TRANSNAV
http://www.transnav.eu
the International Journal on Marine Navigation and Safety of Sea Transportation
Volume 10
Number 2
June 2016

DOI: 10.12716/1001.10.02.04

Ship Behavior Analysis for Real Operating of Container Ships Using AIS Data

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ABSTRACT: The aim of this paper is to understand the real activity and operating situation of container ships in order to improve navigation efficiency. The study focused on the navigation for an entire ship voyage to understand the real activity of container ships using the historical ship navigation based on Automatic Identification System (AIS) data, which is possible so as to unveil the characteristics of real ship activity. The analysis considers ship voyages in the Seto Inland Sea and its oceanic waters, which are the primary traffic routes for container transportation particularly for China, Japan, and South Korea. The results of this study can be used to improve the efficiency of container ships and develop a smoother maritime transportation.

1 INTRODUCTION

The development of international trade requires the transportation of a substantial amount of goods and materials between countries. Particularly in recent years, as the Chinese economy rapidly grows, maritime transportation centering on Asia has intensified. The large container ports in the world are mostly in East Asia (WSC, 2011-2013). The vessels responsible for the mass transportation of goods have grown in size and quantity (WSC 2015). Consequently, maritime accidents and ship congestion are frequent. Therefore, it is important to improve the safety and efficiency of maritime transportation.

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, because container ship navigation is difficult and sensitive to the weather, it is possible to affect the ship navigation. 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. (2013) and Kobayashi E. (2015) have carried out optimization of ship routing to increase the operating efficiency based on weather influence. In the studies of port operation, Avriel M. (2000) has focused on the stowage plan for containers, and Zhen L. (2016) has investigated the concept of yard congestion to increase the port operation efficiency. Since ship anchoring is influenced by multiple reasons (WSC 2015), 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. We focused on the navigation for an entire ship voyage to understand the real activity of container ships using Automatic Identification System (AIS) data. The purpose of this study is to improve the ship navigation efficiency with on-time arrival. We analyze the container ships navigating in Seto Inland Sea, Japan and its waters and entering the Kobe and Osaka ports, Japan, where the number of container ships departing and arriving from China, Japan, and South Korea continues to increase. 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.

This paper is organized as follows. Section 2 describes the method and related prior studies. Section 3 provides the actual navigation situation of container ships based on statistical analysis and ship trajectory. Section 4 presents the extraction of the entire ship voyage including ship waiting and cargo handling, and the result is explained by a case study. The interpretation of results is discussed in Section 5. Finally, Section 6 concludes the findings of this study.

2 APPLICATION OF AIS DATA

Usually, ship navigation is investigated by visual observation and radar image observation (Niwa et al., 2009). However, it is impossible to obtain data over a long period and accurately measure the position, course, and speed of the vessel. Many studies have understood the ship movement by performing simulation models (Montewka et al. 2010, Roh M and Ha S 2013). Although these models can describe the dynamic motion of the ship, majority of them can only be applied to a few specific ships.

The method used in this study is the analysis of ship navigation history. The actual ship movement utilizes automatic identification system (AIS), which is a technology that automatically provides information about a ship to other nearby ships and coastal authorities. With this, it is possible to obtain the navigation information of ships in an accurate and quantitative manner. The AIS is required to be 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 (IMO, 2003). The data transmitted include static information [vessel's maritime mobile service identity (MMSI) number, type of ship, overall length of ship, etc.], dynamic information [the current location, speed over ground (SOG), course over ground (COG), heading, navigational status, etc.], and voyage-related information such as draft and destination.

As it is possible to observe the ship navigation information more easily and quickly, AIS data have been used in maritime research such as the investigation of traffic flow (Olindersson F et al., 2015), environmental pollution survey (Coello J. et al., 2015), and so on. Makino (2012) and Gao et al. (2013) have shown that the analysis of historical ship navigation record using AIS data can reveal the characteristics of actual ship movement. These studies were good use of the actual ship navigational data. In this study, the entire voyage of container ships is analyzed by dynamic analysis technique. The navigation situation (such as the position of ship, navigation speed and ships distance, etc.) have calculated and analyzed with time. The method is possible to understood the actual situation of the enter ship voyage in a detailed and accurate manner, including the ship navigating the traffic route, waiting for berth and cargo handling.

