Efficiency Evaluation of Global 20 Major Container Ports Based on AIS Data

Zhao Nan, Chen Weijie, Zhang Jing, Xie Wenqing

Shanghai International Shipping Institute

To improve the safety and efficiency of navigation, the International Maritime Organization (IMO) requires all ships of 300 gross tonnage and upwards engaged on international voyages and cargo ships of 500 gross tonnage and upwards not engaged on international voyages and passenger ships irrespective of size to be fitted with an automatic identification system (AIS), which contributed to the widely application of AIS. Meanwhile, the application of AIS produces a large amount of ship trajectory data.

According to Gartner's IT Glossary, big data is defined as high-volume, high-velocity and high-variety information assets that demand cost-effective, innovative forms of information processing that enable enhanced insight, decision making, and process automation. From this point of view, big data has at least two major characteristics. One is that the big data has a huge amount of data. And the other one is that it can realize the "value added" function through processing the massive data. Therefore, the research of big data should also be equipped with these two basic characteristics.

AIS trajectory data is huge and various, including the static information such as ship name, ship type, ship draught, etc., and also the real-time dynamic information such as ship position, ship speed, ship heading, etc. Thus, this paper proposed an effective and valuable analysis through processing the AIS trajectory data of ship.

In traditional, the evaluation and comparison analysis of ports usually depends on the indicator of throughput. However, the evaluation based on throughput can only reflect one aspect of ports, which may lead to non-comprehensive result. Firstly, the handling capacity of port has a strong correlation with the investment of shoreline and land resources. It is difficult to evaluate the ports efficiency based on scale of throughput, especially for those with similar throughput. For instance, as the integration of port resources, the cumulative throughputs of integrated ports are statistically, which results in the rapidly increase in the port throughput ranking, but cannot reflect the improvement of port efficiency. Secondly, the geographical location and distribution characteristics of each port are different. The frequency of ships handled in the ports belong to the island or river-sea junction is higher than that in the ports belong to inland. And this feature also cannot be reflected by the throughput indicator. Thirdly, the efficiency of the port is not only the productive efficiency, loading and unloading efficiency, but also the comprehensive efficiency, including towing, pilotage, mooring waiting, and other port services which occurred after ships enter the ports. However, it is difficult to quantify these efficiency indicators by the traditional port statistics. To overcome the above obstacles, the Port Research Department of Shanghai International Shipping Institute would like to use the AIS data to study the comprehensive efficiency of the port from multiple perspectives and provide more detailed analysis in *Global Port Development Report.*

This paper selects the container ports ranking high in terms of container throughput as the research objects. The original data is collected from the ships engaged in international route from January to December 2017.

Part 1: Arrival Vessels' Structure Analysis of Global 20 Major Container Ports

The analysis of the arrival vessels' structure is intended to assess the hub status of ports. Hub port often have three characteristics: first, the number of vessel arrival is higher; second, there are more large-scale ships arrivals; third, the proportions of ships type and ship size are balanced.

Figure 1. Arrival Vessels' Structure of Global 20 Major Container Ports

According to the above three characteristics, the conclusion can be found by comparing the arrival vessels' structure of global 20 major container ports.

1. Singapore Port is the busiest port in the world.

Judging from the scale of arrival ships, these 20 ports can be divided into three echelons. The first echelon, represented by Singapore Port, Shanghai Port, Shenzhen Port, Hong Kong Port, Busan Port and Ningbo Port, can reach more than 10,000 of container vessels in 2017. Rotterdam Port, Kaohsiung Port, Qingdao Port and Xiamen Port form the second echelon with the number of ship arrival between 5,000 and 10,000 ships. Antwerp Port, Tianjin Port, Guangzhou Port, Dubai Port, Tanjung Pelepas Port, Hamburg Port, Dalian Port, Port of New York and New Jersey, Port of Los Angeles, and Port of Long Beach are the third echelon, with less than 5,000 ship arrival in 2017. Among those ports, Singapore Port is undoubtedly the busiest port in terms of the number of arrival ships.

In addition, it can be found that the number of arrival ships is not exactly consistent with the throughput by comparing the ranking of 20 container ports in terms of these two indicators. Taking Ningbo Port, Busan Port and Hong Kong Port as examples, although Ningbo Port has become the fourth largest container port in the world by container throughput in 2017, it is still not as good as Hong Kong Port and Busan Port in the indicator of ship arrivals. And although the container throughput of Guangzhou Port has ranked seventh in the world, the number of arrival vessels engaged in international trunk transportation is relatively small, mostly based on small barges in the Pearl River.

Moreover, ports in United States are the least in terms of ship arrivals among the 20 container ports. The main reason is that the ships arrived in the United States ports are almost large vessels engaged in international trunk transportation, or 4,000-8,000TEU vessels engaged in north-south route transportation. And the main distribution way of United States ports is transported by rail, which leads to less demand for coastal shipping.

Table 1 Ranks of Global 20 Major Container Ports in Terms of Container Throughput and Number of Ship Arrivals in 2017

Ranking	Container throughput	Vessel arrivals of Port
1	Shanghai	Singapore
2	Singapore	Shanghai
3	Shenzhen	Shenzhen
4	Ningbo	Hong Kong
5	Hong Kong	Busan
6	Busan	Ningbo
7	Guangzhou	Rotterdam
8	Qingdao	Kaohsiung
9	Dubai	Qingdao
10	Tianjin	Xiamen
11	Rotterdam	Antwerp
12	Antwerp	Tianjin
13	Xiamen	Guangzhou
14	Kaohsiung	Dubai
15	Dalian	Tanjung Palapas
16	Los Angeles	Hamburg
17	Hamburg	Dalian
18	Tanjung Palapas	New York & New Jersey
19	Long beach	Los Angeles
20	New York & New Jersey	Long beach

2. Shenzhen Port, Shanghai Port, Singapore Port, and Ningbo Port are the typical handling ports for very-large ships.

According to the analysis of statistical data, the very-large vessels on or above 12,000 TEU are mainly engaged in the Asia-Europe route. For the number of arrival ships on or above 12,000 TEU, each of Shenzhen Port, Shanghai Port, Singapore Port and Ningbo Port has more than 1,000 callings in 2017. Shenzhen unexpectedly became the most popular port to call for the ships on or above 12,000 TEU. The number of containers transported to Europe and America accounts for 50% of the international container throughput of Shenzhen Port, and 65% of the container throughput of Ningbo Port is shipped to Europe, America, Middle East and ASEAN. Furthermore, on the Asia-Europe route, the number of ports called by container ships on or above 16,000 TEU have been reduced to five in East Asia, and the container ships on or above 18,000 TEU can only be handled in Shenzhen Port, Shanghai Port, Ningbo Port and Hong Kong Port. In addition, with verification of trajectories of the ships on or above 18,000 TEU, it is obvious that the above four ports are the typical hub nodes in trunk route.

