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Study on the improvement of production efficiency of major container terminals in China

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Study on the improvement of production efficiency of major container terminals in China

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A dissertation submitted to the World Maritime University in partial fulfilment of the requirements for the award of the degree of Master of international transport and logistics

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Declaration

I solemnly promise that the thesis submitted was completed by me independently under the supervision of Gang Zhao and in strict accordance with the relevant regulations of the university and the college. The ideas and references cited in the paper have been marked and annotated. There is no plagiarism or falsification of data in the research process. I am willing to take legal responsibility for any infringement of intellectual property rights of others.

(Signature): 林盛

(Date): 29 May 2023

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Abstract

Title of Dissertation: **Study on the improvement of production efficiency of major container terminals in China**

Degree: **Master of Management**

Since the implementation of Chinese 21st Century Maritime Silk Road policy, Chinese cargo throughput has been increasing year by year. Among them, the cargo throughput of China reached 15.5 billion tons in 2021. However, according to the global container port performance index ranking, the overall performance of Chinese container port efficiency is not as superior as the container throughput, and the problem of Chinese container port efficiency needs urgent improvement. As a part of the port composition, how to evaluate the efficiency of container terminal enterprises and find the path of efficiency improvement has become the key to realize the smooth trade flow in China.

In this paper, 23 Chinese container terminals are selected as the research objects, and the following research is carried out based on the statistics related to the operation of container terminal enterprises from 2017 to 2020 and DEA efficiency theory. (1) From the perspective of container terminal enterprise operations, this paper divides the main operational processes of container terminal enterprises into berthing and handling sub-processes, and constructs a network structure model for the convergence of the two sub-processes of container terminal enterprises.(2) This paper uses DEA efficiency index and Malmquist productivity index to study and analyze the relevant data of 24 container terminal enterprises, focusing on the static efficiency and dynamic efficiency of container terminal enterprises in 2017-2020 are evaluated.The efficiency differences between inland and coastal terminal enterprises are compared and analyzed.(3)This paper uses overall, berthing and handling efficiency as the explanatory variables, with hinterland city GDP, ownership structure, maximum berthing capacity, and multimodal transport as explained variables.Tobit regression model is used to verify the main factors affecting the efficiency of container terminal enterprises.

Key words: Container terminal enterprises, Production efficiency, Influencing factors, DEA model.

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List of Abbreviations

CPPI -Global Container Port Performance Index

DEA -Data Envelopment Analysis

TE -Technical efficiency

OE -Overall efficiency

BE -Berthing efficiency

HE -Handling efficiency

EC -Technical efficiency change

PTE -Pure Technical Efficiency Change

SEC -Scale Efficiency Change

ML -Malmquist Productivity Index

EC -Technical efficiency change

TC -Technological change

Charpter 1 Introduction

1.1. Background

In the fall of 2013, China proposed the "One Belt and One Road" initiative, namely, the "Silk Road Economic Belt" and the "21st Century Maritime Silk Road", which will provide an initial structure of interconnected transportation infrastructure from Asia and Europe to Africa, the Americas and Oceania. The initial formation of the interconnected transport infrastructure structure along the route from Asia and Europe to Africa, America and Oceania. In the international trade transportation, the proportion of sea transportation accounts for more than 70%. As shipping hubs and gateways for foreign trade, ports are important infrastructure for the turnover of goods along the route.

The standardized transportation system of containers makes it one of the most advanced tools of modern logistics, which not only enables unprecedented development of international trade and shipping, but also assumes an extremely important role in the process of economic globalization. 2022, the national ports completed 15.684 billion tons of cargo throughput, up 0.9% year-on-year, of which coastal ports and inland river ports completed 10.131 billion tons and 5.553 billion tons respectively. But according to the Container Port Performance Index 2021 in Table1.1, which shows Chinese container port performance value ranking is not proportional to the container throughput ranking. 2021 global container port throughput ranking of the top 10, led by Chinese container ports occupied 7. However, in the CPPI ranking, there are only 3 top 10 container ports, namely Yangshan Port, Ningbo Port, and Guangzhou Port. In addition Shanghai port's performance ranking but located at 316, performance is seriously less than the average score, CPPI of Zhoushan port is 22.5, slightly higher than the global average CPPI. The reason is that Shanghai container port is divided into three areas, respectively STC, Waigaoqiao port and Yangshan port. Due to the policy of Shanghai port construction, the throughput of all container ports in Shanghai is uniformly included as Shanghai Port, which does not reflect the real port throughput, and the same is true for Ningbo-Zhoushan Port. Secondly measurement of CPPI of port performance is not throughput, but will be the vessel time in port. Therefore, by virtue of throughput alone, it cannot truly reflect the productivity of Chinese container terminals.