3 ANALYSIS OF REAL ACTIVITY OF CONTAINER SHIPS USING AIS DATA

3.1 *Investigation of container ship traffic*

The research area for this study is the Seto Inland Sea and its oceanic waters located in the western part of Japan (32°31′N~ 34°57′12″N; 130°28′40″E~ 135°39′4″E). Figure 1 shows the map of the research area. In the figure, the black and blue dots indicate the trajectories of ships navigating in the research area in one day, according to the ships' position from AIS data. The trajectories of container ships are shown by blue dots. This area contains two Japanese international trade container terminals, namely Kobe and Osaka. The Kanmon Strait, located in the westernmost side of Seto Inland Sea, is the west entrance of the inland sea as the portal ships pass through and into the port of Japan.

Based on the trajectories, it is can be observed that there are two main traffic routes for ships navigating between Kanmon Strait and Kobe and Osaka ports. One of them is the Seto Inland Sea traffic route, and the other is the Pacific Ocean route.

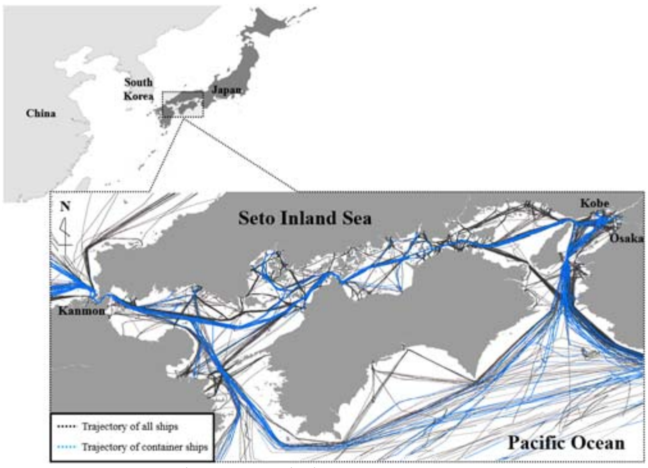

Figure 1. Research area and ship trajectories

We can check that most ships passing through these routes reside in Kobe and Osaka ports, and just a few container ships represent direct traffic into these ports without operating in the Kanmon Strait. The routes are important for Japan and are utilized as international routes for container liners owing to the East Asian economic development in recent years.

The investigation research period was between March 1 and 7, 2012. By examining the AIS data, the vessel traffic volume was obtained. The bar graph in Figure 2 shows the statistical results of the number and types of ships. We verified from the MMSI number that there were 2,610 passing ships during the research period, and more than 1,400 ships navigated this area in 1 day. The graph shows that the number of passing ships was highest 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, which includes container ships, with a contribution of approximately 63% of all passing ships.

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 1 shows the investigation result of the number and percentage of container ships according to the operators' region.

Table 1. Percentage of container ships by operators

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

We 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 2 shows the number of container ships based on TEU. The figures are based on maximum TEU.

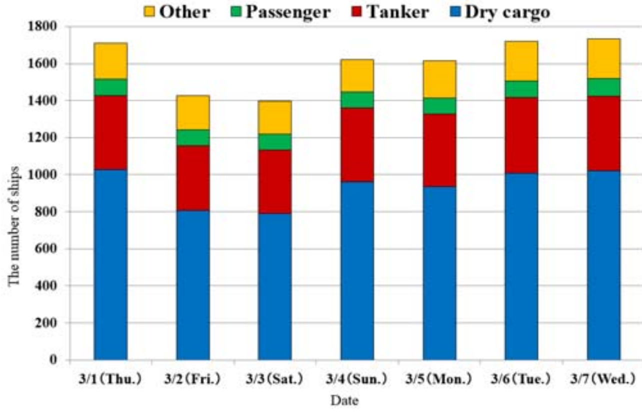

Figure 2. The number and Types of vessels in the research area

Table 2. 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.

3.2 *Analysis of container ship operations based on trajectory*

We analyzed the real activity of container ships based on tracking. Figure 3 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 geographic information system (GIS) based on the ship's position.