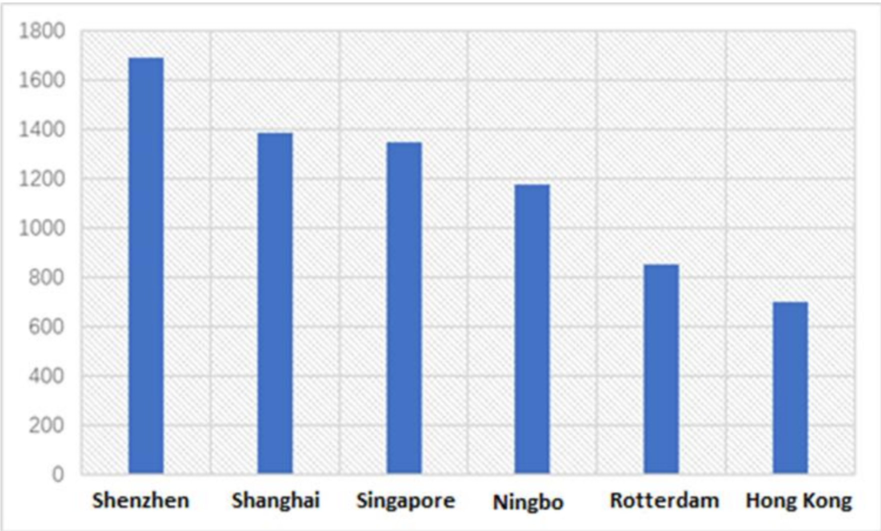


Figure 2. The Call of Ships on or above 12,000 TEU of Global Hub Ports in 2017

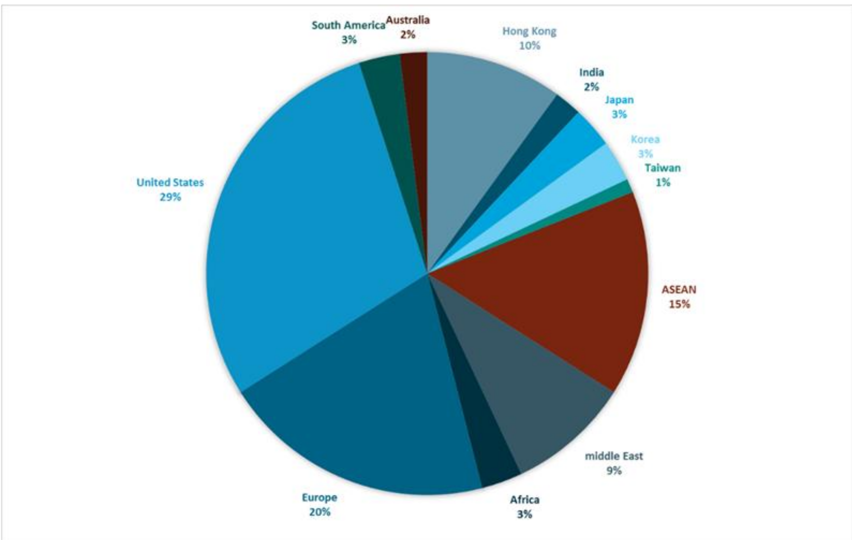


Figure 3. The Proportion of International Containers in Shenzhen Port in 2017

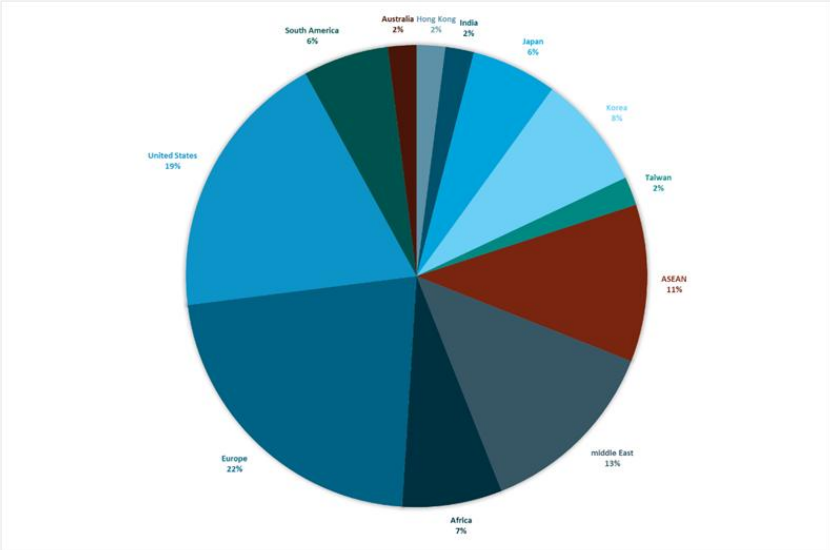


Figure 4. The Proportion of International Containers in Ningbo Port in 2017

Figure 5. Trajectories of ships on or above 18,000 TEU in 2017

3. Ports have different features in arrival vessels' structure.

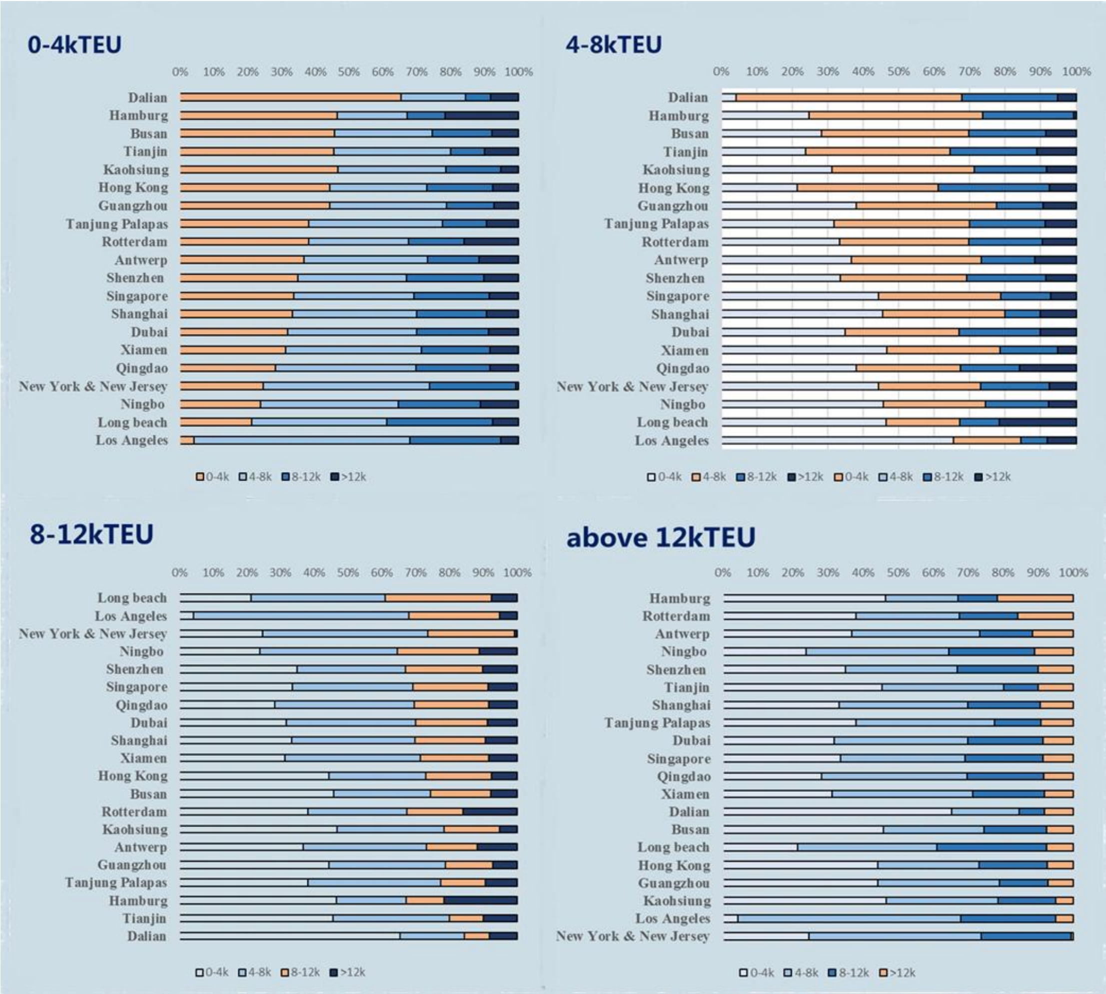


Figure 6. Arrival Vessels' Structure of Global 20 Major Container Ports by Ship Type

Ships of 0-4,000TEU account for a relatively high proportion of the arrival ships in regional hubs. Typically, it can be seen that container ships of 0-4,000 TEU account for nearly 70% of the total number of arrival ships in the port of Dalian, Rotterdam, Kaohsiung and Busan. Dalian Port is a regional container hub in northeast China, with 45% domestic container transportation and 90% international containers from three northeastern provinces. While, Rotterdam Port is located at the mouth of the Rhine with a large part of the transportation carried out by barge within the European region.