Table 1.1 Ranking of the Global Container Port Performance Index

World rank in 2021	Name of container port	CPPI
1	KING ABDULLAH	217.914
2	SALALAH	197.675
3	HAMAD	194.823
4	**YANGSHAN**	**183.455**
5	KHALIFA	182.649
6	TANGER-MEDITERRANEAN	178.096
7	**NINGBO**	170.696
8	JEDDAH	161.493
9	**GUANGZHOU**	**161.331**
10	YOKOHAMA	159.234
11	ALGECIRAS	155.851
12	CARTAGENA(COLOMBIA)	152.95
13	CAI MEP	148.433
14	DAMMAM	143.504
15	SAID	141.336

Table 1.2 Ranking of global container port throughput

World rank in 2021	Name of container port	Throughput（TEU)
1	**SHANGHAI**	**47,030,300**
2	SINGAPORE	37,470,000
3	**NINGBO ZHOUSHAN**	**31,070,000**
4	**SHENZHEN**	**28,767,600**
5	**GUANGZHOU**	**24,180,000**
6	**QINGDAO**	**23,710,000**
7	BUSAN	22,706,130
8	**TIANJIN**	**20,269,400**
9	**HONG KONG**	**17,798,000**
10	ROTTERDAM	15,300,000
11	DUBAI	13,742,000
12	KLANG	13,724,460
13	**XIAMEN**	**12,045,700**
14	ANTWERP	12,020,000
15	TANJUNG PARAPATH	11,200,000

Table 1.3 Ranking of major container port performance index in china

World rank in 2021	Name of Chinese container port	CPPI
4	**YANGSHAN**	**194.823**
7	**NINGBO**	**170.696**
9	**GUANGZHOU**	**161.331**
27	**TIANJIN**	**109.448**
42	**QINGDAO**	**95.043**
45	**XIAMEN**	**92.212**
50	**HONG KONG**	**83.775**
136	**ZHOUSHAN**	**22.522**
316	**SHANGHAI**	**-51.827**
Global average score		**0**

Resouce:World Bank and IHS Markit

And the container port cannot be separated from the construction and operation of container terminal enterprises, a container port is usually operated by one or more container terminal enterprises, such as the first phase and the second phase of the Yangshan terminal operated by Shanghai Shengdong Container Terminal Company, while the third phase is operated by Shanghai Guan Dong Container Terminal Company and forth phase automated terminal operated by Shanghai Shangdong. The operational efficiency of the container terminal enterprises to a certain extent reflects the operational efficiency of the port. The transformation, upgrading and change of the terminal will bring about changes in port efficiency, and terminal efficiency is the main indicator of the core competitiveness of the container terminal. This makes it particularly important to conduct a reasonable analysis and assessment of container terminal efficiency.

1.2. Research Purpose

According to the CPPI ranking, the overall performance of Chinese container terminal efficiency is not as superior as the container throughput, and some of the inefficient container ports are overshadowed by the container throughput. This paper takes the Maritime Silk Road as the background, in order to promote Chinese ports to realize the foreign trade conditions of facility connectivity and trade flow, and to achieve efficient container ports as the goal.

Firstly, this paper tries to explore the relevant indicators that affect the productivity of container terminals through the analysis of relevant literature, such as factors directly related to the amount of production inputs, such as the number of bridge cranes, the length of quay, the number of tire cranes, etc. The key indicators affecting the productivity of container terminals are then analyzed through quantitative screening of indicators based on the historical data of relevant indicators. The key container terminals listed in the China Port Yearbook are used as the research objects. Relevant analysis methods for studying the productivity of enterprises are used to evaluate and study the productivity of Chinese container terminals from a technical perspective. The efficiency differences and the influencing factors of efficiency changes are searched for in order to provide some quantitative data support for the decisions of port management and planning departments.

At the same time, this paper will explain the unreasonable results of the above efficiency calculations in relation to the factors of internal and external environment to provide a more reasonable solution for improving the productivity of Chinese container terminals and provide some suggestions for the future construction and development of Chinese container ports.

