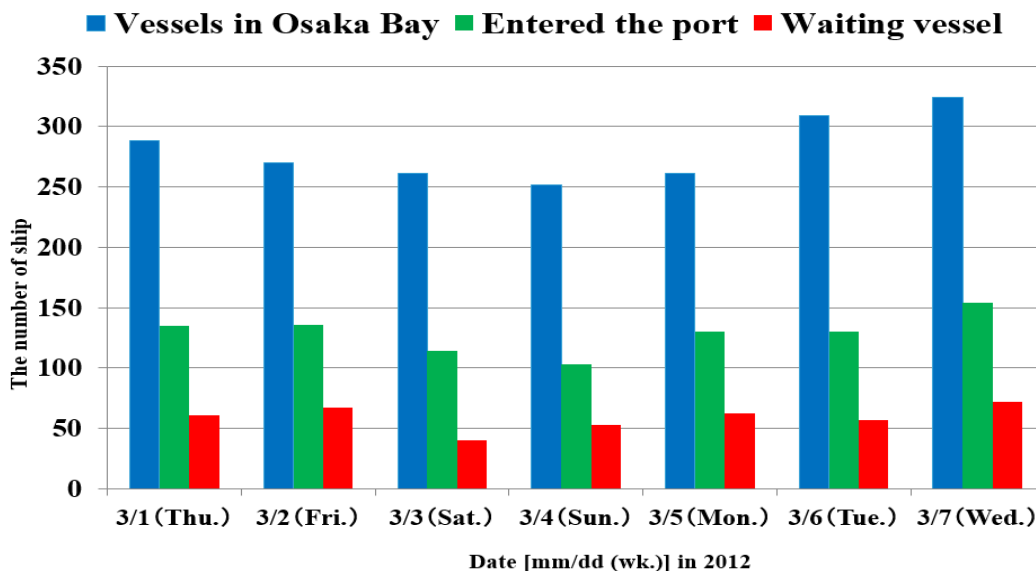

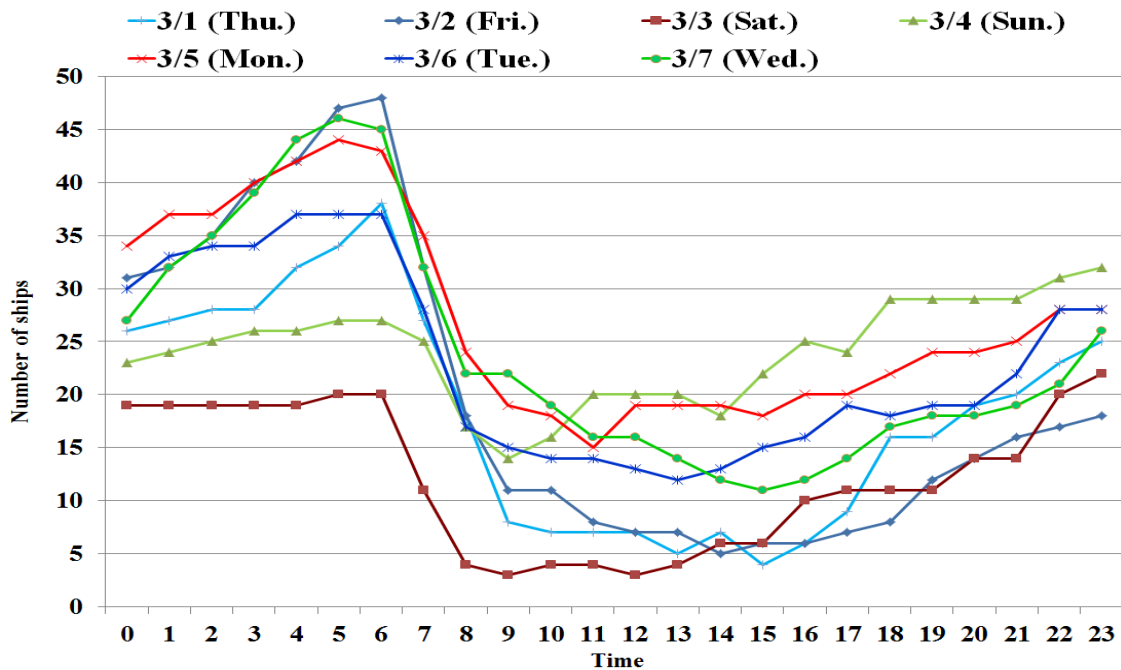Fig. 4-1 Numbers of ships entering and waiting to enter Osaka Bay

Fig. 4-2 Trend for number of waiting ships

Fig. 4-3 shows the port areas and coastal industrial zones in Osaka Bay. The orange color represents the industrial zones in the coastal area. Green parts in the figure indication the port areas. A leading major industrial area exists in this area in Japan, such as the Hanshin industrial area, Sakai Senboku coastal industrial zone, and Kansai Airport. Especially, heavy industries, such as petrochemical industries, are concentrated and located in the eastern part of Osaka Bay, and these areas are large. If a fire or explosion occurs, it will rapidly spread in the neighboring industrial area and adjoining residential streets and it will be may induce a large-scale disaster. Furthermore, two or more international strategy ports exist in Osaka Bay, and many large-sized vessels are always cruising. In addition, as many fisheries exist, the ocean space is always congested by a variety of ships.
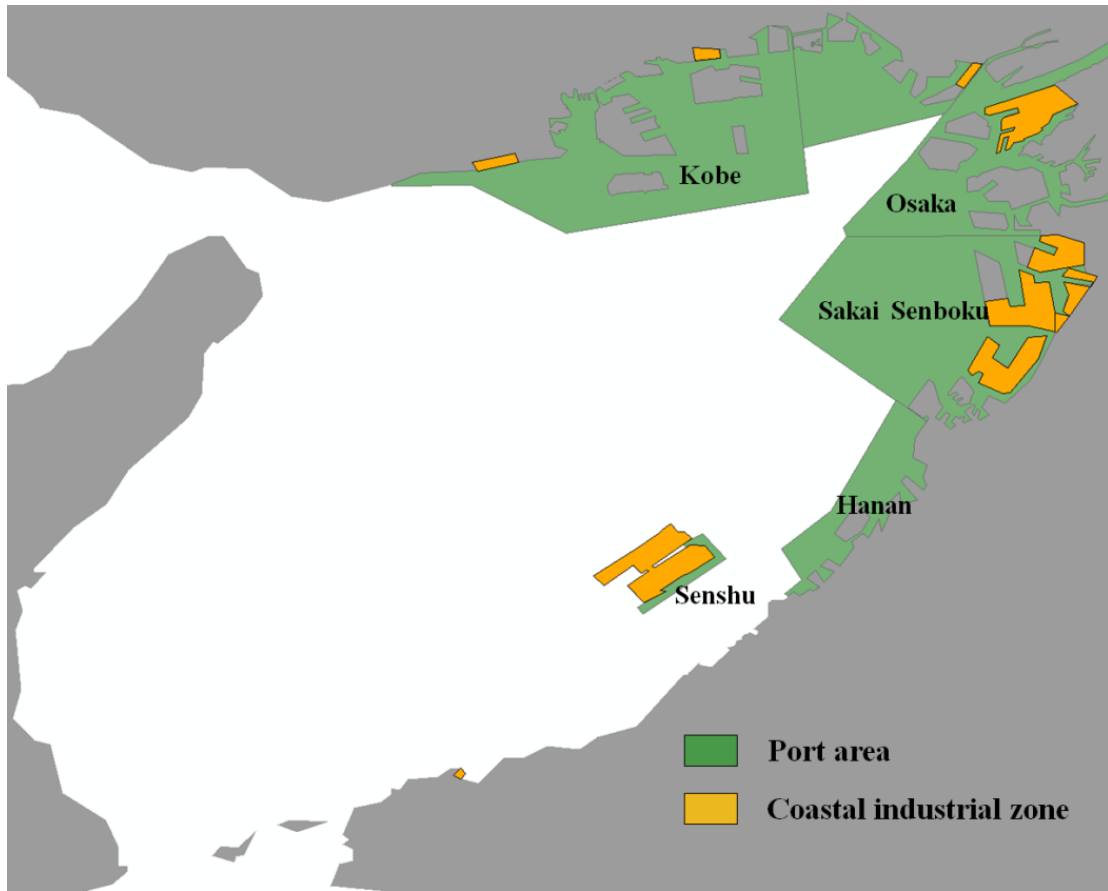
Fig. 4-3 Port areas and coastal industrial zones in Osaka Bay

Table 4-1 shows the percentage of waiting ships in the ports of Osaka Bay. 42% of the all waiting ship entered the Sakai Senboku, and the most of them was confirmed the tanker ships. Subsequently, the other ports were Kobe (27%), Osaka (24%), the most waiting ships belong with these two ports were the type of cargo ships.

Table 4-1 Percentage of waiting ships in the ports

Ports	Percentage (%)
Sakai Senboku	42
Kobe	27
Osaka	24

Amagasaki-Nishinomiya- Ashiya	4
Senshu	2
Hanan	1

4.1.2 Analysis of Waiting Time

The study analyzed the actual situation of waiting ships by the application of AIS data. This made it possible to grasp the movement of the ships efficiently and correctly. Using this method to determine the waiting ships overcame the various weaknesses of using observation in an investigation. It could be used to investigate the waiting ships over a long period. At the same time, an analysis of the AIS data made it possible to understand the behaviors of the waiting ships in detail. However, this study found that the number of waiting ships gradually increased from the evening to the next morning when the port opened, which indicated that most ships arrive early and anchor offshore to wait for a berth to open. This phenomenon was examined, and it was found that it leads to ship congestion. Therefore, it is not enough to simply expand the use of ports to solve the problem of waiting ships. Understanding the actual situation of waiting ships is the key to solving the ship congestion problem.

According to analyze the AIS data with MMSI number and type of ship, the time of individual waiting ship was obtained. There were two types of waiting ships: cargo ships and tankers. The waiting times (H) according to the type of ship are listed in Table 4-2. There were 149 cargo ships and 120 tanker ships waiting for berths during the investigation. Based on the results, it is confirmed that about one-third of the cargo ships entered the port within 6 h. However, most of the other cargo ships had to wait half a day or longer. During the investigation, the longest waiting time for a cargo ship was 89 h, but we also found that some ships entered the port without waiting. Compared with the cargo ships, few tankers had a short waiting time. Most had to anchor for more than 2 days.

Table 4-2 Waiting time of cargo ships and tanker in Osaka Bay

Waiting Time (H) (h)	Type of ships (number of ships)	
	Cargo	Tanker
$0 < H \leq 6$	53	31
$6 < H \leq 12$	32	35
$12 < H \leq 24$	44	43
$24 < H \leq 48$	13	10
$H \geq 48$	7	1

Most container ships navigate the regular lines and have an expected time of arriving at the berth. However, based on the analysis of navigation for the entire ship voyage, it was found that the container ships anchored offshore before entering the ports. The waiting activity of container ships was analyzed quantitatively. Based on the analysis, the activity characteristic of container ships was known. A follow-up survey of waiting activity confirmed that there were 26 container ships waiting for berths during the investigation. These waiting ships anchored around the ports. It confirmed that majority of container ships entered the port within 6 h. During the investigation, the longest waiting time for a container ship was 46 h. This was a large ship with a length of approximately 336 m. Such a large ship that is anchored for a long period is like a large piece of floating wreckage with swing. It has an adverse effect on the traffic and decreases efficiency. Fig. 4-4 shows a bar graph displaying the number of waiting container ships over time based on capacity. From this graph, the start and end times of the waiting activity of container ships were determined. These results confirmed that the flow of waiting ships sharply decreased from 7:00, and there were a large number of waiting ships between 0:00 to 6:00. Majority of ships anchored offshore overnight; it was explained that most ships arrived early and then passed the night waiting for a berth. Moreover, a large proportion of container ships were always anchored.
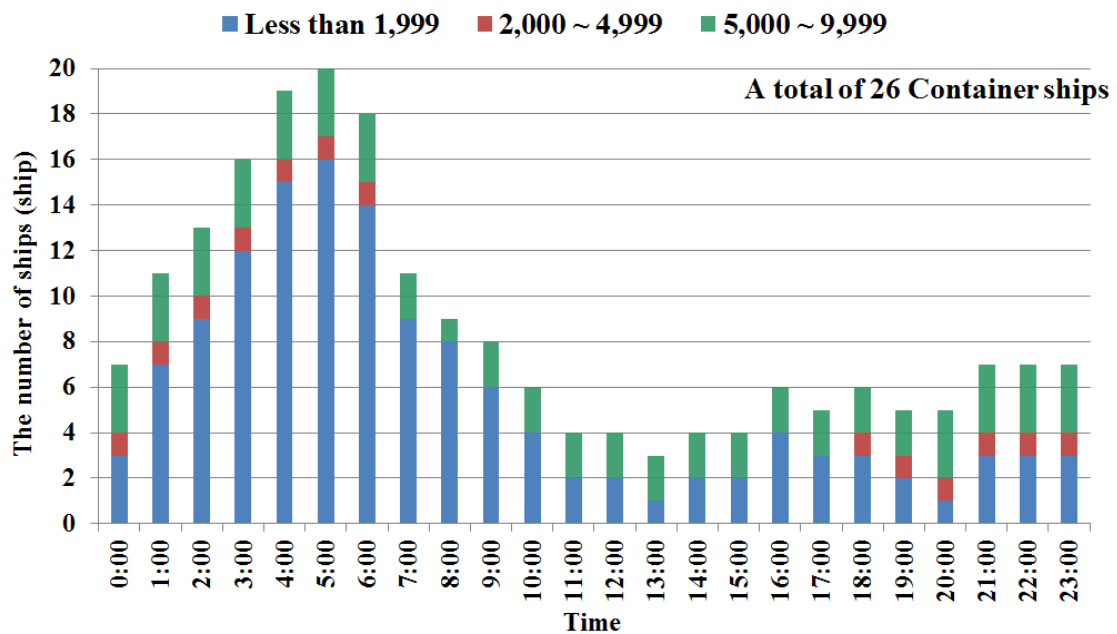
Fig. 4-4 The number of waiting ships over time based on capacity

In the section, according to the behavior of waiting ships, the waiting situation of ports in Osaka Bay and waiting time of ships. It is found that the number of waiting ships gradually increased from the evening to the next morning when the port opened, which indicated that most ships arrive early and anchor offshore to wait for a berth to open. The number of waiting ships and their waiting times were determined according to the day and time period during the investigation. This study obtained the waiting ships that have never been understood so far. Using this information, port management side can understand the situation of waiting ships in detail. It can contribute to the safety and efficiency of port operations, such as the conservation of route and the enactment of the anchoring areas for the safety and efficiency for the port operating.

4.2 Analysis of Navigation for Entire Ship Voyage in Seto Inland Sea

These waiting ships are the one of reasons caused the ship congestion in coastal areas and ship accident. In order to ease the ship congestion around the ports, and reduce the waiting ships, this study analyzed the ship navigation for an entire ship

voyage. Data on the ships that sailed between Kanmon and Osaka were obtained from the analysis. In previous years, studies on maritime traffic were performed by dividing the Seto Inland Sea into small areas [5]. There is no study that has tried to analyze the entire ocean area of the Seto Inland Sea. Therefore, the navigation for an entire ship voyage has never before been understood. In order to improve maritime safety and efficiency, and ensure an eco-friendly operation, it is necessary to understand the navigation behavior for the entire voyage.