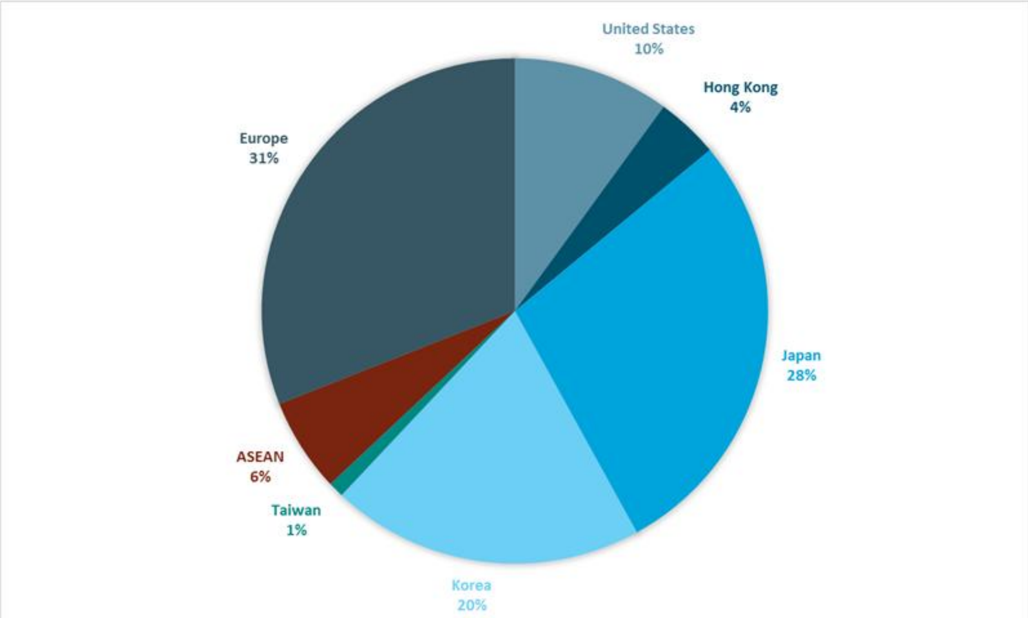


Figure 7. The Proportion of International Containers in Dalian Port in 2017

Ships of 8,000-12,000TEU occupied a higher proportion of the arrival ships in the ports of United States. According to statistics, American Ports, including Long Beach Port, New York New Jersey Port and Los Angeles Port, had the highest proportion of 8,000-12,000TEU container ships among the global 20 major container ports. The international trade of United States mainly comes from Canada, Mexico, China, Japan, and major European countries. Affected by the Panama Canal, the ship types engaged in the route from Far East to North America, North America and Europe are mainly focus on 8,000-12,000 TEU, while the proportion of ships on or above 12,000 TEU operated in the ocean line is relatively small. Moreover, ships engaged in North-South American route are mainly above 4000 TEU. Therefore, from the point of ship size, the proportion of ships above 12,000 TEU or below 4000 TEU is relatively small in American Ports.

Singapore Port, Shanghai Port and Hong Kong Port are similar in the proportions of arrival ships' configuration. Comparing the proportion of arrival ships in Singapore Port, Shanghai Port and Hong Kong Port, it can be found that the container ship of 0-4,000TEU accounted for nearly half of the total number of arrival ships, and the proportion of the container ships of 4,000-8,000TEU is about 20%-25%, 8,000-12,000 TEU container ships represent 13%, and container ships on or above 12,000 TEU occupied 7%-10%. In the past researches, some experts recognized Singapore Port and Hong Kong Port as typical international hub ports for its's more