1.3. Innovation of the research

In the selection of the research object, the research object of this study is more specific, not the overall container port efficiency, but the container terminal enterprise efficiency. Container ports are usually composed of multiple terminal operators, and efficiency evaluation by terminal enterprises can better help port enterprises judge the allocation effect and production efficiency of operating resources in port operation, and thus improve the overall competitiveness of container ports.

In terms of the selection of indicators, this paper will refer to CPPI, not only the container throughput as a performance indicator, but also the indicators that better reflect the productivity of container ports, such as average ship time handling, average bridge crane time handling, and average container dwell time in the field. At the same time, the operation process of container terminals will be refined, such as dividing them into berthing operations and handling operations, so that the evaluation model will be more consistent with the operation of container terminals.

In terms of factors affecting productivity, this paper also considers external environmental factors, such as hinterland economic factors, enterprise system structure, and port competition factors, to help enterprises cope with the external environment.

1.4. Technology Road map

Here is the technology road map for this paper.

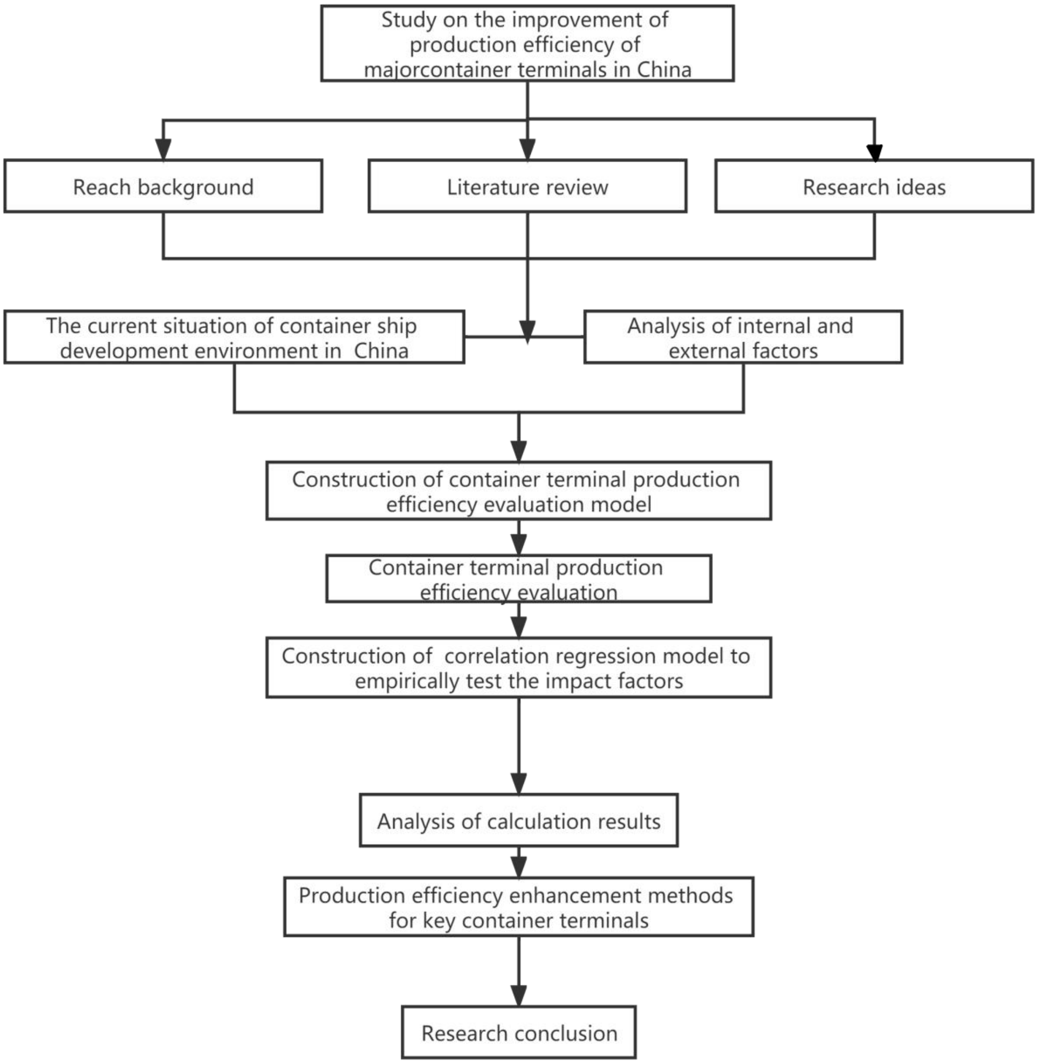


Figure 1.1 Technology Road map

Charpter 2 Literature review

2.1 Theoretical basis of efficiency

2.1.1 Introduction and Explanation of Efficiency

The efficiency of enterprises includes technical efficiency and allocative efficiency (Farrell, 1957). Technical efficiency (TE) refers to the relationship between input and output at the current level of technology, which means the output that can be brought by the current level of technology when the number and type of inputs are certain. Technical efficiency reflects the ability to use resources at a certain technological level; Allocative efficiency (AE) refers to the ability to achieve the optimal combination of inputs and outputs at a certain price level. Generally speaking, the examination of efficiency is mostly for technical efficiency.