Figures 4 to 6 show the trajectories of container based on the TEU. Red dots present the trajectories of the TEU within the range of less than 1,999,

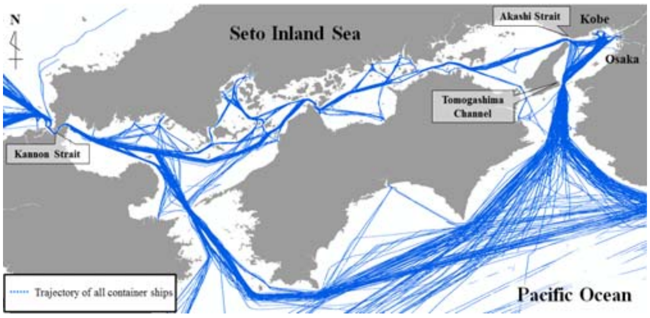

Figure 3. Trajectory of all container ships

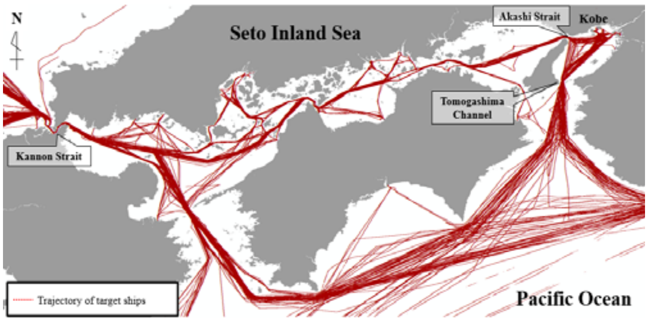

Figure 4. Trajectory of TEU within less than 1,999 (152 ships)

2,000–4,999, and 5,000–9,999, respectively. 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. 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. We 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.

From these results, the real activity of container ships navigating the different routes were understood.

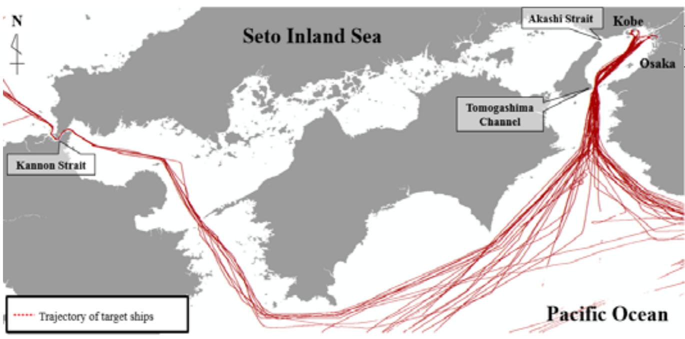

Figure 5. Trajectory of TEU within 2,000–4,999 (30 ships)

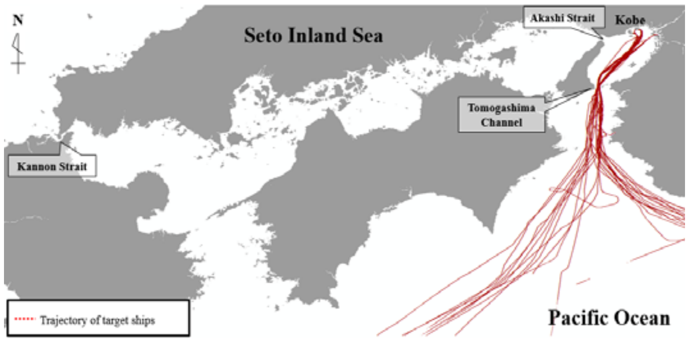

Figure 6. Trajectory of TEU within 5,000–9,999 (15 ships)

4 ANALYSIS OF CONTINER SHIP NAVIGATION FOR AN ENTIRE VOYAGE

4.1 *Extraction of entire voyage for container ships*

This study analyzed an entire ship voyage of the container ships. We obtained the navigation including ship navigating the route, anchoring offshore for waiting the berth and cargo handling.