than 70% international transshipment containers, while of Shanghai Port is not considered as an international transit hub port with the T/S ratio less than 10%. However, the differences between Shanghai Port, Singapore Port and Hong Kong Port have been ignored. The ratio of transshipment cannot be used to measure whether a port is an international transit hub due to the differences in hinterland of different port. From the perspective of vessel arrivals, Shanghai Port has functioned as an international hub port to serve the international trunk route as Singapore Port and Hong Kong Port.

Table 2. The Structure of Arrival Ships of Major Container Hubs by Ship Type

	0-4k	4-8k	8-12k	>12k
Singapore Port	53.4%	25.8%	13.0%	7.9%
Shanghai Port	55.1%	21.9%	13.4%	9.6%
Shenzhen Port	38.7%	27.3%	19.1%	14.9%
Hong Kong Port	56.4%	23.3%	13.6%	6.7%

Part 2: Time Cost Analysis for Ships in Port of Global 20 Major Container Ports

As the port customer, the shipping company would like to judge the service quality of a port in two aspects: time and cost, and even will be more sensitive to time requirements. The service efficiency of the port can be reflected by the time cost of the ship in port. In general, the services provided by the port for ships can be divided into two categories: berth loading and unloading services and ancillary services. Auxiliary services include towing, pilotage, mooring, port inspection, etc. Therefore, this paper focus on the efficiency of berth loading and unloading services and also the efficiency of ancillary services.

1. Berth Loading and Unloading Time Cost Analysis

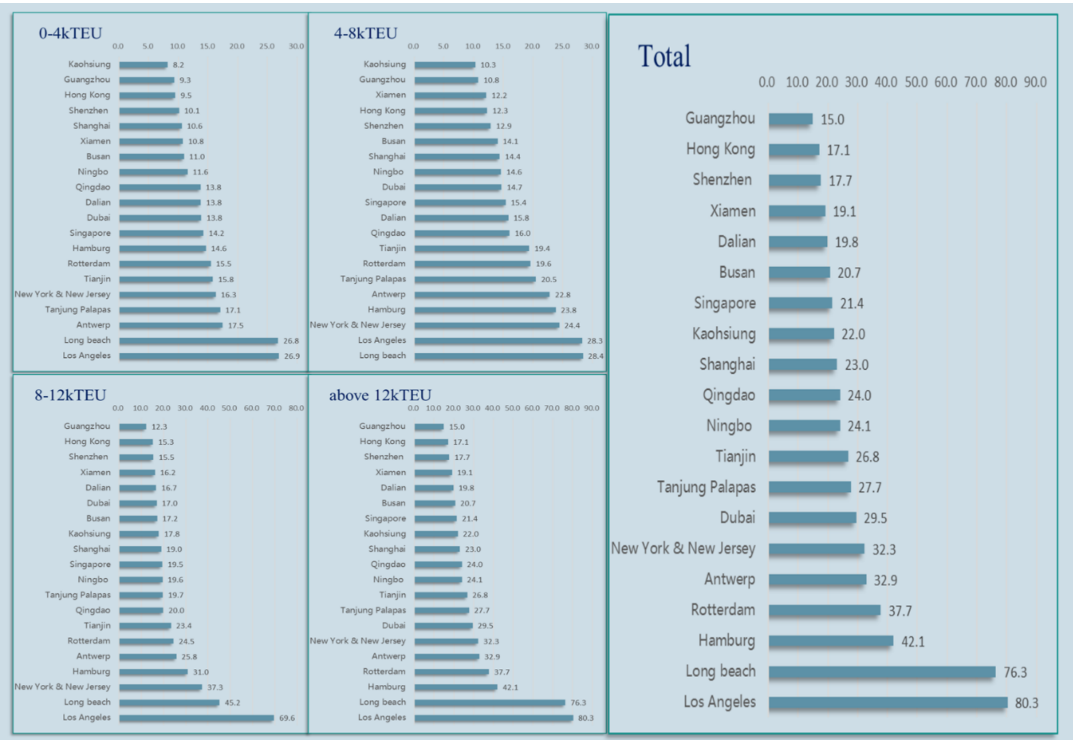
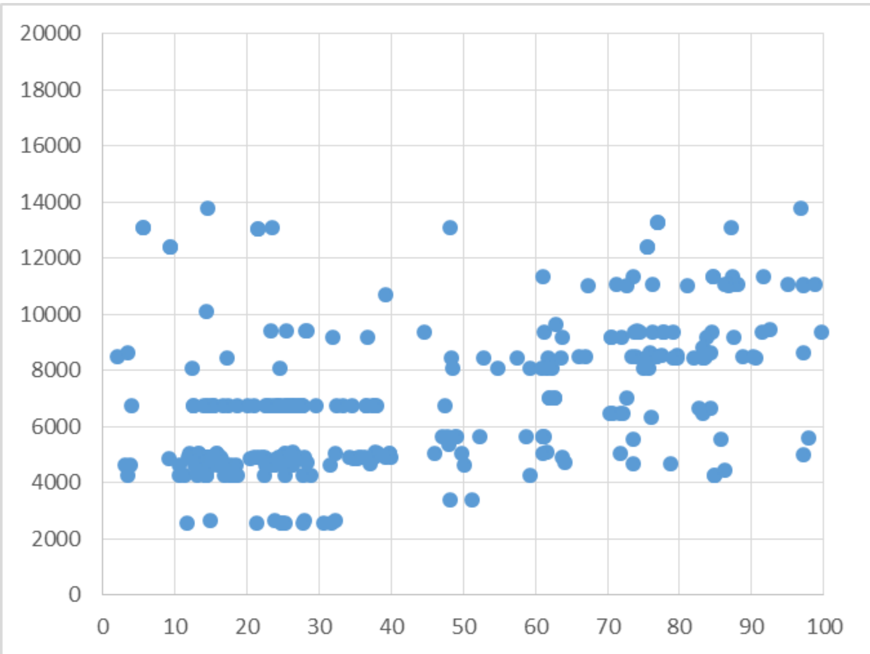