2.1.2 Meaning of Total Factor Productivity

Solow defines total factor productivity (TFP) as the "residual value of growth" in economic growth after deducting capital and labor inputs, also known as broad technical progress(Solow, 2017). Total factor productivity reflects not only the technological level of production, but also all the relevant factors that cannot be explained by the input factors, including the management level, operation strategy and system of the company. The increase in total factor productivity can be interpreted as the increase in output brought about by factors other than input factors in the production activities in the adjacent period, so the change in total factor productivity can be regarded as dynamic efficiency.

2.2 Methods of evaluating the efficiency of container ports and terminal enterprises

When evaluating port efficiency, the mathematical and theoretical methods used are mainly divided into two categories: the first category is parametric analysis: factor analysis, hierarchical analysis AHP, gray correlation analysis, fuzzy class clustering analysis, these analysis methods are more subjective, and the weights given by this human-based subjective evaluation method directly affect the analysis results, and the results are not objective enough. The second type of non-parametric analysis methods: DEA, fuzzy class clustering analysis, BP neural network analysis. This analysis method does not involve subjective human scoring.

The above-mentioned methods have their own strengths and drawbacks to varying degrees, and scholars choose the most appropriate research evaluation method according to the actual situation, the purpose of the study, the object of the study and the indicators chosen for the study. Some use only one method alone, some use a combination of two methods, and some use a derivative model for refinement in order to achieve better evaluation results.