4.2.1 Ship Traffic of Entire Ship Voyage in Seto Inland Sea

Fig. 4-5 shows the The trajectories of ships based on the position information included in the AIS data. The red dots indicate the exact positions of the ships. The gate lines (A, B, C and D line) were set based on the position of the straits, as shown in the figure. Kanmon and Osaka are entrances located on the east and west sides of the Seto Inland Sea, respectively. In order to analyze the navigation for an entire voyage across the Seto Inland Sea, the target was defined as a ship sailing between Kanmon Strait and Akashi Strait, without stopping at any of the ports when passing through the Seto Inland Sea.
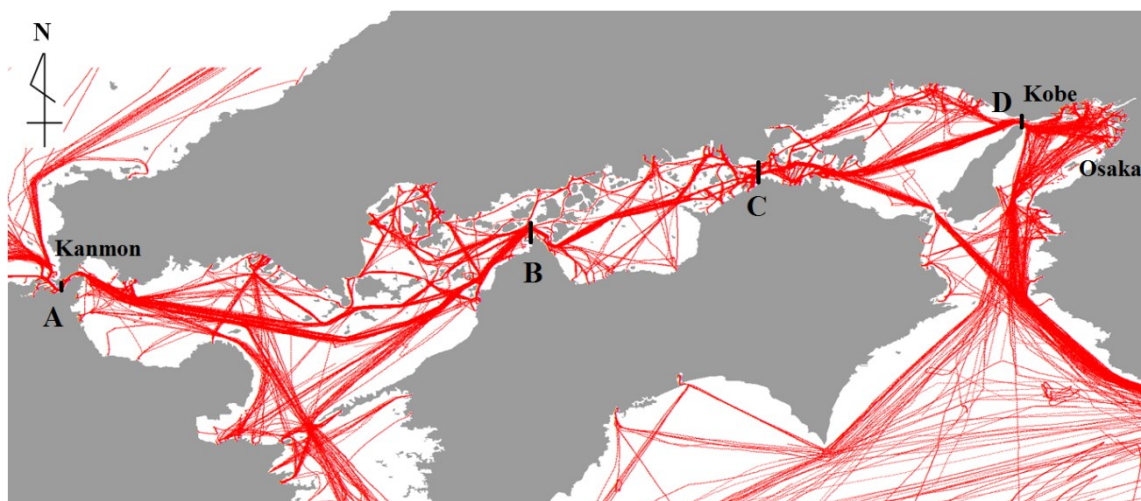

Fig. 4-5 Ship trajectories in Seto Inland Sea based on AIS data

The target ships were extracted from the AIS data. The flowchart for this extraction is shown in Fig. 4-6. If the position of a ship was included in the Kanmon Strait area and Akashi Strait area, and speed was 4konts or more, the program has judged the ship to pass through them. Then, the target ship was obtained by combining the information about the ship's destination and position.

Table 4-3 lists the results. According to the statistics for the extracted target ships with MMSI numbers, a total of 106 ships passed through the entire Seto Inland Sea during the investigation, and it was confirmed that 91 of all these ships were cargo ships, 11 ships were tankers, and 6 ships were passenger liners. The tracking of these target ships is shown in Fig. 4-7, where the red dots indicate the ship trajectories.
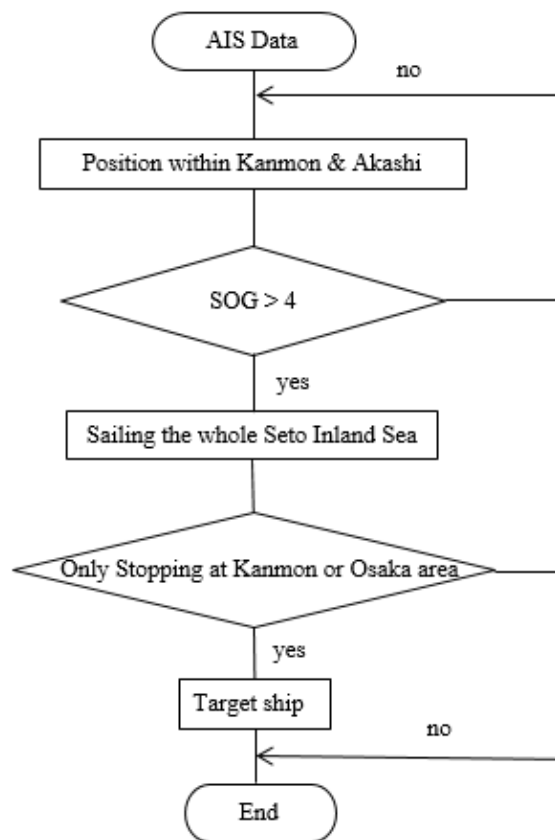
Fig. 4-6 Flowchart of extraction of target ship

Table 4-3 The number of ships navigation for entire voyage in Seto Inland Sea

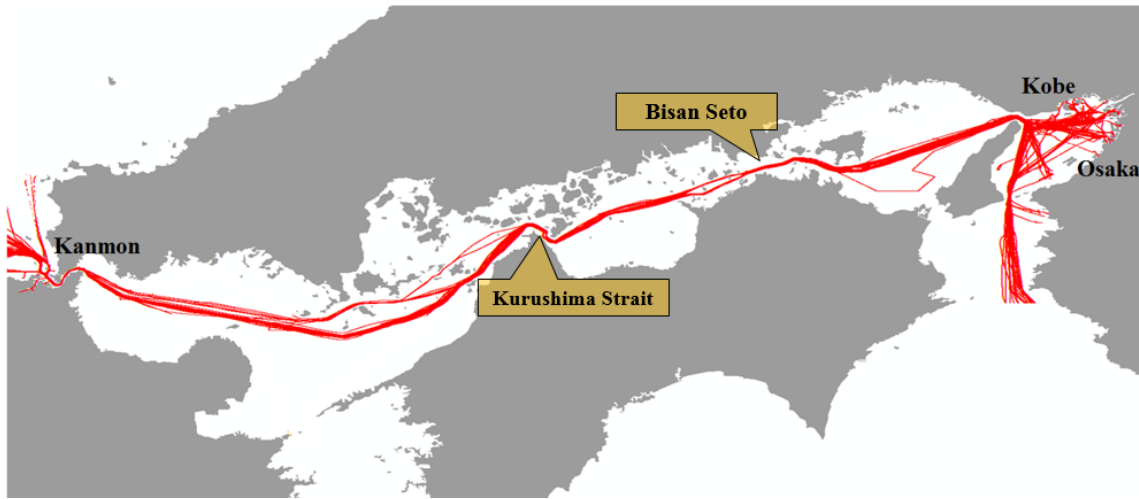| Type of ships	The number of ships
Dry cargo	91
Tanker ship	11
Passenger ship	6
Total	106

Fig. 4-7 Tracking of vessels between Kanmon Strait and Osaka Bay

Fig. 4-8 to Fig. 4-9 show the number and type of ships passing the straits based the gate lines on March 1, 2012. The passing ships sailed between the Kanmon and Osaka directly. Fig. 4-8 shows the ship traffic of ship navigating the entire voyage in Kanmon Kaikyo. It is confirmed that ship congestion in the strait from 11:00 to 15:00, and from 19:00 to 22:00, in particular at 13:00 was the peak. According to the type of ship, it is checked that the cargo ships passed the Kanmon Kaikyo in all time, the tanker ships passed only during the day from 8:00 to 15:00. Moreover, the passenger only passed through after 19:00. The passenger ships carry the many lives that pass the strait during the nighttime. However, the ship traffic is heavy during the time. As the Kanmonn Strait is narrow and has the strong current, it is necessary to reconsider the navigation plan.

Fig. 4-9 shows the number of ships passing through the Kurushima Kaiky. From the distribution of time, it is found that the sailing ships sailing in Seto Inland Sea with nonstop can not be checked during 11:00 to 16:00. Instead, there were many ships crowded in night. Due to the strong current, the ships are very difficult to navigate in the strait. If many ships pass through in the time, it is possible to lead the ship accidents.

The ship traffic in Bisan Seto of nonstop ships sailing the Seto Inland Sea is shown
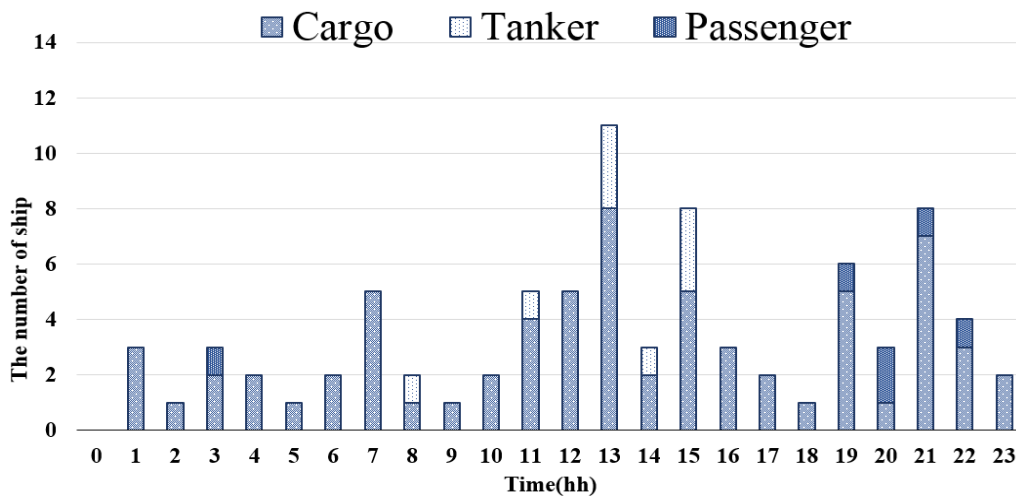
Fig. 4-8 The number and categories of ships in Kanmon Kaikyo
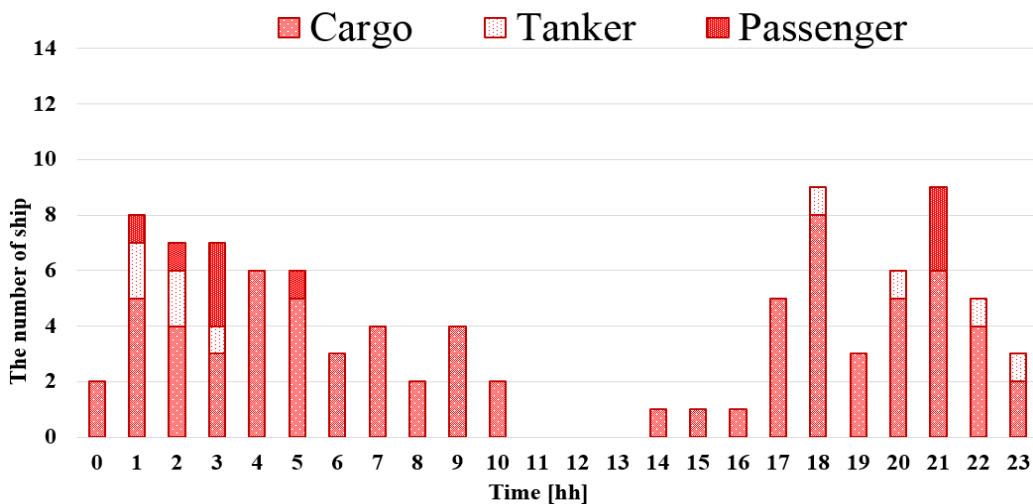
Fig. 4-9 The number and categories of ships in Kurushima Kaikyo

in Fig. 4-10. It is understood that a larger number of ships sailed the Bisan Seto from midnight through morning, and few ships passed through between 15:00 and 18:00.

Fig. 4-11 indicates that the number of ship passing through the Akashi Strait. These ships passed the strait toward entering the ports or passing through the Tomogashima Channel. in order to catch the time of entering the ports, many ships passed the Akashi Strait during 5:00 to 7:00. This situation is conjectured that the time of ship passing these straits is to match the working time of ports.
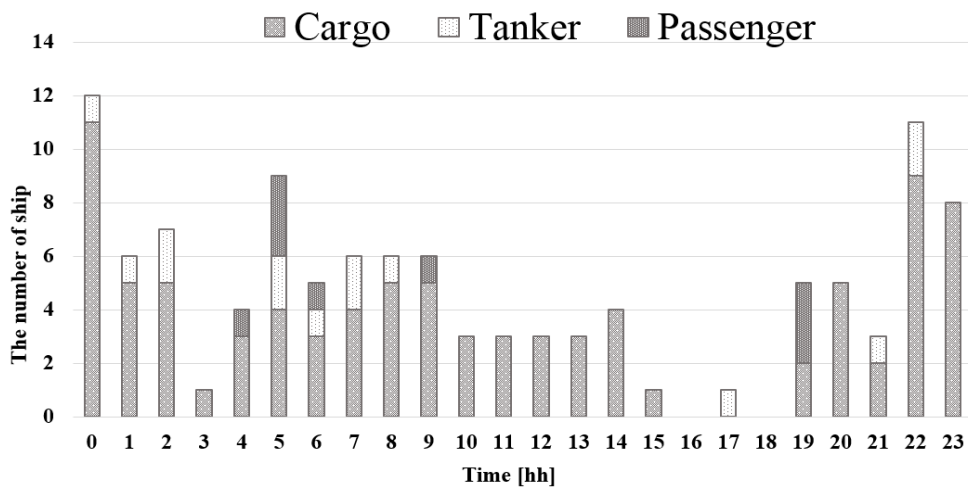
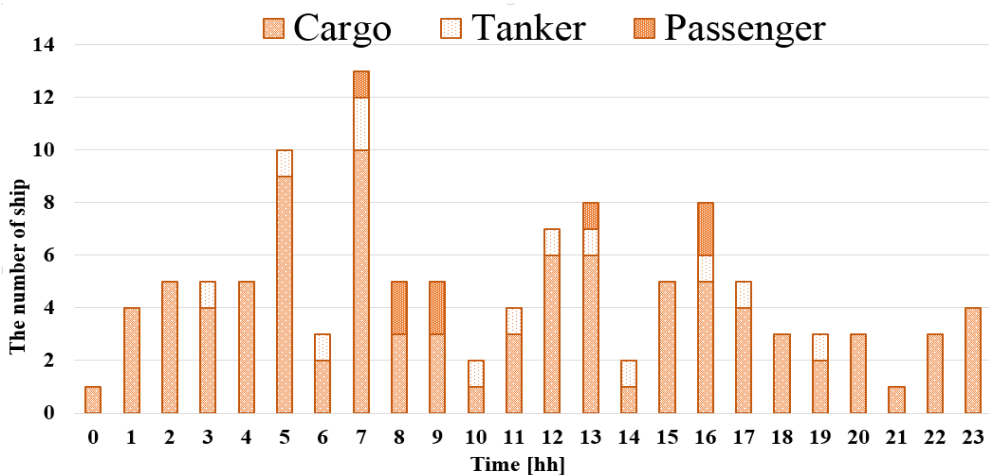Fig. 4-10 The number and categories of ships in Bisan Seto

Fig. 4-11 The number and categories of ships in Akashi Strait

4.2.2 Actual Navigation Situation of Container Ship in Seto Inland Sea

Container shipping is the principal means of international maritime transportation. The majority are regular liner shipping services. The container ships support the economy and logistics, visiting designated ports on a regular schedule. Thus, when a container ship arrives at the port and delivers the containers very late, the operators have to cope with high extra costs due to delays. Moreover, the container ship is easy to affect by the winds and currents, it is different to operate. Consequently, the operating of many container ships is to arrive at their destination earlier and anchor offshore waiting for berth. This often results to port congestion. If the situation of ships anchoring offshore can be mitigated, ship congestion around ports will be resolved, and the waiting time can be used to reduce the navigation speed during their voyage. As the result, the cost fuel will be reduced. Moreover, most ships anchor offshore without stopping their engines. Thus, the mitigation of anchoring ships will also reduce the hazardous substances discharged.