Figure 8. Berth Loading and Unloading Time of Ships in Global Major Container Ports by Ship Type

(1) The berth loading and unloading time cost of arrival ships in each port is very close.

The berth loading and unloading time cost of ship is relative with the amount of containers that the ship handled in a port. However, it is meaningful to compare the loading and unloading time cost of similar type ships for the ports with same throughput scale. According to Figure 8, it can be found that the port in the same throughput scale has similar performance in terms of berth loading and unloading time. For example, for a ship of 0-4,000 TEU, the berth loading and unloading time is about 8-15 hours, and for a 4,000-8,000TEU ship, it is usually about 10-16 hours. The efficiency of loading and unloading operations is closely related to the number of shore bridges and operating systems of port. With the development of technology, the technical differences in global major container ports are tiny, so there is no significant difference in berth loading and unloading efficiency. From another point of view, as the small difference in berth loading and unloading efficiency, the shipping company's perception of port service efficiency may be more reflected by the time cost of auxiliary services.

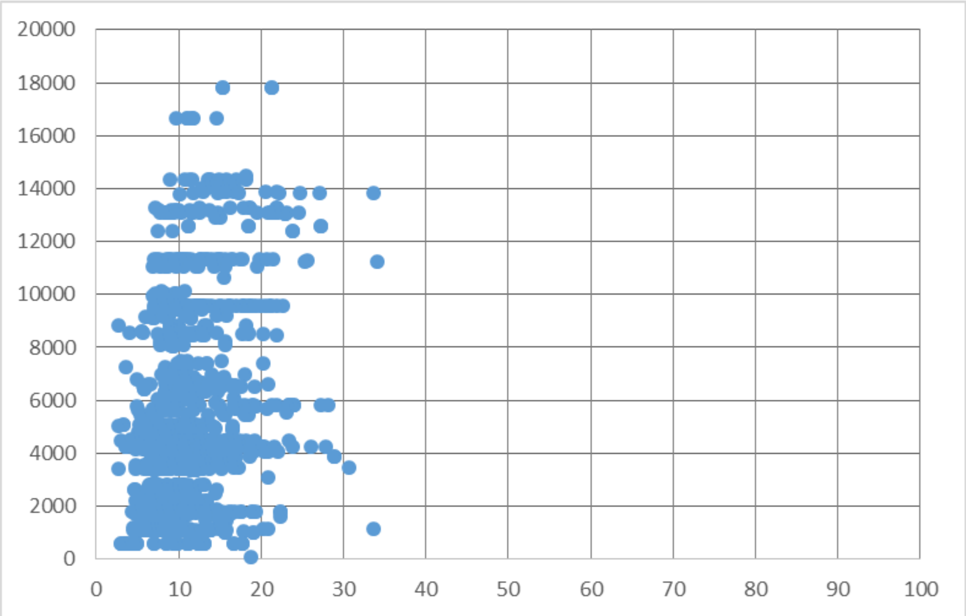
(2) The berth loading and unloading time of American ports is higher than that of others. According to Figure 8, among the 20 major container ports in the world, the berth loading and unloading efficiency of American ports is significantly lower than that of other ports. For example, for a container ship of 0-4,000 TEU, the berth loading and unloading time of several ports in the United States is almost three times than that of the most efficient port. And a ship on or above 8,000 TEU needs stay in berths for up to 7 days. Although compared with Chinese ports, US ports have relatively high loading and unloading capacity for a single large ship, but the difference between the scale and time is not proportional. The main factor influenced the loading and unloading time is the labor regulation limitation of United Stated.



Note: The horizontal axis is time/hour; the vertical axis is the ship type /TEU.
Figure 9. Berth Loading and Unloading Time of Ships in Los Angeles Port

(3) China's major container ports has higher loading and unloading efficiency.

According to Figure 8, the loading and unloading efficiency of the main container ports in China is generally high, and the operation of container ports in other regions is relatively backward. On one hand, China's container ports above designated size are densely distributed, which divert the volume of container ships, resulting in a relatively short loading and unloading time for single ships at berth. On the other hand, technology and operation level of Chinese ports are indeed leading the world, and the short berth loading and unloading time cost is a relatively favorable proof. Among major ports in China, Guangzhou Port has the shortest berth loading and unloading time for all types of ships, concentrated between 5-20 hours. In addition to the high efficiency of loading and unloading, another reason for the shorter berth time of Guangzhou Port is that the loading and unloading volume of a single container ship is relatively small, usually between 500 - 1,000 TEU/ship.