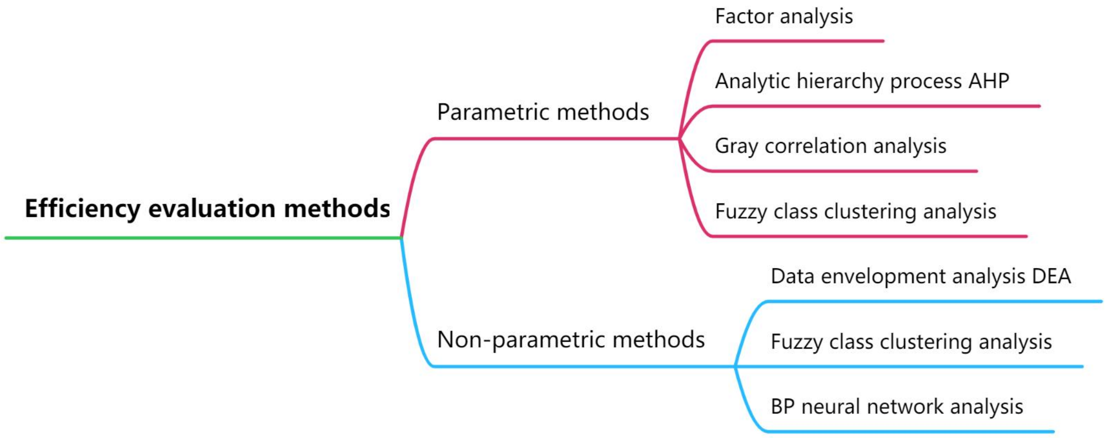


Figure 2.1 Organized efficiency analysis methods

Tongzon established a linear regression model using shore and bridge efficiency, etc. as dependent variables to study the influence of multi-dimensional factors on port efficiency (Tongzon, 1995). Clark used linear regression to explore the relationship between maritime transportation costs and international bilateral trade policies and port efficiency, and the study found that U.S (Clark, 2004) . Port efficiency is the main factor affecting maritime transportation costs. Zhong Ming used a grey target model to study the efficiency of six major consolidation ports in China, aiming to solve the problem of port efficiency with small samples and multiple indicators (Ming, 2007) . In the academic literature published in 2004, Su Qi conducted an in-depth investigation on the competitiveness of Shanghai port through factor analysis, and his article features the selection of indicators divided into two categories, including the construction of basic environment and soft power construction, which are specifically subdivided into ten secondary indicators and several tertiary indicators, and the evaluation system is very playful and comprehensive (Qi, 2004). Ling ling Liu uses BP neural network model to evaluate the efficiency of major container terminals in China. However, the BP neural network method is relatively inefficient due to the algorithm and requires a large amount of data to calculate, and the application in port efficiency evaluation has not been explored in depth (Lingling, 2010).

2.3 Selection of production efficiency indicators

To summarize the literature related to port efficiency, there are two methods of selecting indicators, the direct evaluation method and the indirect evaluation method.1. The direct evaluation method can be understood as the port is directly involved in the production activities of production factors such as equipment, sites, personnel and other measurable physical factors input quantity as input indicators. A series of indicators around the terminal operations are used as output indicators. 2. Indirect evaluation method takes port assets, scale, etc. as input indicators and profit, income, etc. as output indicators. The above indicators mainly reflect the situation of the operation of the port enterprise and are not directly related to the production operation of the terminal.

Table 2.1 Efficiency evaluation index selection statistics

	Author	Input indicators	Output Indicators
Operational Direct Evaluation Indicators	Jianmin Shou[7]	Length of production wharf, number of berths, number of 10,000-ton berths	Cargo throughput, foreign trade cargo throughput
	Zhang Jianyong[8]	Length of coastal wharf, coastal berths, 10,000-ton berths	Container throughput, cargo throughput, passenger traffic
	Chen Rong[9]	Length of berths, number of berths and number of 10,000-ton berths	Cargo throughput, container throughput, territory-wide passenger

			throughput
	David Shi[10]	Number of port berths, length of port berths	Cargo throughput
Operational Indirect Evaluation Indicators	Guo Peng[11]	Total assets, operating costs, number of employees in service	Operating revenue, total profit
	Feng Feng[12]	Fixed assets, operating costs, administrative expenses	Operating income, net profit
	Dan Liu[13]	Operating cost, fixed assets, number of employees	Operating income, net profit

2.4 Port efficiency influencing factors

Yuen et al. studied the effect of intra-port, inter-port and inter-ship competition on the efficiency of container terminals and the results showed that intra-port and inter-port competition has a facilitating effect on the efficiency of container terminals （L Y. C., 2013）.In contrast, Gabriel et al. reached a different conclusion when they studied the effect of competition on container port efficiency, and his study concluded that the extent of the effect of this factor can vary when measured at different ranges, such as within 400-800 km, port efficiency decreases with the intensity of competition, and the effect of competition is not significant when measured locally (less than 300 km) or globally (more than 80 km) （Gabriel, 2015）. Perez, studying the determinants of inefficiencies at major container terminals in Latin America and the Caribbean, found that inter- and intra-port competition contributed to efficiency. Merkel also studied competition as a factor and showed a negative relationship between intra-port competition and port efficiency （Perez, 2016).

Chang's study concluded that intense port competition promotes efficiency in dry ports, and in addition, it showed that dry ports with more convenient rail services are more efficient. Bichou, in his study of the effect of operational and market conditions on container terminal efficiency, concluded that incremental port investment leads to port inefficiency, that automated terminals are more efficient, and that administrative efforts also have an impact on port operational efficiency (Bichou, 2013). Tovar, in his observation of Spanish port authorities, also agrees that specialization has a positive impact on technical efficiency and that large ports enhance this positive impact (Tovar B, 2017); Sun, studying the environmental efficiency of Chinese port companies, shows that the number of port assets and berths can significantly affect the environmental efficiency of port companies. In a study on the factors influencing the operational efficiency of the coastal transportation industry (Sun I, 2017). Wu concluded that the fixed asset investment in coastal transportation industry and the container capacity of barges affect the operational efficiency of maritime transportation industry (Wu S, 2019). Tovar study concluded that larger and more complex port authorities, which have considerable technological advantages, have a positive impact on productivity improvements.