Researches on the efficiency of container ships have always focused on economic efficiency and energy reduction. To address the problem, several studies have been made on optimized routing, port operation, and so on. For instance, Lin Y. [6] and Kobayashi E. [7] have carried out optimization of ship routing to increase the operating efficiency based on weather influence. In the studies of port operation, Avriel M. [8] has focused on the stowage plan for containers, and Zhen L. has investigated the concept of yard congestion to increase the port operation efficiency. Since ship anchoring is influenced by multiple reasons [9], it is necessary to adopt an integrated approach for the investigation and analysis of ship operation. Previous researches have carried out the analysis of ship navigation and port operation separately. However, they have not really improved the operation efficiency. In this study, the analysis combined the ship navigation and port operation, and was focused on the navigation for an entire ship voyage to understand the real activity of container ships using AIS data. The purpose of this study is to improve the ship navigation efficiency with on-time arrival. Improving the efficiency of container ships in this ocean area is crucial to the stabilization and development of the Asian economy. The results can contribute to the development of a

smoother maritime transportation.

The container ship targets in this study were periodical container service. Unfortunately, the information of container ships do not exist in AIS data. Therefore, we used AIS data and an original list of container ship based on the International Transportation Handbook 2013 (Ocean Commerce Limited, 2013) to extract the container ships. This handbook collects the international transport and periodical service information. The container ship was obtained based on the IMO number included in the databases. As a result of the extraction, we obtained 197 container ships based on the MMSI numbers, and confirmed that 7% of all passing ships in the area were container ships. Due to the combination of databases, the information of container ships was obtained in detail, including the ship operators, size, and loading capacity of the container ship. Table 4-4 shows the investigation result of the number and percentage of container ships according to the operators' region.

Table 4-4 Percentage of container ships by operators

Operators' region	Percentage (%)	The number of ship (ships)
China	40	78
Japan	19	37
South Korea	17	33
Taiwan	13	25
Denmark	5	10
Hong Kong	1	3
Others	5	11

This study verified that majority of the operators belonged to Asian countries, particularly China and South Korea. The total percentage of the contribution to traffic from these two countries exceeds 50% of all container ships. China has the largest

number of container ships in the study area.

The loading capacity of container ships is typically described in twenty-foot equivalent units (TEUs), which is a unit of the cargo capacity of a standard container. Table 4-5 shows the number of container ships based on TEU. The figures are based on maximum TEU.

Table 4-5 Container ships based on capacity

Cargo capacity (TEUs)	The number of ships (ship)
Less than 999	107
1,000–1,999	45
2,000–2,999	13
3,000–3,999	1
4,000–4,999	16
5,000–5,999	5
6,000–6,999	5
7,000–7,999	1
8,000–8,999	3
9,000–9,999	1
Total	197

From this investigation, it was verified that the majority of ships were within the size of 999 TEU. Container ships in this range have overall lengths between 79 m and 150 m. A total of 107 ships were within this range. During the investigation, the largest size of container ship was 9,012 TEU, and the overall length was 338 m.

This study analyzed the real activity of container ships based on tracking. Fig. 4-12 shows the trajectories of all container ships in the research area during the investigation.

The trajectories are shown by blue dots and obtained from the GIS based on the ship's position.

Fig. 4-13 to Fig. 4-15 show the trajectories of container based on the TEU during the research period (March 1- March 7, 2012). Red dots present the trajectories of the TEU within the range of less than 1,999, 2,000–4,999, and 5,000–9,999, respectively.
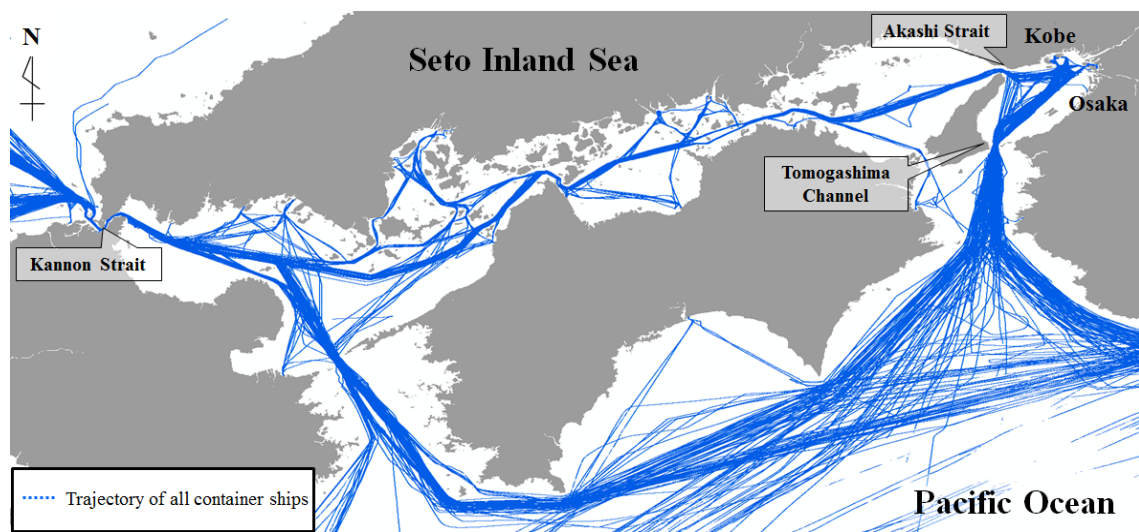

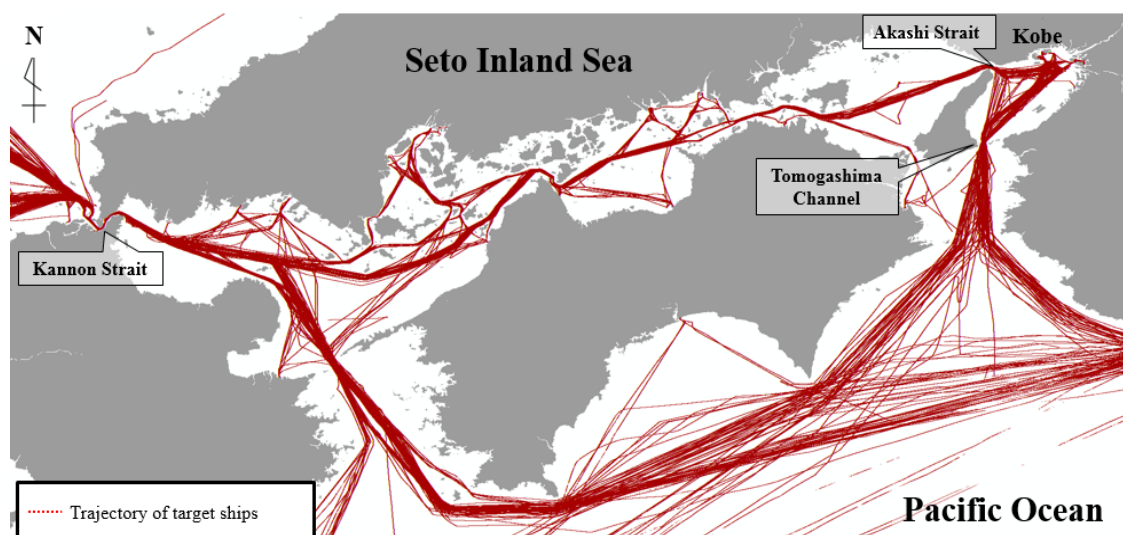Fig. 4-12 Trajectory of all container ships

Fig. 4-13   Trajectory of TEU within less than 1,999 (152 ships)

From the trajectories in the range of less than 1,999 TEU, it can be seen that there were two routes used to navigate between Kanmon Strait and Kobe and Osaka ports: the Seto Inland Sea route and Pacific Ocean route. There were 152 ships within the said range. It was found that approximately 45% of all ships in this range navigated between Kanmon and Osaka passing through the inland sea, and approximately 7% of all ships navigated in open sea passing between Kanmon and Osaka. Ships have overall lengths of less than 200 m, and the overall length of 198 m was the longest ship in this range that sailed both the inland sea and open sea.
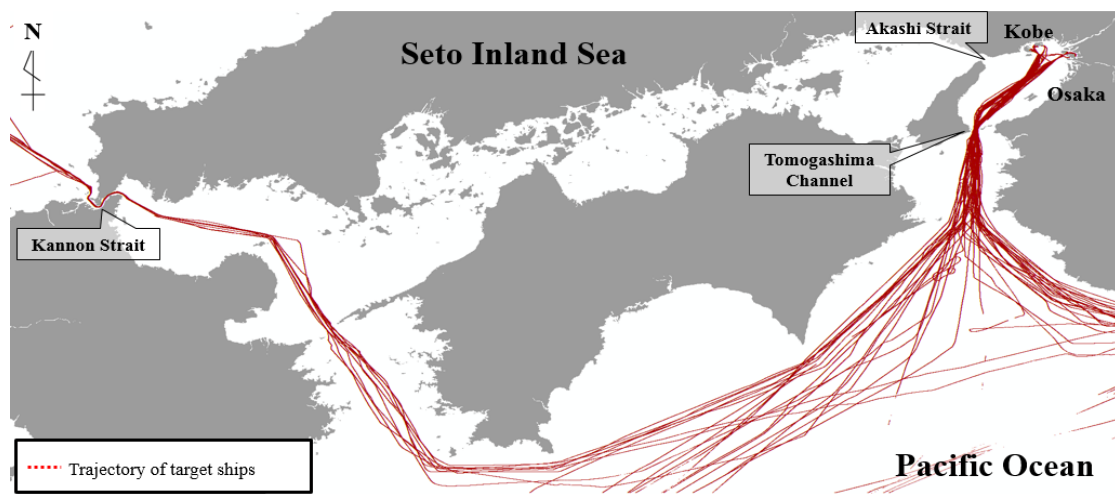
Fig. 4-14   Trajectory of TEU within 2,000–4,999 (30 ships)
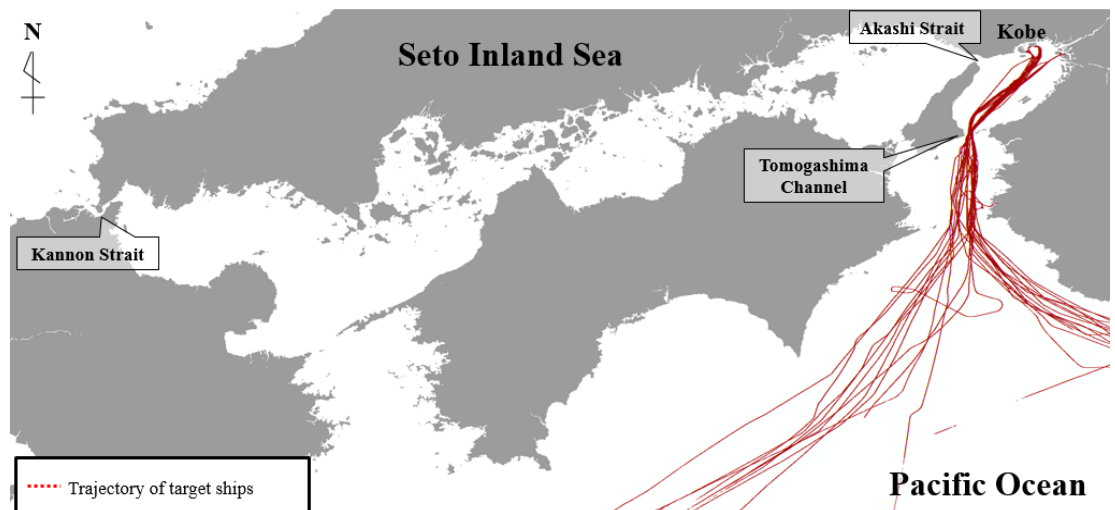
Fig. 4-15   Trajectory of TEU within 5,000–9,999 (15 ships)

Ships with a TEU in the range of 2,000–4,999 navigated only in open sea between Kanmon and Tomogashima Strait. A total of 30 ships were in this range. This study confirmed that container ships over 2,000 TEU are large container ships that operate at the outward passage because the length of ship is approximately 200 m, and it is difficult to navigate the narrow water in the inland sea with this length.

According to the trajectories of container ships exceeding 5,000 TEU, the container ships departed and arrived Kobe and Osaka ports only by sailing the open sea and passing through the Tomogashima Strait. It was confirmed that there were 15 ships in this range, and their overall length was approximately 300 m or more. These ships navigate the inland sea by traffic regulations, and the risk is high.

This study analyzed an entire ship voyage of the container ships, and obtained the navigation including ship navigating the route, anchoring offshore for waiting the berth and cargo handling. This study analyzed the detailed ship activity for an entire voyage in the research area, which can help improve the ship navigation efficiency to the optimum. All container ships in the investigation were analyzed. Here, the analysis results were explained by a sample ship A navigating in Seto Inland Sea route. Table 4-6 lists the principal characteristics and navigation information of the sample vessel.

Table 4-6 Principle sample ship A characteristics

Item	Characteristics of sample ship A
Route	Seto Inland Sea
Ship length (m)	148
Max. TEU capacity	1,118
Navigation distance (n.m.)	252
Navigation time (h)	24

The sample ships A are container ships. The ship has equal lengths and TEUs, making their maneuverability identical. This study used the identical ships transiting the

east-west route. The analysis of the entire ship voyage used speed and sailing time.