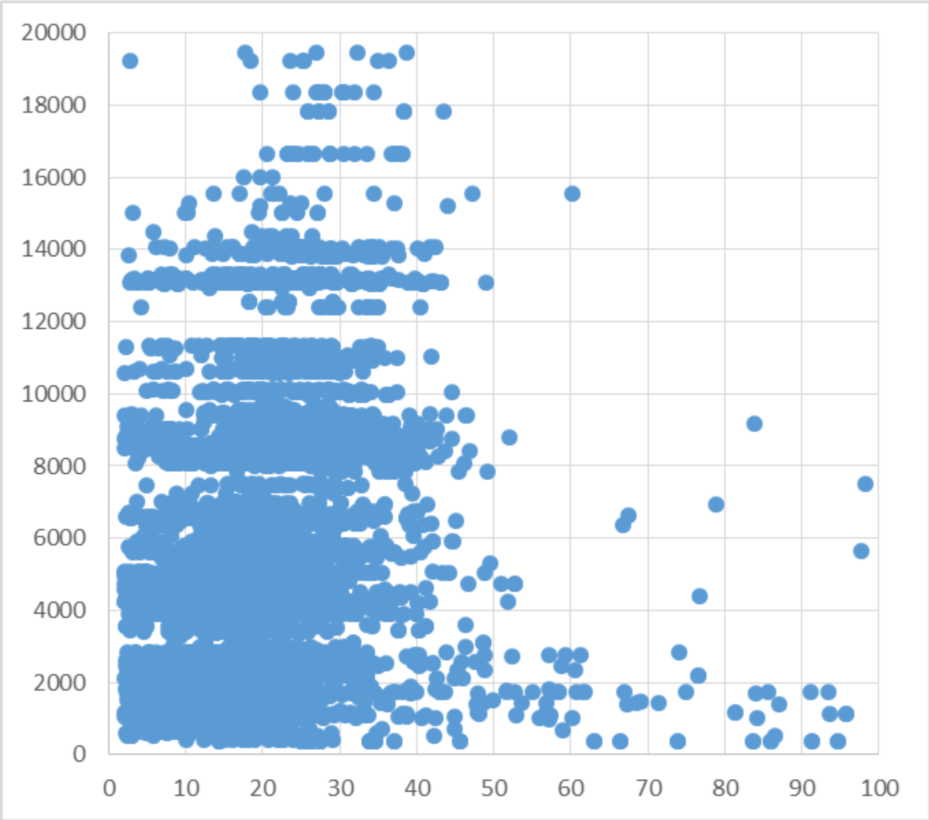


Note: The horizontal axis is time/hour; the vertical axis is the ship type /TEU.

Figure 10. Loading and Unloading Time of Ships in Guangzhou Port

(4) The longer time for ships in Singapore Port is due to its comprehensive service supply.

Compared with other international container hubs such as Hong Kong Port and Shanghai Port, the loading and unloading time for ships in Singapore Port is relatively long. The main reason is that Singapore Port is an international supply port, which can provide other services, including ship supply and maintenance after the ship is docked. According to statistics, after arrival in Singapore Port, 36.2% vessels carried out refueling and loading and unloading services at the same time, 4.5% of vessels carried out cargo handling and material supply, 10.8% of the vessels carried out the above three services, while just 32.8% vessels only for cargo handling.



Note: The horizontal axis is time/hour; the vertical axis is the ship type /TEU.

Figure 11. Loading and Unloading Time of Ships in Singapore Port

2. Port Auxiliary Service Time Cost Analysis

Port auxiliary service time refers the time needed by operation ships from receiving port operation commands, sailing from the anchorage to complete the production operation and departing from port, including the time for towing and pilotage. Therefore, by processing AIS data, the trajectories of the tugboats and pilot vessels of each port have been analyzed to determine the scope of the port boundary. Based on this, the time statistics of ships from entering the port boundary to leaving the port boundary with the loading and unloading time eliminating are collected.

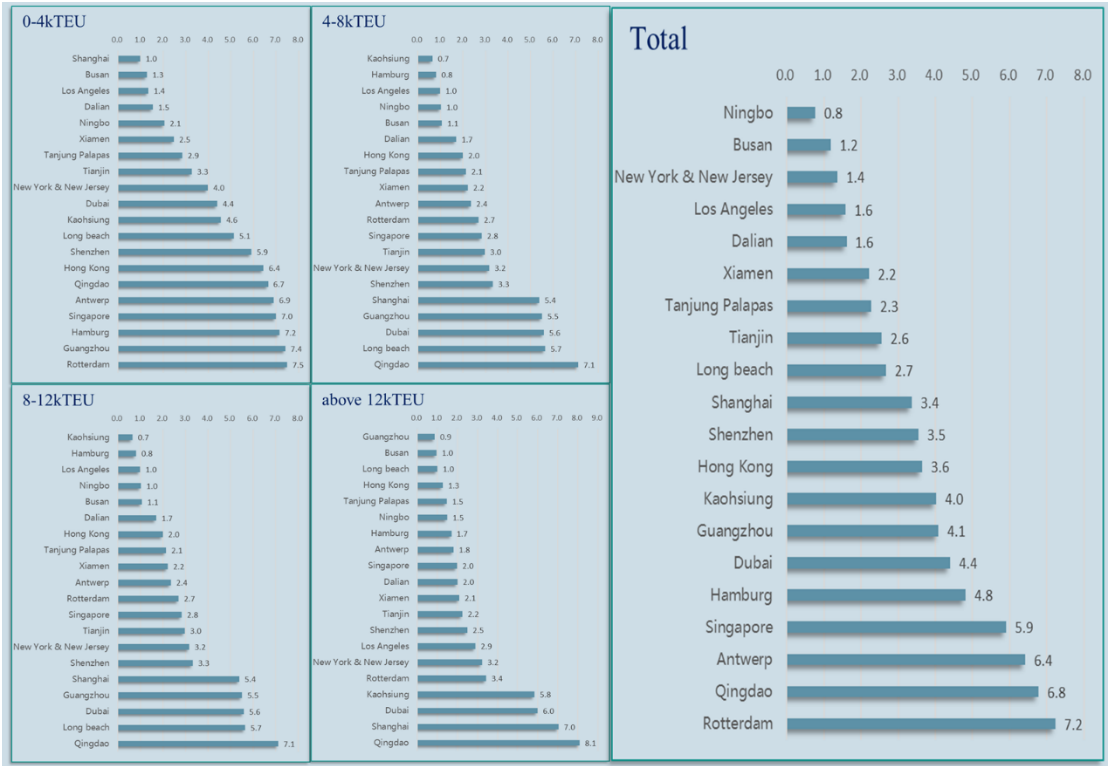


Figure 12. Port Auxiliary Service Time of Ships in Global Major Container Ports by Ship Type