Actually, the navigation status information included in the dynamic AIS data is used to indicate either a sailing or anchoring ship. However, some errors may have occurred (because this information is inputted manually), and most ships drifted in an area without anchoring during a temporary stay. Therefore, using the navigation status information only would make it difficult to determine the target data

To address this problem, we extracted the ship navigation for the entire voyage using the position and speed data. We interpolated the position data on a per-second basis using linear interpolation method. Figure 7 shows the extraction process of the entire container ship voyage. According to the information during the research period, the weather had no significant effect on the ships. Consequently, we established whether a ship was anchoring or sailing based on its speed over ground (SOG) and sailing distance. We conducted the computations when the branch condition was satisfied. Finally, ships that were cargo handling or waiting offshore were determined based on the ship position within and without berths. At the same time, waiting and cargo handling times were calculated and recorded.

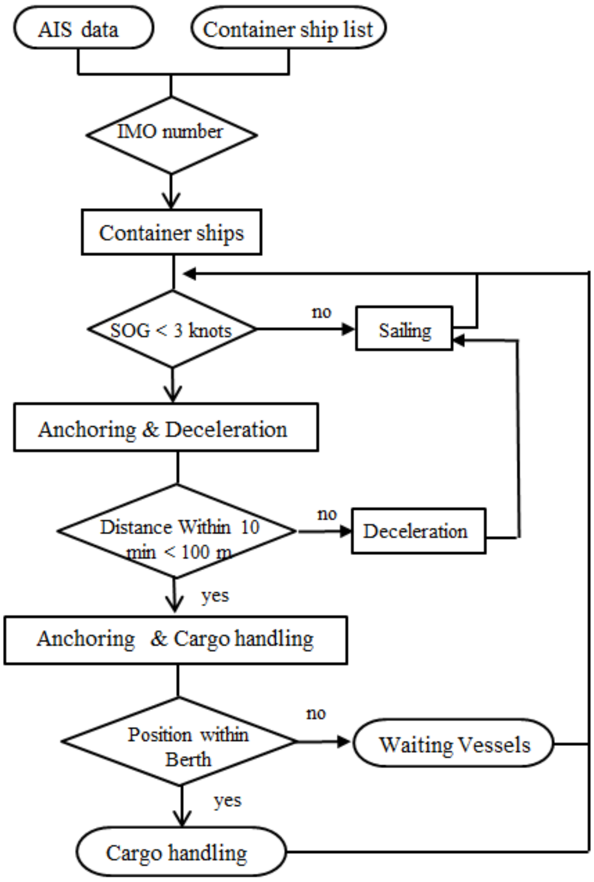

Figure 7. Extraction process of entire voyage of container ship

4.2 *A case Analysis of container ship operations based on trajectory*

We 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 three sample ships navigating in Seto Inland Sea route and Pacific Ocean route, respectively. Table 3 lists the principal characteristics and navigation information of the sample vessels.

Table 3. Principle sample ship characteristics

Item	Ship A	Ship B	Ship C
Route	Seto Inland Sea	Open Sea	Open Sea
Ship length (m)	148	148	338
Max. TEU capacity	1,118	1,118	9,012
Navigation distance (n.m.)	252	329	-
Navigation time (h)	24	22	-

All three sample ships are container ships. Ships A and B have equal lengths and TEUs, making their maneuverability identical. Ship C was the largest ship during the investigation. We used the identical ships transiting the east-west route. The analysis of the entire ship voyage used speed and sailing time.

Figures 8 to 10 show the trajectories with speed distribution and changes in ship speed for Ships A, B, and C. The higher illustration in each figure 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.

Figure 8 shows the sailing analysis of ship A; 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. 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. We 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.

Ship B is also a container ship having the same length and TEU as Ship A. However, these similar ships navigated through different routes. 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 h and traveling 329 nautical miles. Compared with Ship A, 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. Ship C belongs to Northern Europe service. The ship navigated from Hong Kong toward Kobe port passing through the open sea. According to the data provided by Japan Meteorological Agency during the investigation period, the weather conditions were zero visibility, low rainfall, and low wind speed. Therefore, it was assumed that the current affected the fluctuation of speed before passing through Tomogashima Channel. The maximum speed was over 20 kns after passing through the channel, approximately at 19.5 h and 295 nautical miles. 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.