Fig. 4- 16 shows the trajectories with speed distribution and changes in ship speed. The higher illustration in each figure shows the trajectory and speed distribution of the ship. Low and high speeds were coded by blue and red. The lower illustration in each figure shows the transition of ship speed when sailing. This ship passed through the Kanmon Strait at 8:00 on March 5 and arrived at the Port of Kobe at 8:00 on March 6, taking approximately 24 h to navigate 252 nautical miles.
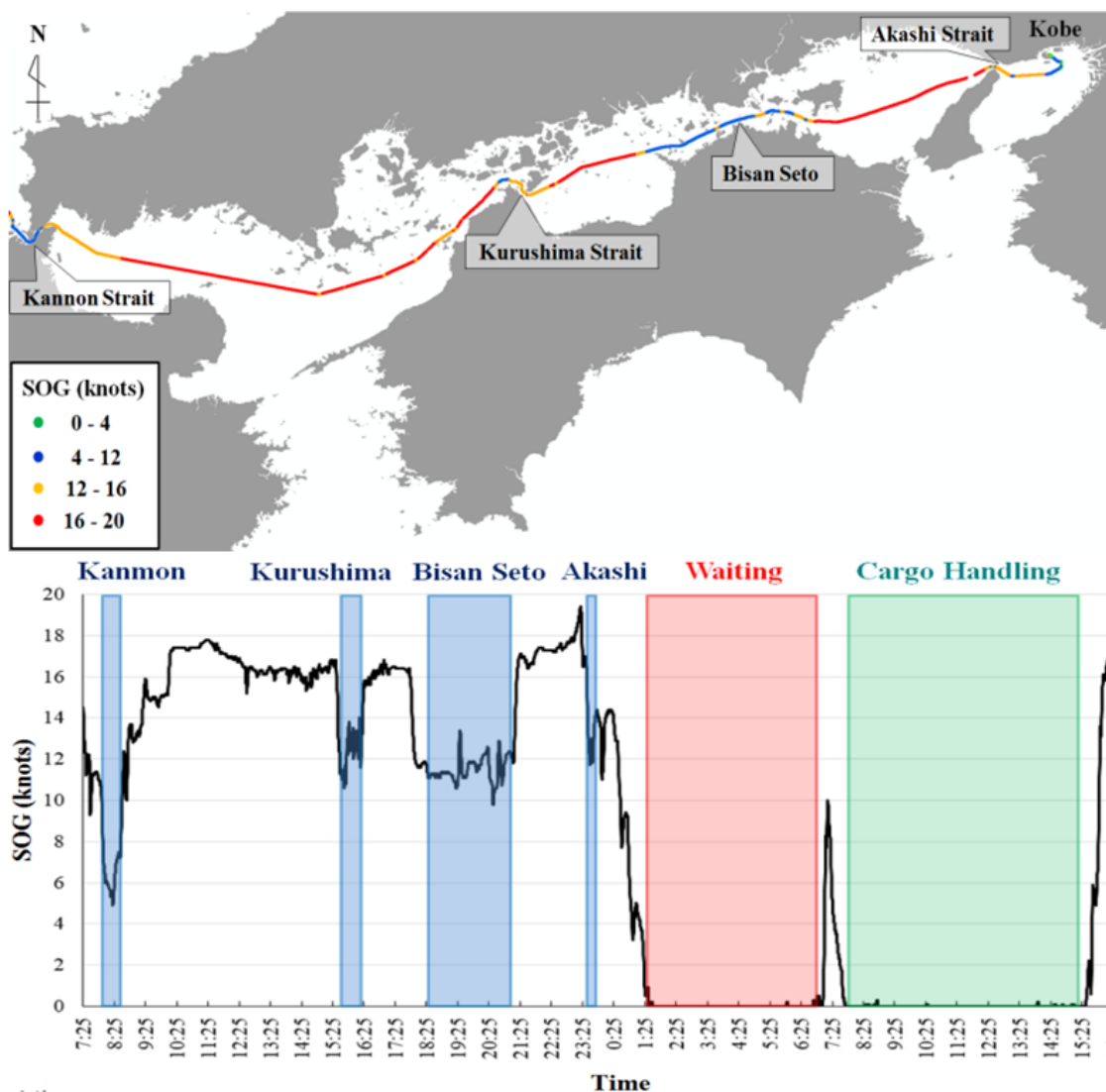
Fig. 4-16 Tracjectory and speed distribution of the sample ship

During sailing, the maximum speed was 19.4 kns, and the average speed was 14.5 kns. Navigating the inland sea requires passing through the four narrow waters of Kanmon Strait, Kurushima Strait, Bisan Seto, and Akashi Strait. The time zones in which this ship navigates each strait are indicated by the blue rectangle in the ship speed graph. The change in speed was frequently checked; in particular, the speed reduced when passing through both straits. This ship rapidly decreased its speed when passing through each strait, and after passing, the speed sharply increased. The maximum difference in the speed during the voyage exceeded 10 kns. It is confirmed a similar tendency of all ships that sailed in the inland sea from the analytical results. Moreover, many routes have speed restrictions that ships shall not navigate at speeds exceeding 12 kns, such as in Bisan Seto. However, it was found that the navigation speed was decreased to approximately 12 kns (but never less than this speed) in the restricted route. This analysis explains the sailing time of the ships operating in each strait. Therefore, it is possible to estimate the time required for the ship to reach its destination and to effectively plan the navigation. The speed of Ship A was 0 kn before the ship entered the port, which is indicated by the red part in Fig. 4-16. The extracted ship waiting information confirmed that Ship A waited offshore before entering the port. The waiting time was approximately 5.5 h. Table 4-7 shows the results of the encounter situation in the inland sea.

Table 4-7 Results of ship encounter

Number of Domain Counts	Number of Approaching ships	Encounter Situation		
		Crossing	Head-on	Overtaking
1571 counts	114 ships	10 ships	98 ships	6 ships

Fig. 4-17 shows the changes in ship heading for the sample ship by the blue line. It found that head-on was the most frequent type of encounter in the research area. This

encounter situation occurred frequently in the inland sea. Complex encounter situations not only increase the maneuvering difficulty, causing numerous accidents, but also result in the inefficient operations in fuel consumption due to the avoidance behavior. The distribution of the heading indicates that the ship veered frequently, and the heading angle varied considerably in the inland sea, especially when the ship passed through the strait. This phenomenon indicates that the route is very winding. In addition, routes like the Kanmon Strait and the Kurushima Strait have strong currents whereby ships drift. This increases the degree of veering, possibly decreasing the ship maneuverability. Another reason is that it becomes crowded with many ships in the inland sea, and the veering represents avoidance behavior.

This study examined the avoidance behavior of a sample ship in a real navigation situation. Fig. 4-18 shows the avoidance behavior of the sample ship for navigating in Seto Inland Sea. The arrows show the ships and their heading. The red arrow represents ship A, and the dots indicate the tracking of the ship for a total of 15 minutes. The yellow region indicates the domain of one nautical mile.

Fig. 4-18 shows the navigation of ship in the inland sea. Here, this study observed that there were two other ships within one nautical mile. At this time, the ship had just
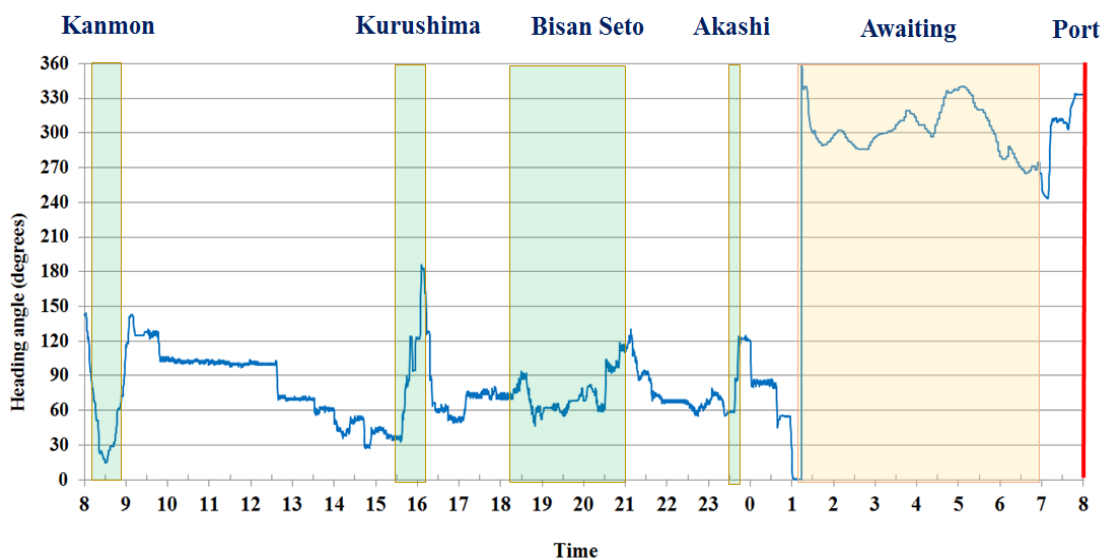

Fig. 4-17 The changes in ship heading for the sample ship

passed through Kurushima Strait and accelerated in order to overtake the target on the port bow. In addition, the head-on ships veered and sailed across. This is because the Kurushima Strait traffic route has a unique rule for navigation: ships should navigate the mid-channel with the tidal current and navigate the west channel against the tidal current.
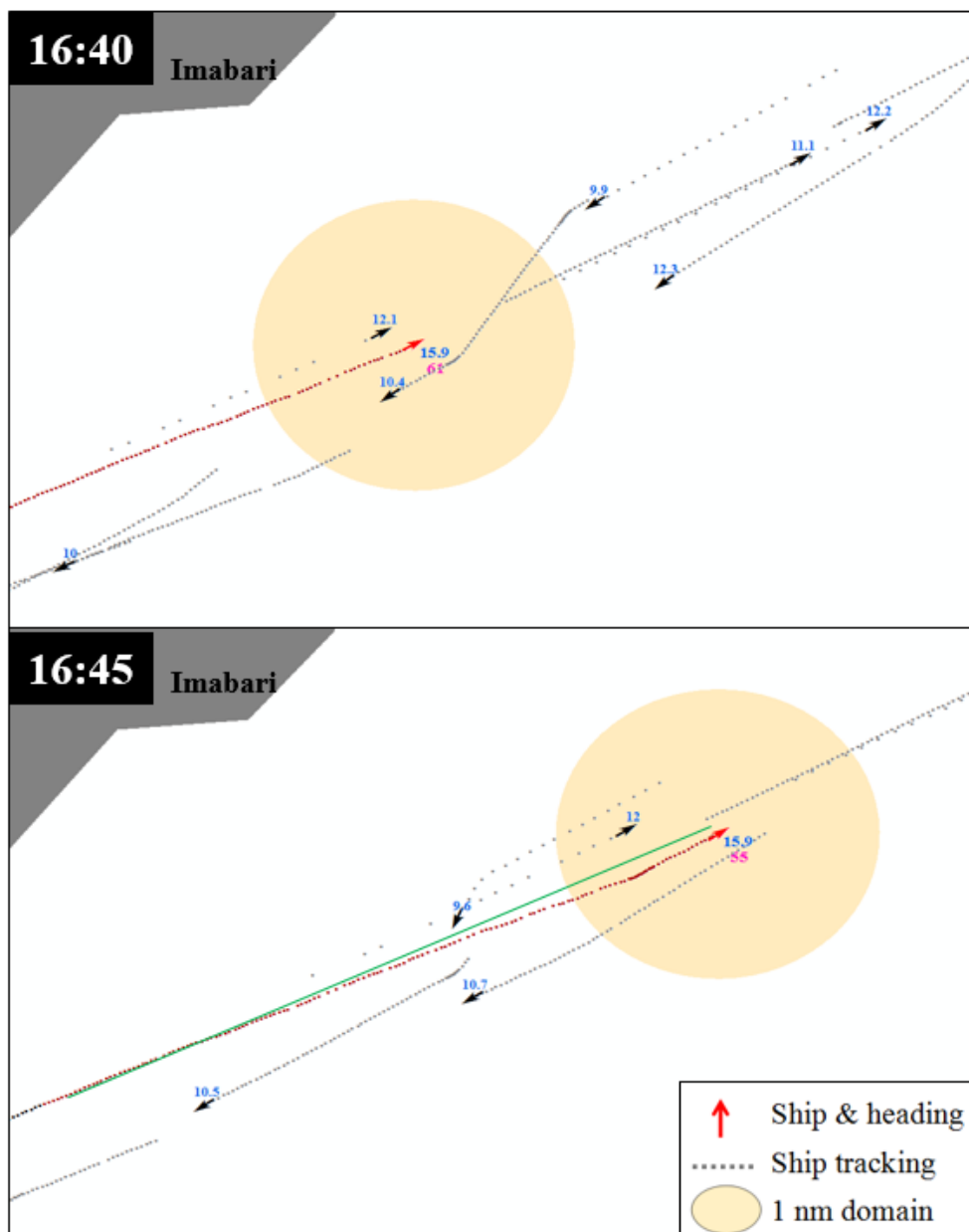

Fig. 4-18 Avoidance behavior of ship navigating in Seto Inland Sea

At the time, according to the current, many ships changed course before entering the traffic route. This complex situation caused the target ship to list toward starboard in order to avoid the other ships. The green line in the lower illustration shows the scheduled course. The deviation of the ship from the scheduled course was checked according to the trajectory. The difference between the heading before and after veering was about 10°. In addition, another head-on ship sailed on the starboard bow of the ship, presenting a high risk of collision. Avoidance behavior also presents latency risk in complex and congested areas.

In this section, this study presented the analysis of the ship navigation for entire ship voyage, in order to ease the ship congestion around the port areas and realize the on- time ship navigation. The main analysis results are as follows:

1. The entire ship voyage in Seto Inland Sea (between Kanmon and Osaka) was extracted.

2. The ship traffic of the entire voyage ships via the straits was understood. It is obtained that many ships passed through toward Osaka or Kanmon during the night time. This information can be applied to ensure safe navigation and the development of an efficient and economic navigation schedule.

3. Container ships navigate in the Seto Inland Sea and the open sea, respectively, based on the size and cargo capacity. From the analysis based on the trajectories of ships, the ships navigated three routes in this area depending on their TEU capacity.

4. The entire voyage of container ships was analyzed based on speed and sailing time. Consequently, this study identified the sailing time distribution of the entire operation and the passing time for each strait in the Seto Inland Sea. Moreover, the characteristic of the change in speed was determined; in particular, the container ships navigated the inland sea with frequent increases and decreases in speed.

5. The waiting activity of container ships was found by the analysis of the entire voyage. Majority of container ships entered the port within 6 h and many ships arrived early and then passed the night waiting for a berth. Therefore, the waiting ships congested between midnight and morning.

6. The avoidance behavior is frequent that result in the inefficient operations in fuel consumption.

7. Port side can use the information to set up more efficient cargo handling schedule. It not only contributes to reduce the waiting ships but also the stagnation of track traffic on land.

4.3 Analysis of the Navigation Behavior of On-time Ship in Seto Inland Sea

In order to achieve the non-waiting navigation, this study analyzed the behavior of ferry that is the on-time ship navigation in Seto Inland Sea. The distribution of speed and time was analyzed. If the operators can grasp the optimum navigation pattern, it is possible to realize the effective navigation.

Here, this study analyzed the on-time arrive ship, that are the particular ferry ships. According to the behavior of particular ferry, the important reference for the on-time navigation is analyzed. These information source help the operators make informed decisions and take effective navigation plan for the efficient maritime transportation.

4.3.1 Sailing Time Distribution in the Seto Inland Sea

In this study, the ship navigation speed was used to analyze the ship behavior. The analysis of speed is a conventional method used to evaluate safety and economic aspects of ship navigation [9].

The position and destination of vessels transiting the east-west route, without stopping at any port, were extracted. Using their MMSI numbers, it was possible to identify 106 ships passing across the Inland Sea during the research campaign. The authors examined the case of a ferry ship, and used this as case study to make a qualitative analysis of the results, and thus to understand the characteristics of the ships navigating the Inland Sea. A dynamic analysis approach was followed, which involved tracking the position and navigational situation of this ship across different time series. In

this way, it is possible to understand the behavior of the ship in a detailed and accurate manner.