(1) Small ships operations often require more mooring time.
According to the above figure, it can be found that container ships below 4,000 TEU generally require longer non-berthing auxiliary service time than other types' ship. The global major container hub ports often take precedence over the calling of large ships. Therefore, the time cost of small vessels in port is often affected under the limitation of berth.

(2) Auxiliary service time is longer for the ports at the junction of rivers and seas
According to statistics, Port of Rotterdam, Hamburg, Antwerp, and Guangzhou have longer auxiliary service time for each type of ship than other ports. The reason is that the distribution of the berths is dumbbell-shaped, except for the berths at outermost seaside piers, some berths are located in the places where the ships need longer time to pass through. And the service such as towing and pilotage often need a long time for ships. The ports located in the inland rivers are often berthed by small vessels below 4,000 TEU due to water depth restrictions. From the data, it can be found that the port of Guangzhou and Rotterdam rank relatively backward for the auxiliary service time of ships on or above 4,000 TEU.

The following figure shows the berth distribution of container terminal in the Port of Rotterdam. A and B are the two main container port areas. The container terminals such as Rotterdam World Gateway Terminal(RWG), ECT Delta Dedicated North (DDN) Terminal, Euromax Container Terminal are located in A area. And Uniport Multipurpose Terminal、Rotterdam Shortsea Terminal (RST) are situated in B area.

Affected by the factor of water depth, large container ships always choose A port area for container loading and unloading operations, and small container ships below 4,000 TEU choose B port area for container handling. From the estuary of sea to the terminal of the B area for container loading and unloading operations, a section of inland river transportation is needed, which lead to a longer auxiliary service time for the ships selected B area for operation. The same reason for longer auxiliary service time for the ships operated in Guangzhou Port. The container terminal of Huangpu Port Area is located inside and always provide service for small container ships.

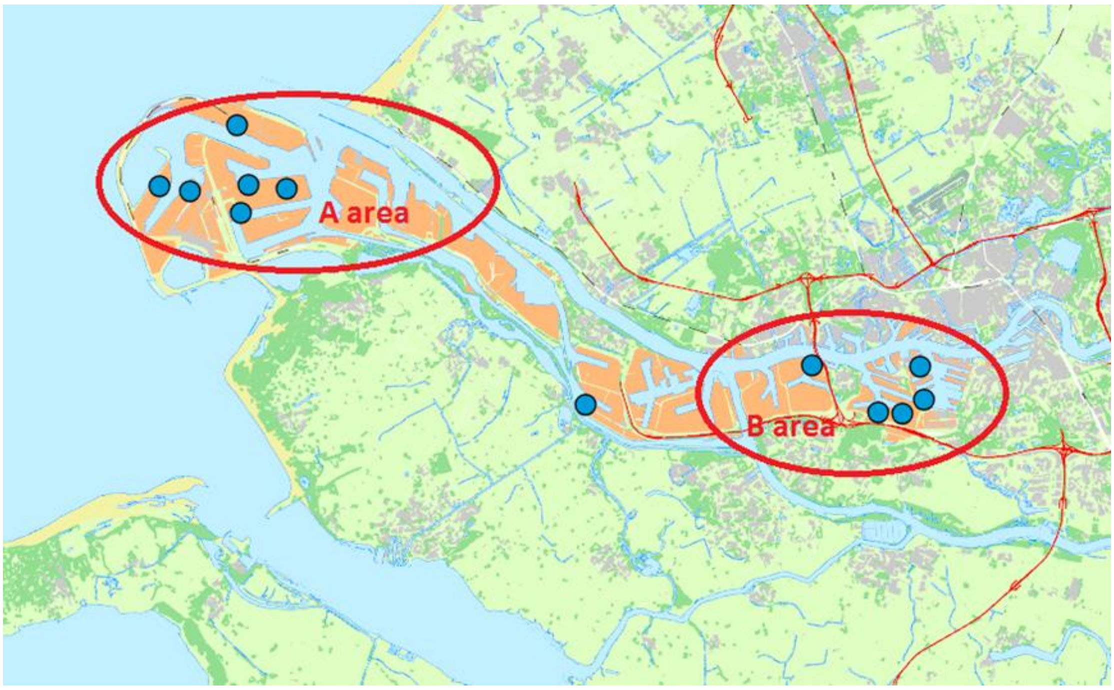


Figure 13 Berth Distribution of Container Terminal in the Port of Rotterdam

(3) American Ports performed more efficiency in port auxiliary services.
Although the loading and unloading time is longer for the ships operated in the ports of United State, the auxiliary service time is shorter and the relative efficiency is higher than that of others. For example, the Port of New York & New Jersey, and the Port of Los Angeles ranked in the top ten by auxiliary operation time, and even ranked top five under special ship type among the global 20 major ports.

(4) Super-large hub port faces the dilemma of port capacity shortage.
From statistical data, the of auxiliary services time of Shanghai Port and Shenzhen Port is not much different from other ports, but does not have advantages in ranking. The main reason is that as a large number of ships arrival and the port capacity supply is gradually tight, ships often need to wait in line to enter the port and the speed of big ships are slower affected by the small ships. However, compared with other ports, the time gap is not large overall.

(5) Auxiliary service efficiency of Ningbo Port is evenly higher.