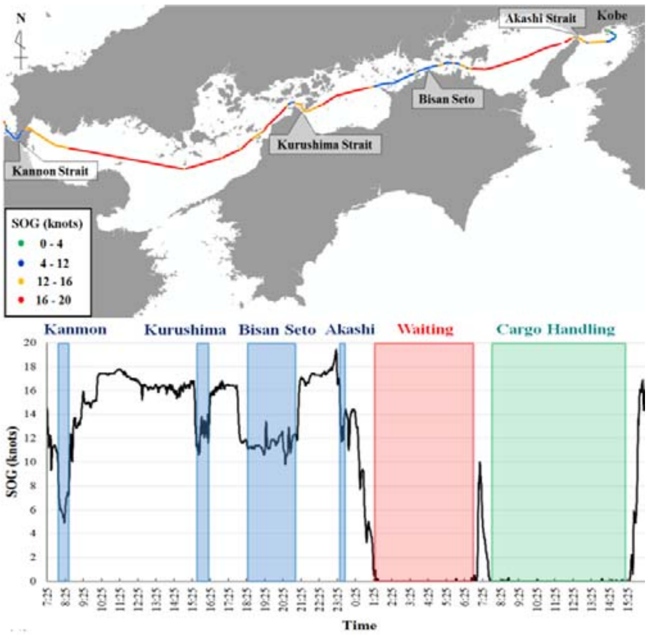

Figure 8. Tracjectory and speed distribution of Ship A

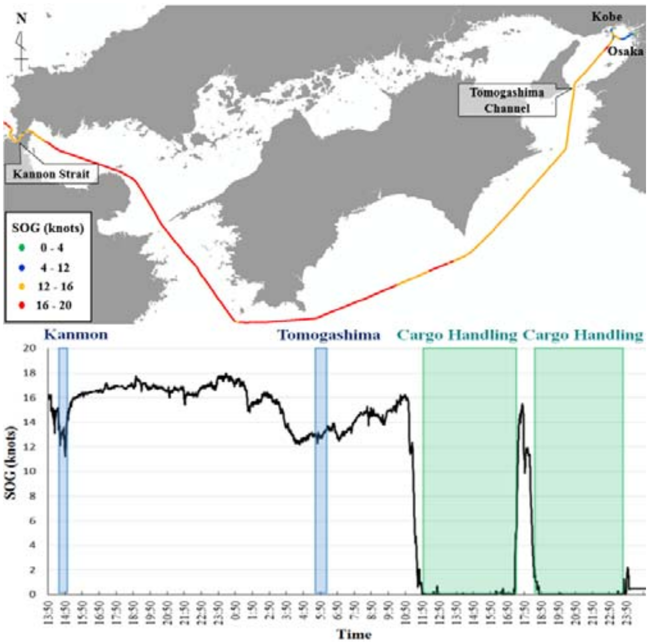

Figure 9. Tracjectory and speed distribution of Ship B

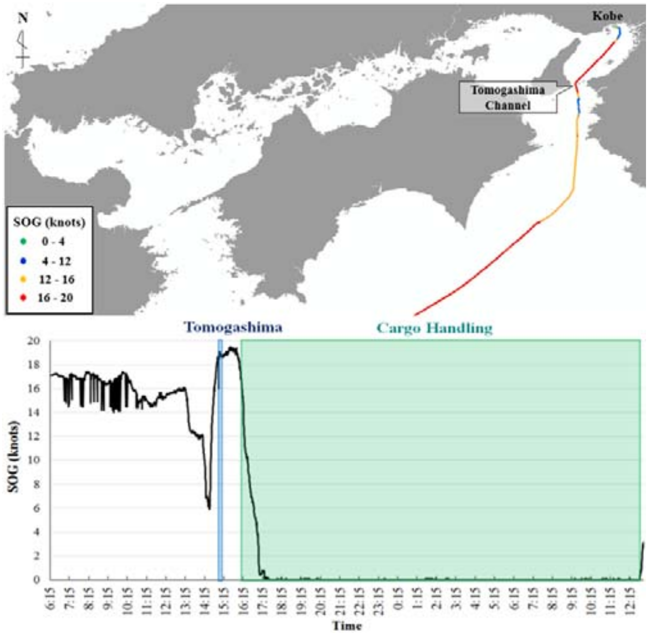

Figure 10. Tracjectory and speed distribution of Ship

The speed of Ship A was 0 kn before the ship entered the port, which is indicated by the red part in Figure 8. The extracted ship waiting information confirmed that Ship A waited offshore before entering the port. The waiting time was approximately 5.5 h. Consequently, Ship A had a longer sailing time than Ship B. Unlike Ship A, Ships B and C entered the port directly. Moreover, the cargo handling was verified. The cargo handling time of Ship A was approximately 7.5 h, which is shown by the green part on the line graph in the figure. Ship B stopped at Kobe port and Osaka port; the cargo handling was done two times during the voyage. Ship C has the largest TEU in the investigation and took approximately 18 h of cargo handling.

4.3 *Waiting activity of container ships*

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 ships waiting for berths during the investigation. These waiting ships anchored around the ports. Moreover, the time of ship waiting was obtained. The waiting times of container ships are listed in Table 4.

Table 4. Waiting time of container ships

Waiting Time (h)	The number of container ships(ships)
$0 < H \leq 6$	17
$6 < H \leq 12$	4
$12 < H \leq 24$	4
$24 < H \leq 48$	1

Based on the results, we 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.

Figure 11 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.

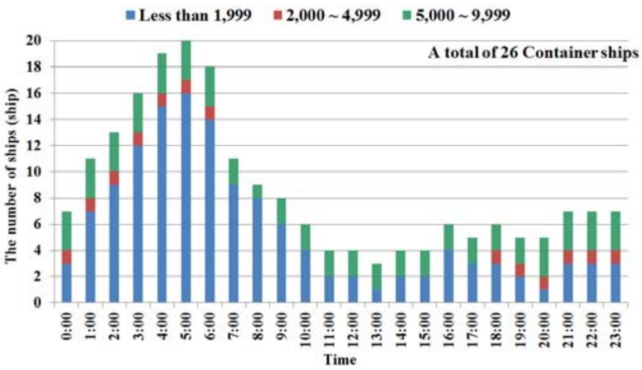

Figure 11. The number of waiting ships over time based on capacity

5 DISCUSSION

This study presented the actual situation of container ships navigating in Seto Inland Sea and its oceanic waters. We successfully extracted the container ship navigation information for the entire ship voyage using dynamic analysis of AIS data. Based on the analysis of the entire ship voyage, the navigation characteristic of container ships was figured out. Container