The total length of the ferry ship was 160 m, and the sea speed (i.e., the maximum speed when the ship is sailing with cargo) was 22.9 kns. During the research period, this ship sailed the Inland Sea route six times, departing at 17:00 and arriving at 5:30 the next day, and cruising between the Moji and Osaka ports every day. In this work, we discussed three cruising cases from Moji to Osaka. According to the data provided by the Japan Meteorological Agency, during the investigation period, the weather conditions were zero visibility, low rainfall, and low wind speed. Therefore, wind had less influence on the navigation speed. The research area was divided into seven zones, accounting for the straits in the Seto Inland Sea, to compare the characteristics of the ship behavior in each area and identify their changes throughout the Inland Sea. The defined zones and the tracking of these sample ferry reference the Fig. 3-14 in the Section 3.2.2. The Kurushima Strait, Bisan Seto, and Akashi Strait correspond to zones 2, 4, and 6, respectively. During the voyages, it took approximately 12.5 h to complete 245 nautical miles. The traveling times according to each zone are listed in Table 4-9.

Table 4-8 Cruising time for cases 1, 2, and 3

	Item	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6	Zone 7
Cruising 1	Navigational time	17:00–22:11	22:11–22:47	22:47–00:17	00:17–02:19	02:19–04:13	04:13–04:25	04:25–05:36
	Traveling hour (hs, mins)	5 h 11min	36 min	1 h 30 min	2 h 2 min	1 h 54 min	12 min	1 h 11 min
Cruising 2	Navigational time	17:00–22:27 h	22:27–23:02	23:02–00:32	00:32–02:31	02:31–04:23	04:23–04:36	04:36–05:46
	Traveling hour (hs, mins)	26 min	36 min	1 h 30 min	1 h 59 min	1 h 52 min	13 min	1 h 10 min

Cruising 3	Navigational time	17:00–22:20	22:20–22:56	22:56–00:27	00:27–02:21	02:21–04:08	04:08–04:26	04:26–05:36
	Traveling hour (hs, mins)	5h 20 min	36 min	1 h 31 min	1 h 54 min	1 h 47 min	18 min	1 h 10 min

Due to the type of service this ship provides, she must sail regularly to arrive the destination on time in spite of the weather conditions and traffic situation every day. It can be seen that the traveling times were similar in each cruising.

4.3.2 Navigational Speed Distribution in Seto Inland Sea

The traveling the speed according to each zones are listed in Table 4-10, and Figs. 4-19 to 4-21 show the time series of the changes in the ship speed for cruising 1, 2, and 3, respectively. The zones in which this ship navigated each strait are indicated with blue strips on the graphs.

Table 4-9 Cruising speed for cases 1, 2, and 3

Item		Zone 1	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6	Zone 7
Cruising 1 (March 1)	Max. speed	22.0	21.9	22.0	21.1	22.2	22.6	21.8
	Mean of speed	20.7	19.5	21.1	16.5	21.0	20.3	19.4
	SD of speed	1.52	0.61	0.47	2.97	0.42	0.95	3.78

Item		Zone 1	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6	Zone 7
Cruising 2 (March 3)	Max. speed	22.0	20.5	22.1	22.3	22.0	20.6	22.2
	Mean of speed	20.5	14.8	21.1	17.1	21.3	19.3	20.1
	SD of speed	1.81	3.26	0.53	2.71	0.49	0.39	3.51

Item		Zone 1	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6	Zone 7
Cruising 2 (March 5)	Max. speed	22.5	22.0	22.0	23.0	23.0	22.5	22.6
	Mean of speed	20.9	15.5	21.0	17.8	22.4	14.9	19.1
	SD of speed	2.68	3.11	0.43	2.19	0.22	2.21	2.95

From the speed distributions and the analysis results in the table, it was found that most of the ship was approximately 20 kns, although in some zones such as zone 1, 2 and 3, the speed reached up to 22.9 kns (sea speed of the ship) at some instants. Moreover, the change in speed was frequently checked, as shown in zones 2, 4, and 6. According to the information of tidal currents, in the Kurushima Strait (zone 2), it was north when the ship navigated during cruising 1, 2, and 3. The slackest current was between 1 and 2 kns during cruising 1, and the strongest one was over 4 kns during Cruising 2. Thus, the speed decreased due to the upstream current. The tidal current in the Akashi Strait (zone 6) was the slackest during cruising 3, but the speed rapidly decreased when passing across this strait. This is considered to be the other influencing factor on the speed.
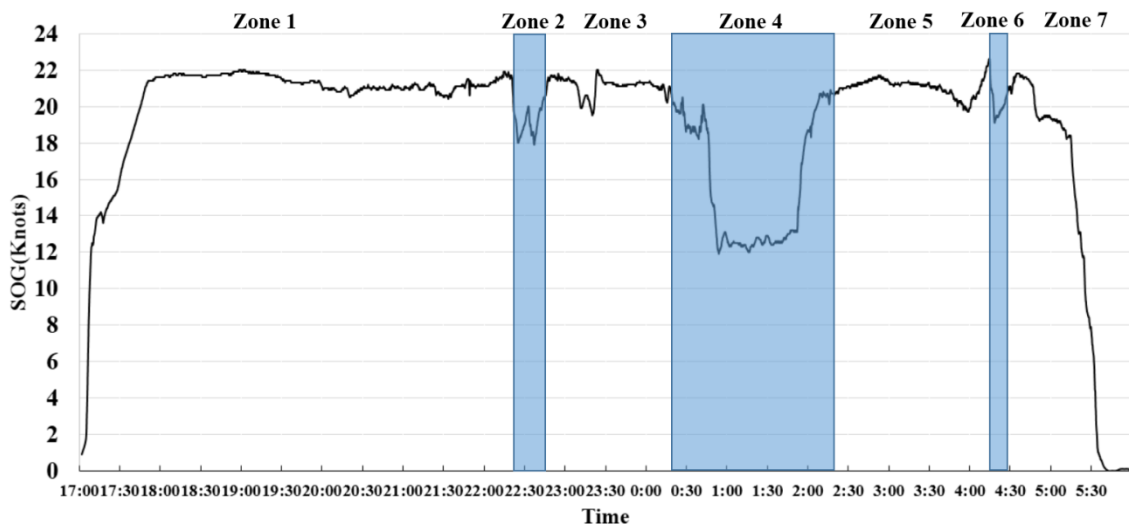
Fig. 4-19 Speed of cruising 1 in the Seto Inland Sea route
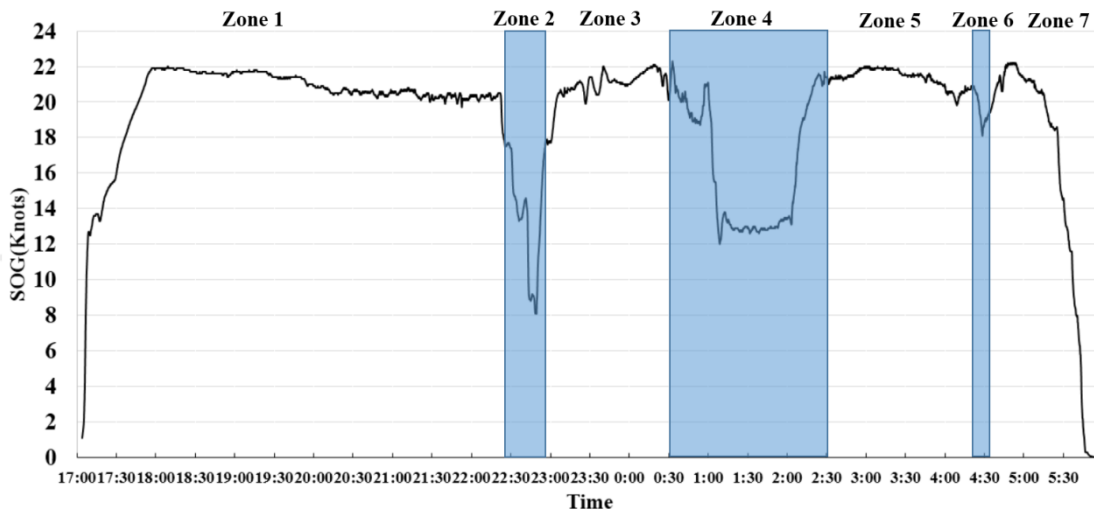
Fig. 4-20 Speed of cruising 2 in the Seto Inland Sea route
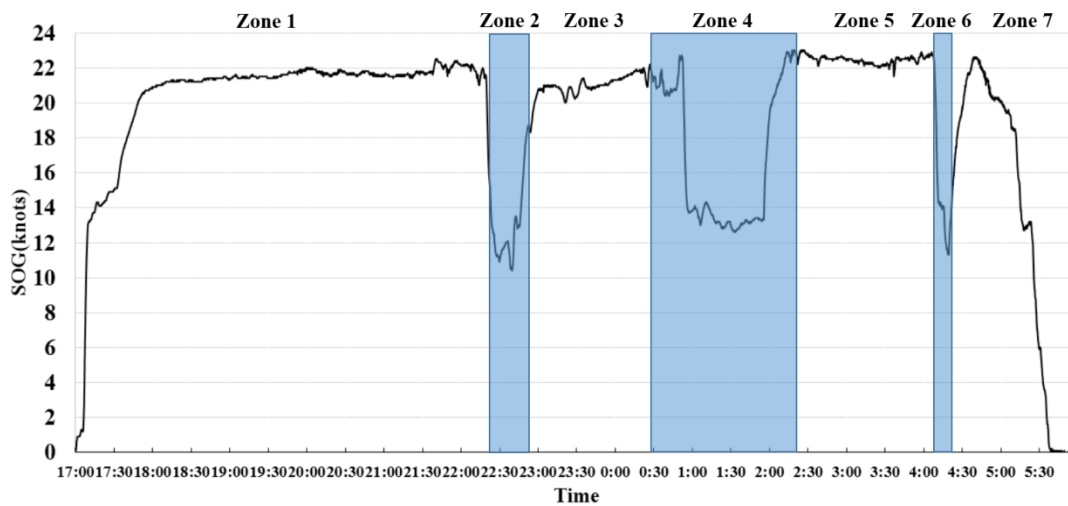
Fig. 4-21 Speed of cruising 3 in the Seto Inland Sea route

The ship decelerated when crossing zone 4, mainly due to the Bisan Seto route speed restrictions that does not allow navigating at speeds greater than 12 kns. The navigational time and traveling schedule were recorded when the ship crossed the lines of each zone. The collected data was used to obtain the maximum, mean and standard deviation (SD) of speed, and are used to observe the navigation situation of the ship in every voyage. In these cases, an average speed of 19.6 kns was used to calculate the SD speed in every zone areas, which obtained from the navigational distance and time. The

SD is a measure of the variability in the speed of the ship, and it is particularly prominent when crossing the straits.

This section presented the analysis of ferry, in order to understanding the navigation distribution of ship navigating Seto Inland Sea for the realization the on-time ship navigation. The main analysis results are as follows:

1. The navigational situation of ferry was obtained. This information can be the important reference to realize the on-time navigation.

2. The ship is changed frequently and slowed down when passing through both straits. It must be remarked that there is a large influence of the currents and route restrictions as well. However, the behavior was not good to the navigation safety and efficiency.

3. The ship was able to rapidly increase the speed after a slowdown, in order to catch the destination on time. Moreover, the navigation speed was decreased close to 12 kns in restricted route, never less than this speed.

4. On the basis of the information, it was found that selection of navigation route and the efficient speed distribution.

5. The navigational speed and time were understood. This information can be applied to ensure safe navigation and the development of an efficient and economic navigation schedule.

6. Detailed flight information by each ship will be an important reference to achieve efficient operations.

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CHAPTER 5 Application of MDA Information in Ship Navigation for the Safety and Efficiency of Maritime Transportation

In this chapter, this study presents the example of the application of the information. Firstly, this study presents the information utilization for the efficiency of ship navigation. The study provides the information that helps the operators to navigate more safety and efficiency. The ship navigation in open sea was analyzed. A compare with ship navigation in open sea was performed, and the navigation risk was presented. According to the comparison, the appropriate route is recommended. Other example indicates the information utilization for the safety of ship evacuation in a stormy weather. This study analyzed the ship traffic and congestion situation of evacuation areas based on the anchoring ships. This support information assist the operators make a decision of evacuation areas effectively. Moreover, the risk areas during ship evacuation were obtained, which can be used to avoid the risk and provide the evacuation route. Moreover, this study performed that an evacuation route was simulated based on a real ship.

5.1 Application of the Information for the Efficiency of Ship Navigation

5.1.1 Ship Navigation in Pacific Ocean Route

In recent years, with the frequent transportation of substantial amounts of goods and materials between countries, ship voyages have increased [1]. However, the profits of ship-operating companies have decreased owing to the escalating price of oil. Generally, a ship is required to navigate the shortest route and deceleration [2] in order to reduce the operating costs. However, this route is often crowed by many ships and thus difficult to navigate, especially when it is narrow and has complex currents. The Seto Inland Sea, located in the western part of Japan, has a navigation route that is used as a primary traffic route for transporting goods and materials in Japan. A Seto Inland Sea route has been developed and stabilized, and is now responsible for the trade between Japan, China, and South Korea, and thus, for their economies. Many ships

move frequently through this area, because it is the shortest route between Osaka and Kanmon to travel between China, South Korea, and Japan.

Fig. 5-1 shows the number of ships passing through the Seto Inland Sea and Pacific Ocean routes. Fewer ships navigated the Pacific Ocean route, i.e., approximately half of the number of ships navigating the Seto Inland Sea route. Classification by ship category reveals that more than half of the ships contributing to the traffic were cargo ships, with tanker ships constituting the second-highest category. Thus, most of the ships voyaging in this area transport goods, materials, and energy resources, and cargo delays may cause issues for the economy and daily life.