Table 2.2 Collation of influencing factors

Internal and External Factors	Factor Classification	Specific indicators
External Factors	Hinterland economic factors	Foreign trade volume
		GDP
		Industrialization level
		Per capita income
	Port Competition	Distance between ports
		Competitive intensity
	Hinterland resources	Level of terminal and railroad construction
		Share of multimodal container volume
		Internet level
		Size of port authority
Internal factors	Port facilities and personnel input	Level of facility automation
		Number of assets, berths
		Container capacity of barges
		Personnel professional level
	Enterprise system structure	Ownership system
		Private ownership

2.5 Conclusion

In the selection of the research object, the research object of this study is more specific, not the overall container port efficiency, but the container terminal enterprise efficiency. Container ports are usually composed of multiple terminal operators, and efficiency evaluation by terminal enterprises can better help port enterprises judge the allocation effect and production efficiency of operating resources in port operation, and thus improve the overall competitiveness of container ports.

In terms of the selection of indicators, this paper will refer to CPPI, not only the container throughput as a performance indicator, but also the indicators that better reflect the productivity of container ports, such as average ship time handling, average bridge crane time handling, and average container dwell time in the field. At the same time, the operation process of container terminals will be refined, such as dividing them into berthing operations and handling operations, so that the evaluation model will be more consistent with the operation of container terminals.

In terms of factors affecting productivity, this paper also considers external environmental factors, such as hinterland economic factors, enterprise ownership system, and port competition factors, to help enterprises cope with the external environment.

Charpter 3 The development environment of container terminals in china

3.1 The current stage of shipping industry development and trend

3.1.1 The present situation of container shipping market

From 2015 to 2016, the market glut led to a decline in freight rates on global routes, and the average freight rates in the China container shipping market also declined significantly, with the most significant decline on the China-Middle East/India route, which reached more than 30%.

From 2017 to 2018, market demand rebounded and freight rates began to show a gradual recovery, but the overall level of freight rates remained low.

From 2019 to 2020, uncertainties such as trade frictions and the New Crown pneumonia epidemic hit the market again, leading to a general decline in global shipping rates, and the average freight rates in the China container market once again experienced large fluctuations and declines.

From 2020 to 2021, influenced by the COVID-19, numbers of global manufacturing and service industries have been severely affected, and regulatory measures in many countries in the areas of freight, aviation and transportation have led to disruptions in the supply chain. Due to the suspension of some ships, as well as the closure or delayed opening of some ports, there is a shortage of container supply, resulting in a significant increase in demand for containers and a corresponding increase in container freight rates.

Table 3.1 China main line tariffs

Average Freight Rate (USD/TEU or FEU)	2015	2016	2017	2018	2019	2020	2021
China-Middle East/India	700	350	850	1150	750	450	3500
China-Latin America	2250	1350	1900	2750	1650	1100	4725
China-Southeast Asia	350	250	450	550	450	250	1500
China-Europe	1300	900	1650	2000	1400	900	4500
China-North America	2250	1350	1900	2500	1650	1100	3500

Data source: Drewry、Alphaliner、Clarkson Research

In general, the overall trend of freight rate changes in China container market is more volatile and influenced by various factors such as macroeconomic factors and market demand supply.

Regarding the impact of freight rate changes on the efficiency of China container terminals, on the one hand, the fall in freight rates will make container shipping companies less profitable, which may lead to a decrease in their service quality and efficiency at ports; on the other hand, the fall in freight rates may bring more orders and cargo volume, increasing the pressure on transportation at ports, which may also lead to a decrease in efficiency.

Table 3.2 Chinese import and export trade volume

Year	Total Foreign Trade (USD billion)	Growth rate	Exports (USD billion)	Growth rate	Imports (USD billion)	Growth Rate
2015	3865.29	-0.07	2270.52	-0.018	1594.77	-0.132
2016	3846.16	-0.005	2205.94	-0.028	1640.22	0.028
2017	4225.11	0.1	2392.75	0.085	1832.36	0.115
2018	4372.73	0.035	2492.16	0.041	1880.57	0.026
2019	4173.17	-0.045	2373.33	-0.048	1799.84	-0.043
2020	4760.2	0.141	2680.11	0.129	2072.09	0.151

Data resource: China Customs

As can be seen, Chinese foreign trade exports and imports show a steady increase from 2015 to 2020, with the growth rate of imports reaching 11.5% in 2017, while the growth rate of exports reaches 12.9% in 2020. In 2015 and 2019, both imports and exports declined, with imports declining by 13.2% in 2015 and exports declining by 4.8% in 2019. Overall, Chinese foreign trade has shown a more stable growth trend.