For the perspective of the of auxiliary services efficiency for each ship type, the auxiliary service hours of Ningbo Port and Busan Port are relatively short, which is closely related to their broad water area and adequate terminal capacity.

Part 3: Connectivity Analysis of Global 20 Major Container Ports

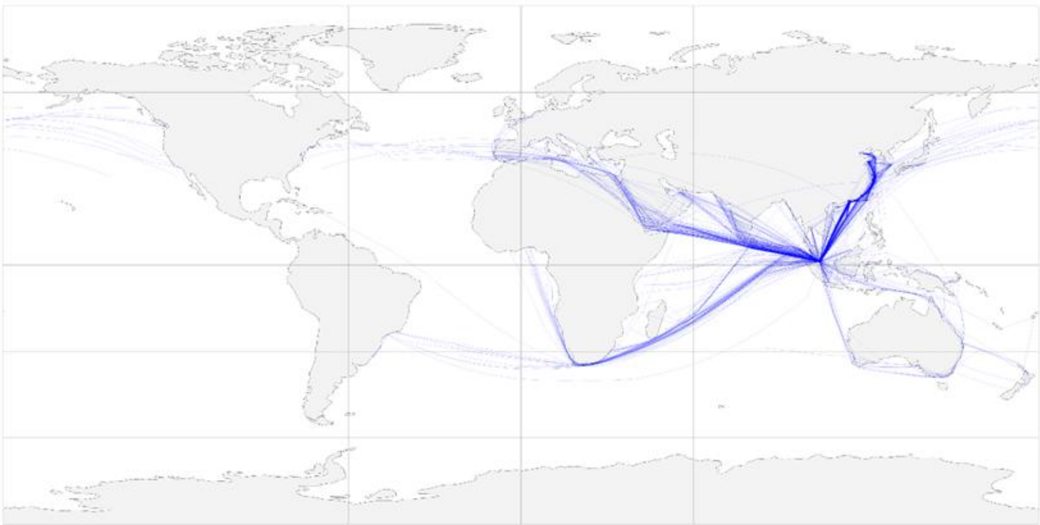
For container ports, in addition to port efficiency, the shipping company and the cargo owner are always interested in the radiation range of the container route network of port and the container liner density. The route network is closely related to the scale of the hub port, and also interrelated to the main countries running trade with port hinterland. Thus, the trajectory of all ships passing through the port is used to reflect the connectivity of its network. In this paper, Shanghai Port and Singapore Port are used as analysis cases.

Shanghai Port is a typical hub port covered by hinterland trade network. From the figure below, it can be found that the container lines of Shanghai Port are very dense, which can reach all parts of the world through Shanghai Port, including Southeast Asia, South Asia, Australia, Europe, Northeast Africa, North Africa, South Africa, South America, North America (East Coast and West Coast). The relatively dense routes are mainly focus on Asia-Europe routes (Far East-Europe), Pacific routes (Far East-North America) and Southeast Asia routes, reflecting the intimate trade flows between the hinterland of port with developed economies such as the United States and Europe.

Noted: drawing based on the November 2017 AIS ship trajectory.

Figure 14 Connective Route Network of Container Ships in Shanghai Port

Singapore Port reflects the network feature as a typical transit port. Comparing the route network coverage and network density of Singapore Port with Shanghai Port, it can be found that the network density of Singapore Port to North America is less than that of Shanghai Port, while the density of the routes and the number of ports calling from Singapore Port to the major ports in South Asia, Australia (south and southeast ports), Africa (South Africa, Northeast Africa and North Africa) are higher than those of Shanghai Port, reflecting the transit status of Singapore Port in the region. The location of Singapore Port makes it as the throat of the shortest route for Europe and Africa to sail eastward to the ports in Southeast Asia, East Asia and Oceania.



Noted: drawing based on the November 2017 AIS ship trajectory.

Figure 15 Connective Route Network of Container Ships in Singapore Port

The above content contains part of our research based on AIS data. And there are still some problems and limitations in the application of AIS data.

(1) The above data analysis is structural data conclusions.

Since in the processing of ship AIS data, the obviously unreasonable data has been eliminated, the above data content cannot reflect the absolute real data result, but reflect the structural data. For example, there may be a ten-digit gap between the number of ships arrival collected by AIS data with and the actual number of ships arrival. But by comparing the actual data obtained with the data ran out by AIS data, it can be found that the data level of them is consistent.

(2) The solitary in data analysis.

At present, the AIS data in the shipping field can only be analyzed from ship position information. Therefore, it is difficult to compare different types of data in the analysis of some indicators. And more subdivided and reliable indicator data is also difficult to obtain. For example, for the analysis of loading and unloading efficiency, it is hard to accurately reflect the efficiency by ships' berthing time. The more accurate way is to match the cargo information of each ship to load and unload with the ship trajectory information, so that more analysis of segmentation metrics can be obtained. Thus, the current shipping big data analysis can be considered as a single-dimensional data analysis, and the data chain has not yet formed.

(3) Problem of data quality.

At present, there are some problems that some ship closed AIS artificially, or the coverage of port AIS base station is still limited, which result in the differences of data quality between different ports. The reliability of data and the technical methods of data de-authentication need to be further explored.

This paper has taken a step to analyze the characteristics of the development of shipping industry by using real time big data. It is also hoped that experts and researchers in the industry could take participate in the development and application of shipping big data.

Zhao nan[1], Chen Weijie, Zhang Jing, Xie Wenqing

Shanghai International Shipping Institute[2]

Email: rockyzhao1986@163.com

Tel: 021-65853850-8033

[1] Dr. Zhao Nan, the team leader of *Global Port Development Report* project with more than 10 years research experiences, is specialized in port policy, port planning, port operation and other sectors of shipping industry. She has published a number of articles in many leading journals and taken participated in more than 80 research projects in the past 5 years.

[2] Shanghai International Shipping Institute (SISI), affiliated to Shanghai Maritime University, is an international maritime consultation and research institute providing government agencies and industry players with decision-making information and consultation service.