In the Seto Inland Sera, Osaka portand Kobe port are one of the most congestion ports, where there are many large container berths and coastal industrial complexes, and most voyaging ships stop at these ports. According to the analysis in the Section 4.1, the ships waiting for berth in Osaka Bay were understood. Here, the waiting ships were divided by passing the inland sea and open sea. Fig. 5-2 shows the tracjectory of the waiting ships between March 1 and March 7, 2012.
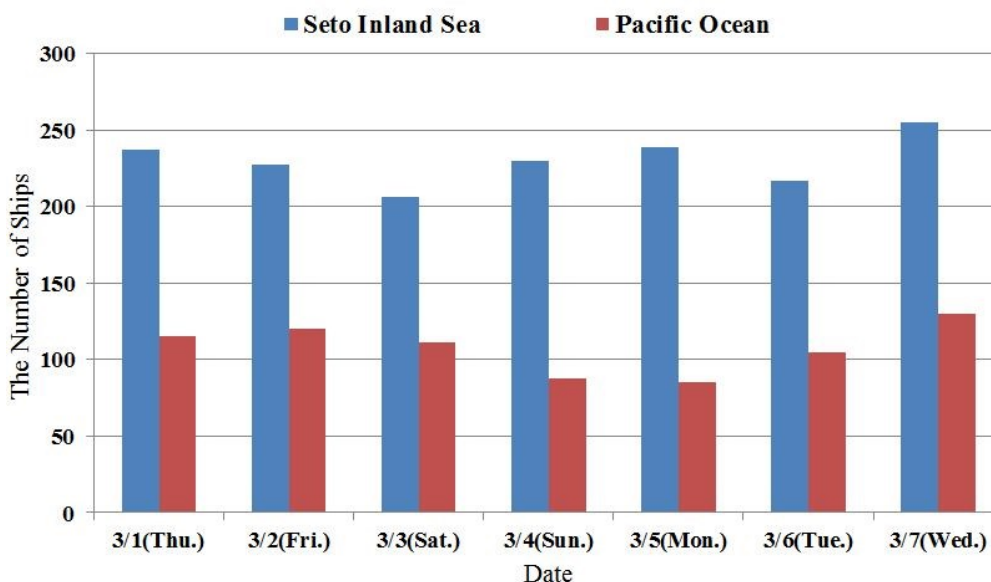
Fig. 5-1 The number of ships passing through the routes
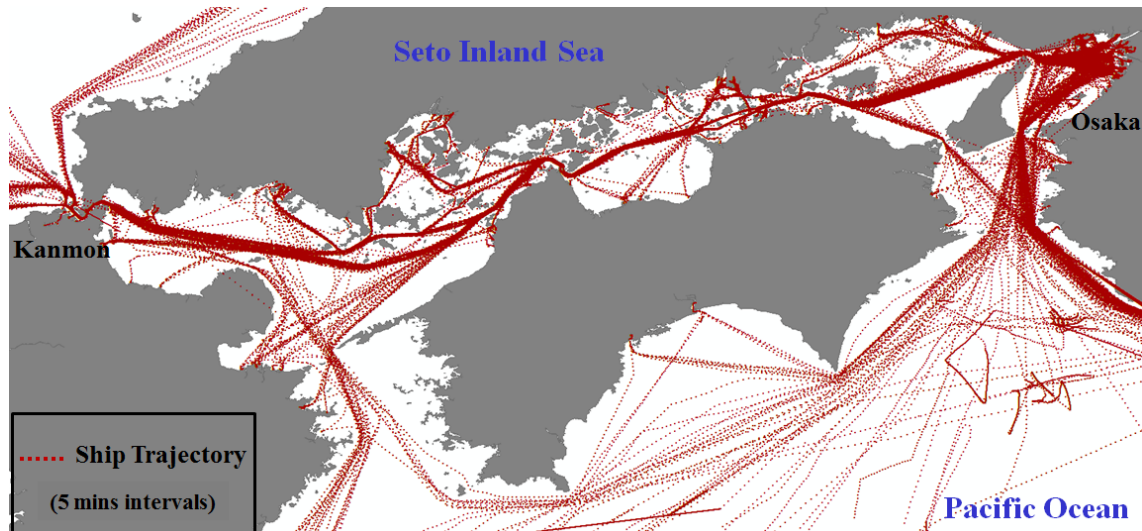
Fig. 5-2 Tracjectory of waiting ships during the research period

As shown in figure, there are two general routes route for ships sailing between Kanmon and Osaka Bay. One is used by ships passing through the Kanmon Strait and the Akashi Strait to sail through the Seto Inland Sea and is always congested by many crossing ships, including fishing boats and ferries. The other route is used by ships passing through Kanmon and sailing the Pacific Ocean to arrive at Osaka Bay. Compared with the inland sea route, the Pacific Ocean route is shorter. From the ship trajectories, it can be confirmed that most waiting ships navigated the Seto Inland Sea. The total number of waiting ships was 268 during the research period, and there were 12 waiting ships passed between Kanmon and Osaka sailing in the Pacific Ocean Route. Therefore, it is understood that most of waiting ships passed through the Seto Inland Sea.

This study obtained the situation of ship navigation in the Seto Inland Sea before. Here, this study used the identical aspects of the ships in order to isolate and compare their navigation situations. As an example, this study explains using a sample ship B. The sample ships is container ship has the same lengths, TEUs, and maneuverability identical with the sample ship A passing through the Seto Inland Sea in section 4.2.2. The container ship B navigated between Kamon and Osaka in Pacific Ocean route. Table 5-1 lists the characteristics of the ship.

Table 5-1 Principle sample ship characteristics

Type	Container ship B
Route	Open Sea
Ship length (m)	148
Max. TEU capacity	1,118
Navigation distance (n.m.)	329
Navigation time (h)	22

Ships A and B are container ships having equal length and GT, making their maneuverability identical. However, these similar ships navigated different routes. Generally, the ships sailed toward the same destination in the area and chose a relatively short distance to navigate. However, ship B sailed the longer route. On the basis of the previous chapter, Ship A passed through the Kanmon Strait at 8:00 on March 5 and arrived at the Port of Kobe at 8:00 on March 6, taking approximately 24 hours to navigate 252 nautical miles, and was anchored for 5.5 hours to wait for berth before entering the port. Ship B navigated the Kanmon Strait at 14:00 on March 2 and arrived at the Port of Kobe at 12:00 on March 3, taking approximately 22 hours and traveling 329 nautical miles. Compared with ship A, ship B traveled a longer distance to sail the route. Fig. 5-3 shows the trajectories with speed distribution and changes in ship speed for the sample ship B navigating in open sea. The higher illustration in each figure shows the sample navigating in open sea. The higher illustration shows the trajectory and speed distribution of the ship. Low and high speeds were coded by green and red. The lower illustration in each figure shows the transition of ship speed when sailing.

According to the above analysis, ship navigation the inland sea was frequently change with speed; in particular, the speed reduced when passing through both straits. This ship rapidly decreased its speed when passing through each strait, and after passing, the speed sharply increased. By comparison, the ship B traveled a longer distance to sail

the same route. The speed distribution of Ship B sailing in the open sea was significantly high or low. The maximum speed of sailing was 18 kns, and the average speed of Ship B was 15 kns, which is faster than Ship A when sailing in the inland sea. Moreover, as the ship A navigation the inland sea anchored 5.5 h for waiting for the berth. Consequently, Ship A had a longer sailing time than Ship B.
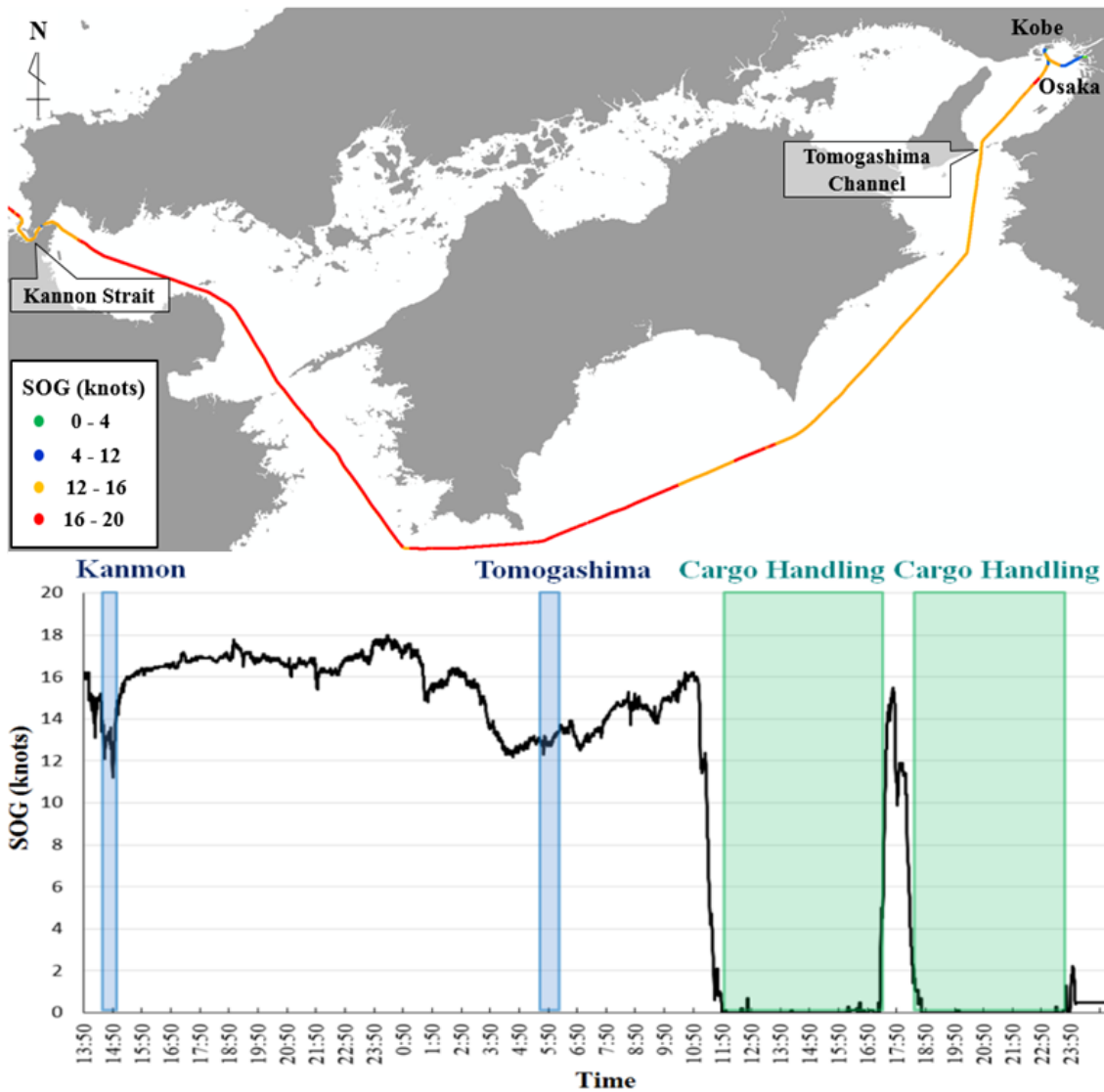
Fig. 5-3 Tracjectory and speed distribution of container ship navigating the open sea

Fig. 5-4 shows examples of the real avoidance behavior for the sample ship B in the Pacific Ocean route. The arrows show the ships and their heading. The red arrow represents ship A, and the dots indicate the tracking of the ship for a total of 15 minutes. The yellow region indicates the domain of one nautical mile. Compared with ship A, the situation was simpler. Only one head-on ship sailed around ship B. The heading before
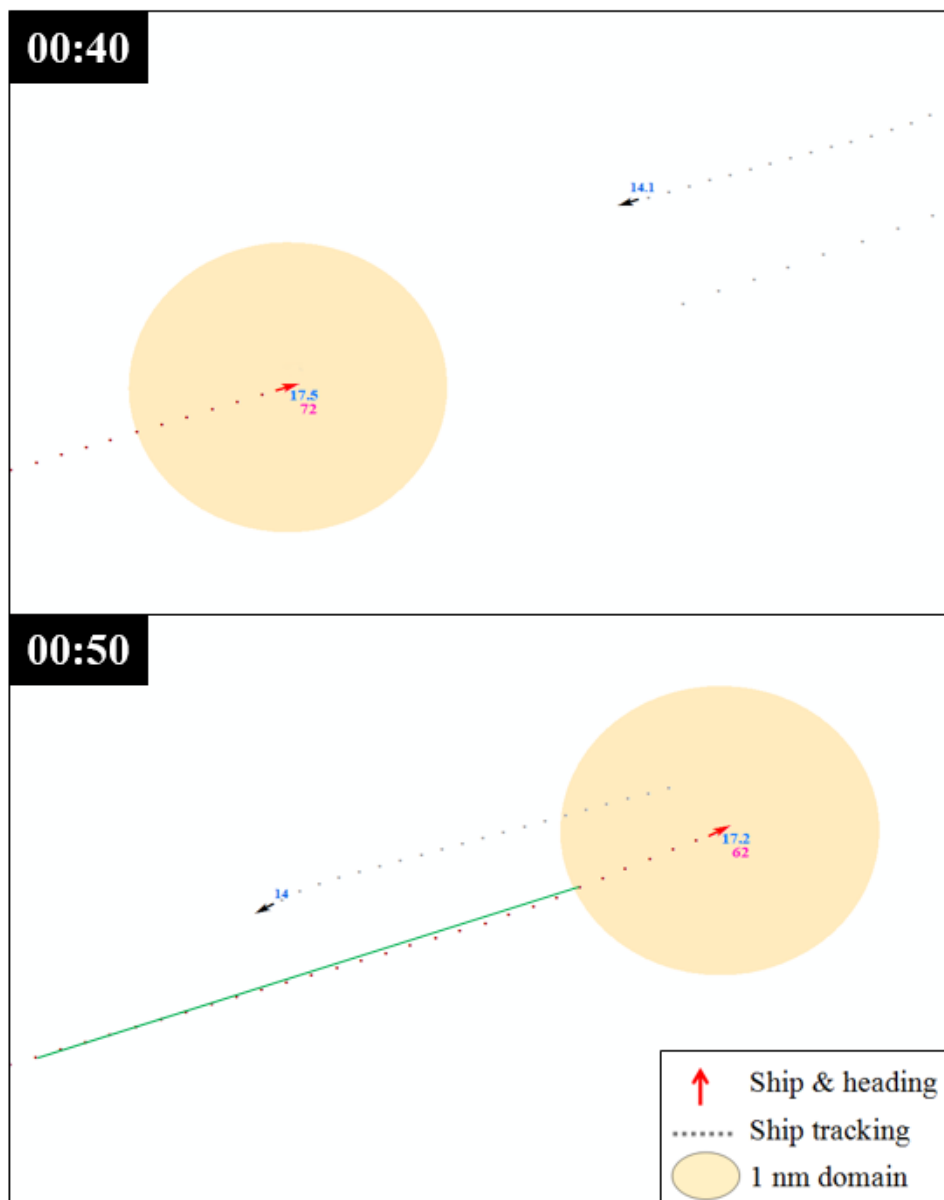
Fig. 5-4 Avoidance behavior of ship navigating in Pacific Ocean

veering was about 60°, and the ship listed 72° to starboard in order to avoid the head-on ship. The trajectories confirm that ship B had a sufficient width for avoidance. Thus, ship B deviated from the scheduled course in a short distance.

According to the dynamic analysis of the AIS data, this study examined the avoidance behavior of a ship in a real navigation situation. The encounter situation is a basic factor for evaluating the collision risk of ships. Table 3 shows the results of the encounter situation in the inland sea and Pacific Ocean, which are based on the analysis of the AIS data. The number of domain counts increased when a ship was within one nautical mile. Using the MMSI number, the number of approaching ships was obtained. Clearly, numerous ships navigated close to ship A. The number of approaching ships was about 4 times greater than that for ship B, which sailed the open sea route. The narrow route of Ship A is one of the reasons for this. According to the angle between the two close ships, we found that head-on was the most frequent type of encounter in the research area. This encounter situation occurred frequently in the inland sea. Therefore, there was a high collision risk during operation in the inland sea. Complex encounter situations increase the maneuvering difficulty because of the action constraints on the other ships, causing numerous accidents.