With the increase in total trade, Chinese container terminals will see a corresponding increase in cargo throughput and revenue. This will improve the profitability and market competitiveness of the terminals. As economic growth and trade activities increase in countries along the "Belt and Road", Chinese container terminals will have more opportunities to serve the trade and logistics needs of these countries and regions.

3.1.2 The trend of large-scale container ships

Since the 1950s, with the development of container ships, the length of ships has shown a trend of increasing year by year. As can be seen from the data table, from Panamax to Triple-E, the ship length has grown from 294 meters to over 400 meters, which indicates the increasing transport capacity of the ships. With the increase of ship length, the width of the ship also increases, from 32 meters to about 59 meters, which indicates that the ship is getting wider to accommodate more containers. Secondly, the draught of the ships also increased to ensure sufficient stability and load capacity. From Panamax to Triple-E, the draught of the ships increased from 12.5 meters to about 16 meters.

Table 3.3 Representative container ship type information

Model	Year built	Cargo Mass (TEU)	Deadweight class (DWT)	Draught (m)	Width (m)	Length (m)
Panamax	1980-2000	3,000-5,000	50,000-80,000	12-14	32.2	294
Post-Panamax	2000-2010	5,000-13,000	100,000-150,000	14-16	45.6-49	294-366
New Panamax	2016-	13,000-15,000	120,000-150,000	15-16	49	366
Neo-Panamax	2016-	13,000-23,000	130,000-200,000	16-18	49	366-400
Ultra Large Container Vessel (ULCV)	2013-	18,000-24,000	150,000-200,000	16-18	59	300-400
Triple-E	2013-	18,000-23,000	165,000-200,000	16-18	59	400
OOCL Hong Kong	2017	21,413	210,890	16.5	58.8	400
MSC Gülsün Class	2019	23,756	224,986	17.2	61.5	400
HMM Algeciras Class	2020	23,964	236,000	16.5	61	400

Data resource:Alphaliner

The shift from Panamax to New Panamax models was driven by the need to accommodate the restrictions imposed by the expansion of the Panama Canal. The size of these vessels was increased, but the draft did not change significantly. On the other hand, the development from New Panamax to Ultra Large Container Vessel (ULCV) saw a substantial increase in vessel length and width, while draft remained relatively stable.

Overall, the increase in vessel size is intended to accommodate the growing number of TEUs and improve vessel stability and wind resistance, while draft remains relatively unchanged.

The main limiting factor that prevents significant increases in draft is the berth depth of container terminals, particularly in coastal and estuarine areas. If the terminal does not have sufficient unloading capacity and facilities, even larger and deeper vessels will not be able to maximize their capacity, resulting in reduced efficiency. Therefore, upgrades and modifications to terminal facilities need to be made to match changes in vessel size to maximize their benefits.

3.2 The current stage of container terminal development

3.2.1 Geographical conditions of container terminals

Regionally, the container terminal berth depth in the Yangtze River Delta region is the deepest overall, with the average water depth above 15 meters.The berth depth in the Pearl River Delta region follows, with the average water depth above 14 meters.The container terminal berth depth along the Bohai Bay coast is relatively shallow, with the average water depth around 12 meters as showed in Figure 3.1.