ships navigate different routes based on size and cargo capacity. Moreover, we discovered the activity of container ship waiting: these ships arrived at their destination early and then passed the night waiting for a berth. One of the reasons considered is that the Seto Inland Sea has a complicated geographical environment—the inconvenience from traffic control and ship congestion causes difficulty in navigating this route. Therefore, most ships provide sufficient time to sail the inland sea rapidly, in order to prevent delay. However, the situation can result to more waiting ships. Consequently, waiting ships cause numerous offshore maritime accidents, ship congestion, and environment issues. 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 optimum navigation route and schedule.

Future work will be devoted to the analysis of the navigational behavior of other types and sizes of ships and more details will be considered. A quantitative and detailed analysis of the real activity is certainly necessary to improve safety and economic efficiency in ship navigation.

6 CONCLUSIONS

This study analyzed the real activity of container ships by the application of AIS data. The container ship navigation for the entire voyage was identified. The main results of the analysis are the following:

1. 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. Ships within the range of 1–1,999 TEU passing between Kanmon and Osaka navigated in the inland sea and the open sea. However, ships with a TEU in the range of 2,000–4,999 navigated in open sea between the Kanmon and Tomogashima Strait and sailed in open sea only. Moreover, ships exceeding 5,000 TEU did not navigate the inland sea; they just pass in and out of the Tomogashima Channel.
2. The entire voyage of container ships was analyzed based on speed and sailing time. Consequently, we 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.
3. 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.

This study provided core research vital to the improvement of safety and efficiency of maritime transportation.

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