Table 5-2 Results of risk analysis

Contents / Sample ship	Number of Domain Counts	Number of Approaching ships	Encounter Situation		
			Crossing	Head-on	Overtaking
Ship A	1571 counts	114 ships	10 ships	98 ships	6 ships
Ship B	412 counts	24 ships	2 ships	18 ships	4 ships

In the application information, this study compared the navigation risk between the Seto Inland Sea and Pacific Ocean routes. According to the analysis, although the Seto Inland Sea is a shorter route for navigation between Kanmon and Osaka, the route is difficult for ship navigation, and there is a higher collision risk compared with the Pacific Ocean route. The ship navigated at a high speed and passed through a shorter route, but was anchored offshore to wait for the berth. Waiting offshore is inefficient. Considering navigation safety and efficiency, the Pacific Ocean route is not congested, and there is sufficient distance for avoiding ships. Although it is possible that ship navigation was affected by the Kuroshio currents, if the ship rides the current, fuel consumption may be reduced. Navigating the Pacific Ocean route is considered safe and effective. The risk areas in a wide ocean area were provided including ship navigation in the Pacific Ocean route. Fig 5-5 and Fig. 5-6 show the congestion area in 22:00 on March 2 and 11:00 on March 3, respectively. The information can be used to avoid the risk and plan an efficiency navigation in the open sea based on the congestion area and time. On the other hand, the speed of container ships sailing in the open sea was significantly high and low. In addition, if the ship rides on the current, it may attain an efficient navigation. Therefore, it is necessary to understand the actual and detailed traffic situation of the ocean area and the characteristics of ship activity for planning an
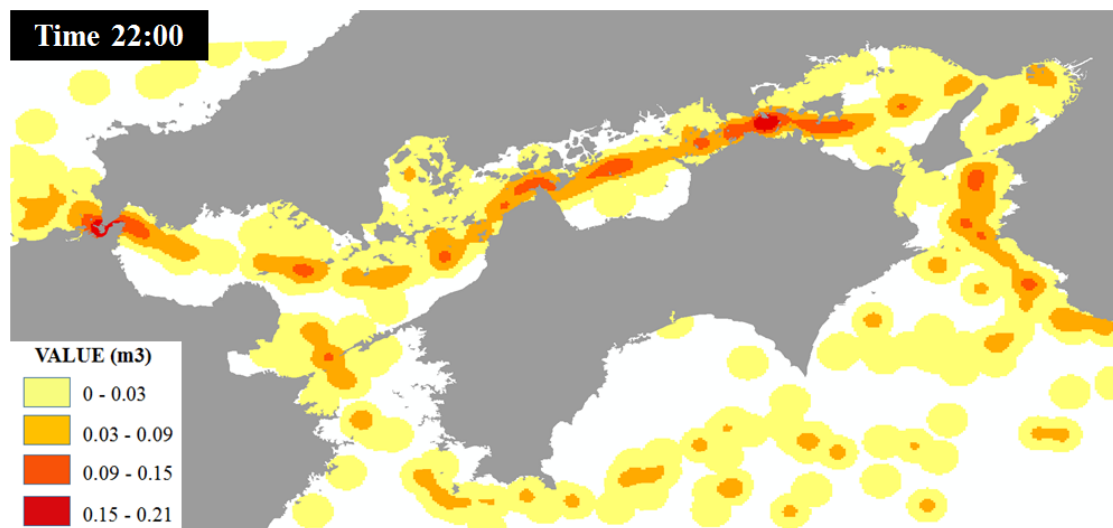
Fig. 5-5 Congestion area in a wide ocean area (22:00 March 2)
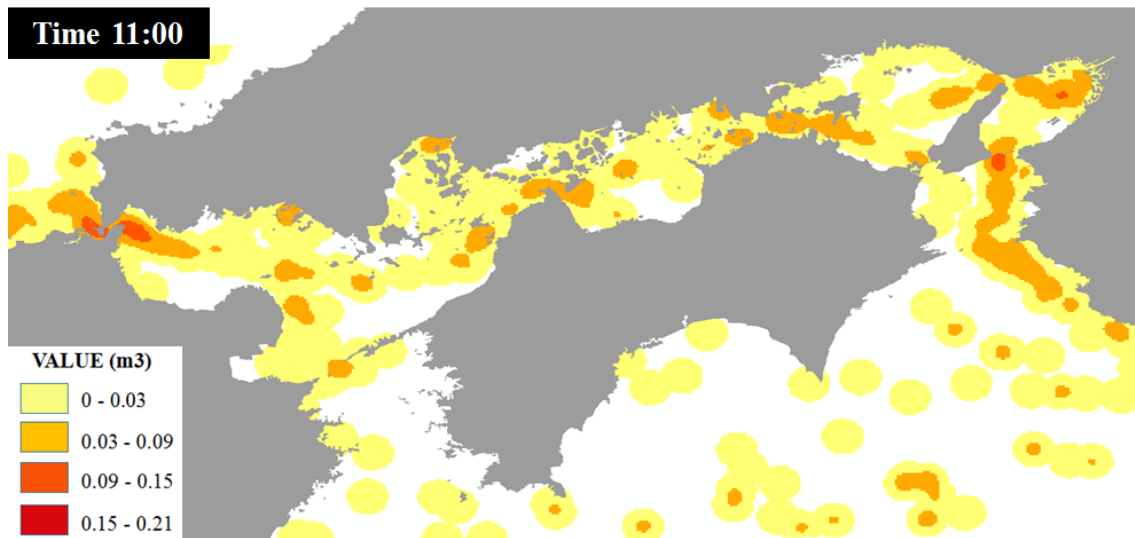
Fig. 5-6 Congestion area (11:00 March 3)

optimum navigation route and schedule. In the further, this study will combine the weather and sea conditions to make the information system more effective.

5.2 Practical Use of Information for Ship Evacuation in a Stormy Weather

5.2.1 The Actual Situation of Navigation Ships in a Stormy Weather

Here, this study presented the ship navigation in a stormy weather. The data corresponding to April 3, 2012, was collected for the research. On that day, a rapidly developed low pressure, similar to a huge typhoon, hit Osaka Bay along with strong winds and high waves. According to the information of Japan Meteorological Agency, the wind speed over 20 m/s has raged intermittently. Especially, from the afternoon to the evening, the maximum wind speed was 30 m/s in Osaka Bay. Under these weather conditions, ships are required to evacuate outside the ports. The purple color represents the industrial zones in the coastal area. A leading major industrial area exists in this area in Japan, such as the Hanshin industrial area, Sakai Senboku coastal industrial zone, and Kansai Airport. Especially, heavy industries, such as petrochemical industries, are concentrated and located in the eastern part of Osaka Bay, and these areas are large. If a fire or explosion occurs, it will rapidly spread in the neighboring industrial area and

adjoining residential streets and it will be may induce a large-scale disaster. Furthermore, two or more international strategy ports exist in Osaka Bay, and many large-sized vessels are always cruising. In addition, as many fisheries exist, the ocean space is always congested by a variety of ships.

In Fig. 5-7, the black dotted line also indicates the ship trajectories in the Osaka Bay. It can be seen that most of the ships enter the ports Kobe and Osaka, which are Japanese international trade ports. The ship trajectories show the main route of ship navigation between the Osaka and Kobe ports and the Akashi Strait and Tomogashima Channel. However, this area is often attacked by typhoons, and a major earthquake has been forecasted in the coming decades nearby. To ensure ship safety in this area, it is very important to understand the behavior of ship evacuation and its latent risk.
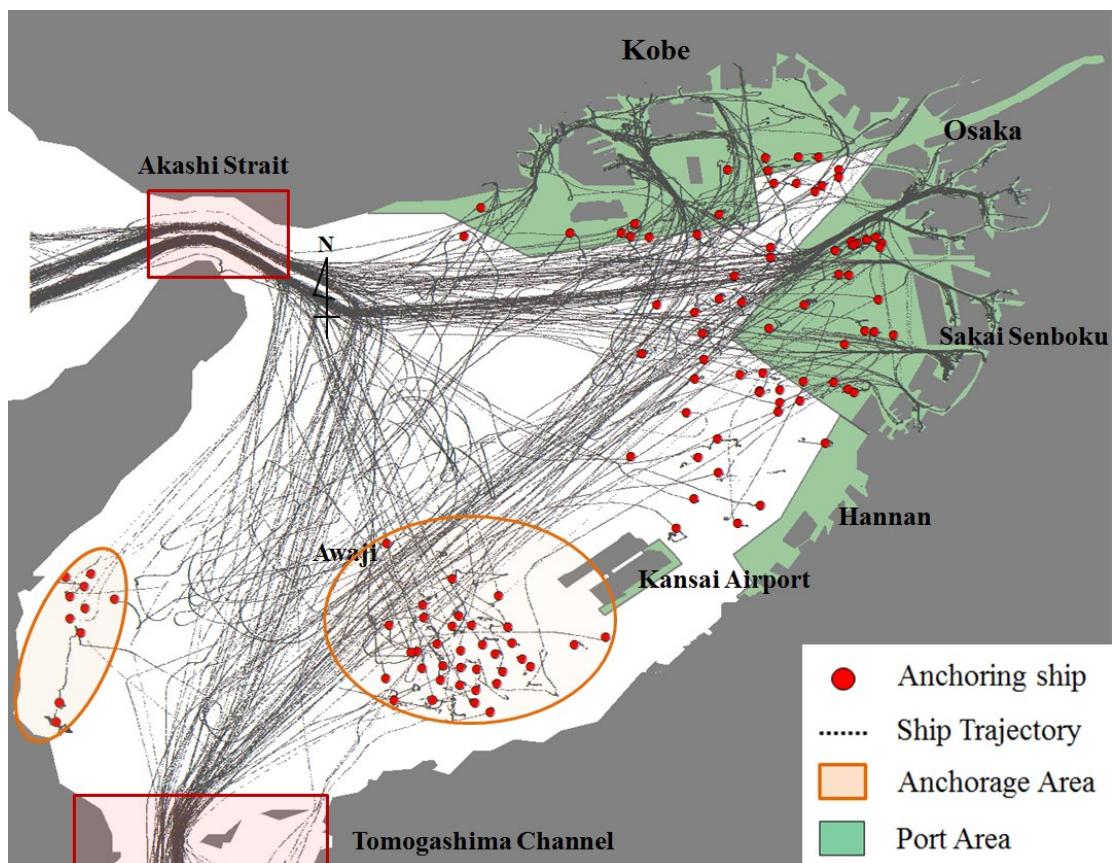
Fig. 5-7 Ship anchoring in Osaka Bay

The definite evacuation areas in Osaka Bay have not been developed yet. Usually, the anchorage areas are on a first come first serve basis. Therefore, it is very important to understand the congestion situation of anchorage areas for the safety and effective evacuation. The red circles in the Fig. 5-7 show the anchoring ships and their position. Form this distribution of anchoring ship, it is understood that many ships congested around the ports. Because many ships stop the ports, the ships cannot sail smoothly into a port, they are commonly crowded together offshore for waiting the berths. In addition, we can see that many ships were crowed in the southwest of Kansai Airport and the south of Awaji for the refuge from the stormy weather. These two areas were confirmed the conventional evacuation areas in Osaka Bay.

This information of the anchorage distribution is useful to make a decision of which evacuation area is more safety and efficiency for the ship evacuation. However, the anchoring ship is easy to be affected by the external forces. Especially in the story weather, the anchoring ships swing and it is possible that the anchoring ships dragging by the strong wind and wave. If a sailing ship approaches the domain of swing, there is a high risk of collision. Fig. 5-8 shows the drift trajectory of a real ship and her drift domain. The drift behavior was around the anchoring point, and the ring of ship swing is the equivalent of chain length. In this study, the drift domain was carried out based on the formula [$r = 4D + 145m + LOA$], which is basic of the length of the anchored chain.
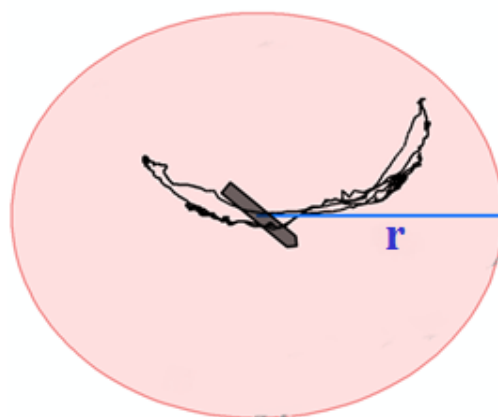
Fig. 5-8 Drift trajectory of a real ship

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The formula of chain length as a norm is widely used in the coastal area of Japan. *D* represents the water depth of ship anchoring. The water depth of an individual anchoring ship was obtained by using the anchorage position of the ship. The domain of each anchoring ships were obtained from the water depth they anchored, and ship length of them.

According to the analysis, the situation of evacuation areas in the stormy weather (April 3, 2012) was understood, that is listed in Table 5-2.

Table 5-3 Situation of Evacuation Areas

Evacuation area \ Item	Southwest of Kansai Airport	South of Awaji
Available of area (km²)	70	45
Water-depth (m)	15 - 30	25 - 45
Number of anchoring ships (ship)	37	10
Rate of anchored occupanc (%)	21	8

It can understand that the evacuation area of southwest of Kansai Airport has larger size and the appropriate water depth for anchoring. There were 34 ships anchored in this area, and with ship congestion. By comparison, the evacuation area of south of Awaji has a low occupancy rate of anchoring to the southwest of Kansai Airport, but this area with a little depth water, that is inappropriate to anchor for small ships.

5.2.2 Latent Risks to evacuation

To ensure ship safety from a natural disaster, it is very important to understand the ship evacuation behavior and its latent risk. In this study, the actual condition of ship dragging was studied by the dynamic analysis of the ship behavior. Moreover, the drift

distance of each dragged ship was calculated. According to the analysis, it is observed that 36 (31%) of the 117 anchored ships dragged the anchor during a stormy weather. According to the investigation of the dragging ships, it is observed that eight tankers dragged the anchor and drifted. The pure car carrier (PCC) was drifted to the longest distance of approximately 290 0m during the investigation. There was a very high risk of collision and grounding.

Fig. 5-9 shows the drift distance of the dragged ships. The longest drift distance was approximately 2900 m, and the shortest distance was about 500 m. Thus, the sailing ships should keep a distance of least 500 m from the anchored ships on the stormyweather. In addition, we confirmed that most of these ships dragged repeatedly.

A ship that is anchored for a long period is the same as a large piece of floating, and is especially at the mercy of the wind and waves. Plus, the traffic situation with the evacuation ships, the situation causes numerous maritime accidents, including collisions and grounding offshore. In order to prevent the accident during the evacuation, this study provided the risk areas of ship navigation. The risk area analysis is basic of AIS data of using the KDE. The point event in the analysis used risk labels related to the condition of the anchored ships and the types of ships. The catalog risk labels are listed
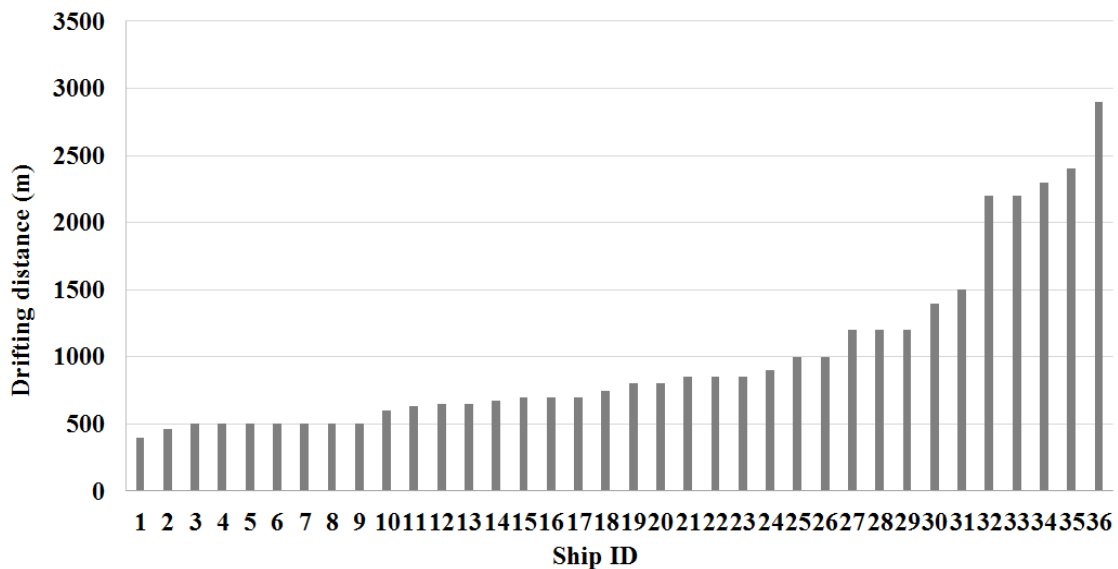
Fig. 5-9 Dragging distance of anchored ships on April 3, 2012

in Table 5-4 with *n* as the number of ships in a given situation. As tankers carry dangerous goods and are harmful during disasters, the risk label is increased depending on the type of ship. Dragging was considered as a high-risk situation. The analysis was carried out considering a ship approaching a domain of drifting anchored ships with the basic length of chain as 4D+145m.

Table 5-4 Risk labels depending on the anchored ships

Risk label	Anchoring situation	
	Normal anchorage	Dragged anchoring
Dry cargo & passenger ship	n × 1	n × 5
Tanker	n × 2	n × 10

Fig. 5-10 shows an example of risk areas in 10AM. This information provided the risk distribution in 15-minute intervals. High and low densities are colored in red and yellow, respectively. The storm and the waves warning was issued at 9:55AM. However, already many ships were crowded in the southwest of Kansai Airport.   In addition, the port areas were congestion, especially at 10: 15. The traffic route of Osaka has high risk, because the large number of ships evacuated out of ports all together. Moreover, as the Awaji evacuation area is located in the opposite of ports, the ships have to cross over the route of ship navigating between Akashi and Tomogashima. Therefore, the risk areas in the west of Osaka Bay also should be care. The analyzed information of risk areas is very helpful to avoid the risk, and can be used to support the evacuation route.

In the chapter, the study presents the examples of the application of the information. According to understand the actual situation of ship navigation in the Seto Inland Sea and open sea, The study provides the information that helps the operators to navigate more safely and efficiently. Considering the safety and efficiency of ship traffic, the appropriate route was recommended based on the comparison.

Moreover, this study presented the information utilization for the safety of ship

evacuation in a stormy weather. Based on the analysis of anchoring ships, the general evacuation areas and their anchorage situation in a stormy weather were understood. In addition, the risk areas were obtained by the ship dragging. The results of this study will improve the ship navigation safety during an emergency evacuation, and it can be used to develop a safety and efficiency ship evacuation system.
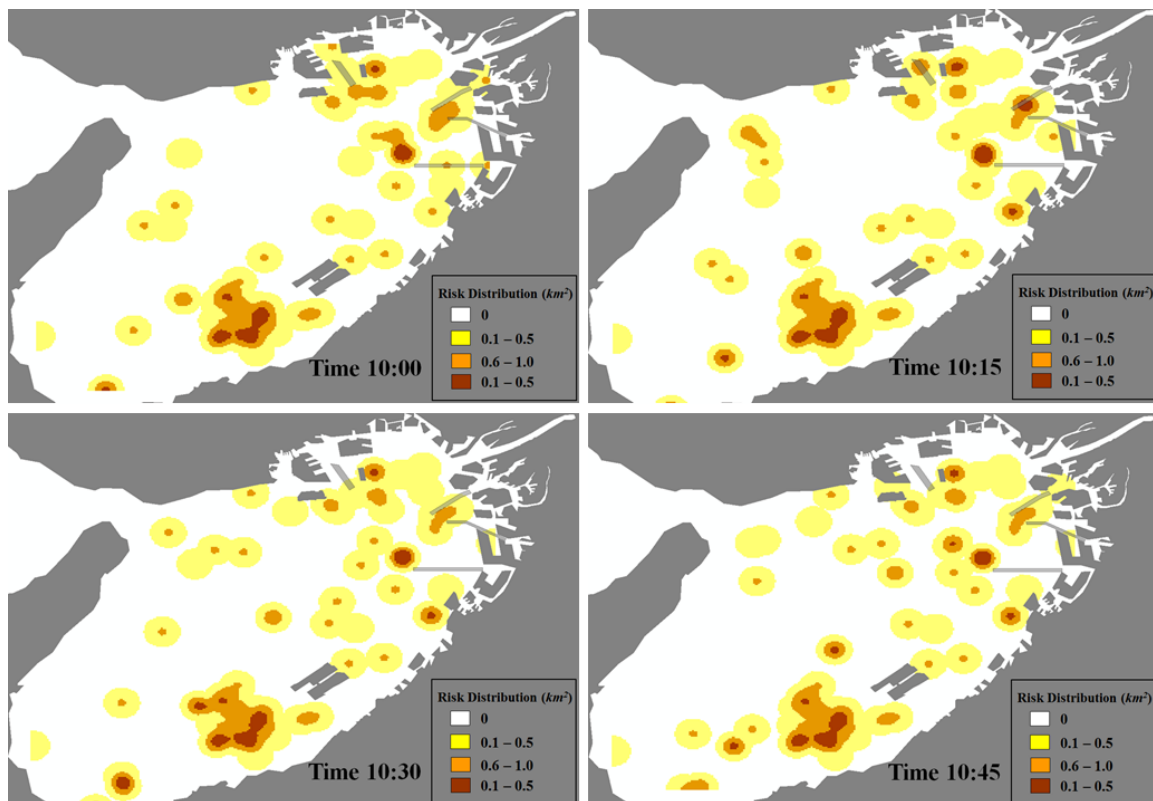
Fig. 5-10 Risk areas of ship navigation in a stormy weather

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CHAPTER 6 CONCLUSION

This study presents an analysis of the actual ship navigation history of ships in Seto Inland Sea based on AIS data. A dynamic analysis was performed to understand the actual behavior of ships in detail. Compared with the maneuvering simulation models, using AIS data is a relatively accurate method, and the method makes it possible to grasp the actual situation of grouping ships quantitatively. According to the analysis of ship navigation the ship navigation behaviors and the characteristic of shipping were understood in detail. In order to secure the ship transportation safety and the realization of the navigation efficiency, the valuable information was obtained in this study. Since the information was presented effectively understood by using GIS, the study constructed an information system that can be used to the preservation of safe navigation. The information database is an important reference data for the all operating officials such as the sailors, ship operator, and traffic manager. Especially, the results are directly connected to the safe navigation of the ship in the MDA, and they are also the important basic data in future policy proposals. This study understood and presents the effective information to prevent the occurrence of ship accidents and achieve the efficient ship navigation. The main result is obtained by the analysis of AIS data that are as follow;

1. In order to the prevention of ship accidents, this study understood the ship traffic and congestion areas in Seto Inland Sea. More than 1400 ships navigated the ocean area in one day. However, the number of ships decreased during the weekend. According to the analysis of ship trajectory, In particular, the operating trends of various ship categories became clear. Moreover, based on the analysis of the density distribution, this study determined the risk areas at specific times in the Seto Inland Sea. It is found that the ship congestion is commonly in the narrow route and the coastal areas. The analysis results can help operators avoid congestion, and navigate efficiently in the inland sea. This information has deepened understanding of ship navigation in Seto Inland Sea.

2. In order to the prevention of ship accidents in the narrow routes, this study presented an analysis of the latent risk based on the analysis of ship drift and ship encounter situation using AIS data. It was understood that approximately 61% of all AIS-equipped

ships exceeded the drifting degree of 15°, many ships passing through the Kurushima Strait route were in potential danger. The drifting ship not only endangers herself, but also other sailing ships. The risk areas of ship drift were obtained by analyzing the kernel density distribution. The risk areas with big drift are clearly. Understanding the ship drift can prevent the occurrence of grounding and collision in narrow route. Certainly, a quantitative and detail analysis of the actual ships drift behavior will result in a sensible and appropriate simulation traffic model and the development of an ideal navigation plan for ensuring the ship navigation more safety and ship energy and economic efficiency. Moreover, the analysis results can improve the ship maneuverability and ship design as an important and valuable reference. The study contributes to the IMO's energy efficiency requirements. The information is valuable for the MDA in ship navigation, especially for the foreign operators. If the operates can understand the risk areas before their voyage, it is more attention to safe navigation. According to understand the ship drift of each ship, the traffic management side can apply the information to support the ship navigation safety in narrow straits. Moreover, According to the encounter situation and approaching distance of ships navigating, the latent risk areas were extracted. These information resources can help the ship to avoid the risk. The information is very valuable information for MDA to contribute in the prevention of ship accidents.

3. Related the congestion areas around ports, this study understood the actual situation of waiting ships. The positional distribution and time period of the waiting ships was obtained. Approximately 25% of all AIS-equipped ships waited in Osaka Bay. It is confirmed that the waiting ships inhibit the sailing ships entering the ports. Due to the waiting ships anchored around the entrance of ports, most sailing ships navigated close to the waiting ships. In real navigation examples, it was found that the waiting ships interfered with a sailing ship's navigation, and the sailing ship changed her course and took a devious route in order to avoid the waiting ships. The waiting ships have a negative influence on maritime traffic, in relation to both safety and the economy. It is important to reduce the quantity and laytime of waiting ships. According to this information, the operators can understand the situation of anchoring ships before the voyage. This information is expected to prevent the ship accidents in the coastal areas.

4. According to the behavior of waiting ships, the waiting situation of ports in Osaka Bay and waiting time of ships. It is found that the number of waiting ships gradually increased from the evening to the next morning when the port opened, which indicated that most ships arrive early and anchor offshore to wait for a berth to open. The number of waiting ships and their waiting times were determined according to the day and time period during the investigation. The waiting time was determined according to the type of ship. Port management side can apply these information to understand the situation of waiting ships. It can contribute to the safety and efficiency of port operations, such as the conservation of route and the enactment of the anchoring areas for the safety and efficiency for the port operating.

5. Analysis of the ship navigation for entire ship voyage, in order to ease the ship congestion around the port areas and realize the on- time ship navigation. The entire ship voyage in Seto Inland Sea (between Kanmon and Osaka) was extracted. The ship traffic of the entire voyage ships via the straits was understood. It is obtained that many ships passed through toward Osaka or Kanmon during the night time. This information can be applied to ensure safe navigation and the development of an efficient and economic navigation schedule. Container ships navigate in the Seto Inland Sea and the open sea, respectively, based on the size and cargo capacity. From the analysis based on the trajectories of ships, the ships navigated three routes in this area depending on their TEU capacity. The entire voyage of container ships was analyzed based on speed and sailing time. Consequently, this study identified the sailing time distribution of the entire operation and the passing time for each strait in the Seto Inland Sea. Moreover, the characteristic of the change in speed was determined; in particular, the container ships navigated the inland sea with frequent increases and decreases in speed. The waiting activity of container ships was found by the analysis of the entire voyage. Majority of container ships entered the port within 6 h and many ships arrived early and then passed the night waiting for a berth. Therefore, the waiting ships congested between midnight and morning. The avoidance behavior is frequent that result in the inefficient operations in fuel consumption. Port side can use these information to set up more efficient cargo handling schedule. It not only contributes to reduce the waiting ships but also the stagnation of track traffic on land.

6. In order to understanding the navigation distribution of ship navigating Seto Inland Sea for the realization the on- time ship navigation, the navigation situation of ferry was analyzed. The navigational situation of ferry was obtained. This information can be the important reference to realize the on-time navigation. The ship is changed frequently and slowed down when passing through both straits. It must be remarked that there is a large influence of the currents and route restrictions as well. However, the behavior was not good to the navigation safety and efficiency. The ship was able to rapidly increase the speed after a slowdown, in order to catch the destination on time. Moreover, the navigation speed was decreased close to 12 kns in restricted route, never less than this speed. On the basis of the information, it was found that selection of navigation route and the efficient speed distribution. The navigational speed and time were understood. This information can be applied to ensure safe navigation and the development of an efficient and economic navigation schedule. Detailed flight information by each ship will be an important reference to achieve efficient operations.

Finally, the study illustrated the applications of the various information, it is valid information that was proofed. The information database contributed to the MDA in ship navigation. In the future, this study will analyze more large quantities data for the information database. Moreover, this study aims at the construction of an effective information system for the user based on the information database.

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Publication List

Journal Publication

(1) 高欣佳，牧野秀成，古莊雅生：AIS データを用いた沖待ち船舶の航行実態解析に関する研究，土木学会論文集 B3（海洋開発），Vol.70，pp.948-953, 2014.

(2) Xinjia GAO, Hidenari MAKINO and Masao FURUSHO: Elucidation of Latent Risk of Navigation Using an Actual Ship Behavior Analysis, Journal of Traffic and Transportation Engineering 4, 131-140, 2016. DOI:10.17265/2328-2142/2016.03.002.

(3) Xinjia GAO, Hidenari MAKINO, Masaki FUCHI and Masao FURUSHO : Comparison of Navigation Risk in Seto Inland Sea Route and Open Sea Route by Actual Ship Behavior Analysis, Journal of Maritime Researches, 9-20, 2016.

(4) Xinjia GAO, Hidenari MAKINO and Masao FURUSHO: Ship Behavior Analysis for Real Operating of Container Ships Using AIS Data, International Journal on Marine Navigation and Safety of Sea Transport (TransNav), Volume10(2), 213-220, 2016. DOI: 10.12716/1001.10.02.04

(5) Xinjia GAO, Hidenari MAKINO, Masao FURUSHO: Analysis of Ship Drifting in a Narrow Channel Using Automatic Identification System (AIS) data, WMU J Marit Affairs, 2016. (Printing)

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(1) 高欣佳，牧野秀成，古莊雅生：AIS データを用いた日中韓の海上交通の保全に関する基礎的研究，日本船舶海洋工学会講演会論文集，第 18 号, 283-286, 2014.

(2) Xinjia GAO, Masao FURUSHO and Hidenari MAKINO: Analysis of Ship Traffic Flow in Narrow Channel Utilizing AIS Data, Asia Navigation Conference (ANC), Xiamen, China, 61-70, 2014.

(3) 高欣佳，牧野秀成，古莊雅生：AIS データを用いた石油コンビナート周辺海域における船舶の沖待ち状況解析，第 25 回海洋工学シンポジウム講演論文集, 565-570, 2015.

(4) Xinjia GAO, Hidenari MAKINO, Masao FURUSHO: Analysis of Navigation for Entire

Ship Voyage in Seto Inland Sea Using Automatic Identification System Data, Asia Navigation Conference (ANC), Kitakyushu, Japan, 326-333, 2015.

(5) Xinjia GAO, Hidenari MAKINO, Masao FURUSHO: Research on the Real Movement of Container Ship between Japan, China, and South Korea Using AIS Data, 11th International conference on Marine Navigation and Safety of Sea Transportation (TransNav2015), Gdynia, Poland, June, 17-19, 2015.

(6) Xinjia GAO, Hidenari MAKINO, Masao FURUSHO: Analysis of Actual Situation of Waiting Ship Using AIS Data, Proceedings of the Twenty-fifth (2015) International Ocean and Polar Engineering Conference, Kona, Big Island, Hawaii, USA, June 21-26, 883-888, 2015.

(7) Xinjia GAO, Hidenari MAKINO, Masao FURUSHO: Study on Ship Evacuation Supporting System based on 3D GIS, （Oceans2016）MTS/IEEE, Monterey California, September, 2016. (Printing)