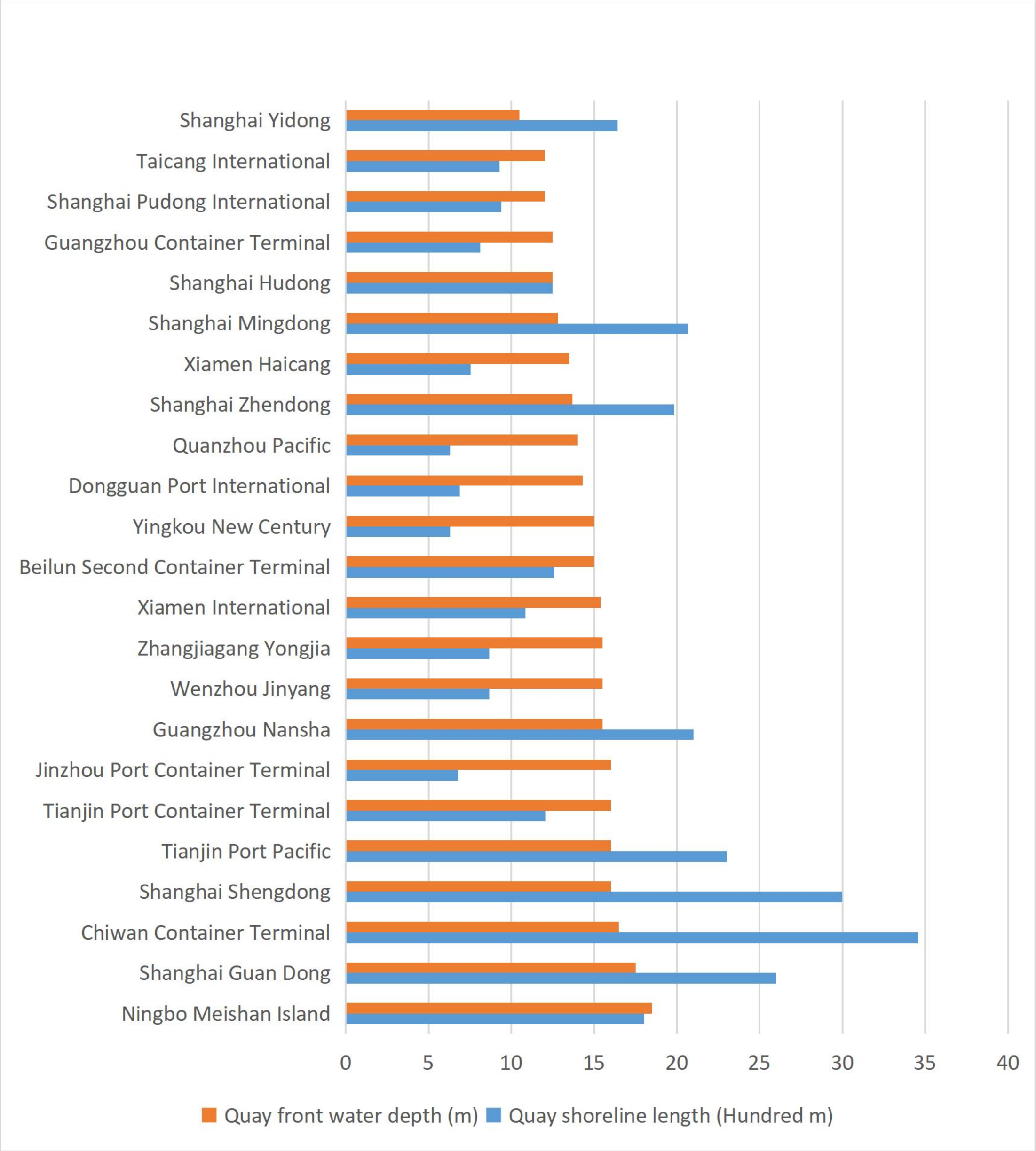


Figure 3.1 Statistics of water depth and shoreline length of main container terminals

The berth depth of relatively deep container terminal companies are mainly distributed in the Yangtze River Delta region and the Pearl River Delta region. Yangtze River Delta region has the largest number of container terminals, the region is located in the east of China, including Shanghai, Nanjing, Hangzhou and other cities, is one of the most economically developed regions in China, the Yangtze River flows through the region, the water depth varies greatly, plus the region has the natural conditions of large seaports, so the average berth depth is also relatively deep. The Pearl River Delta is located in the south of China, including the cities of Shenzhen, Guangzhou and Zhuhai, and the topography is mostly hilly and plain, but at the same time influenced by the Pearl River Delta, the water depth varies more, and has the second largest number of container terminals, and the average berth depth is also deeper.

Table 3.4 Regional statistics of container terminals

Region	Number
Bohai Sea Rim Region	4
Yangtze River Delta Region	11
Southeast Coastal Region	3
Pearl River Delta Region	5

And the port group berth depth shallow container terminal company is mainly distributed in the Bohai Bay area and the southeast coast. The Bohai Bay region has the least number of container terminals, the terrain is relatively flat, the water depth does not vary much, and the average berth depth is relatively shallow. The southeast coastal region has more container terminals, but the average berth depth is also relatively shallow.

Container terminal companies' berth depths correlate with their geographical location. The Yangtze River Delta and Pearl River Delta regions, located in deeper coastal areas, have deeper water depths and are suitable for deep-water port construction, resulting in container terminal companies in these regions having deeper berth depths. Conversely, the Bohai Bay region is shallow, making deep water port construction difficult and resulting in relatively shallow berth depths for container terminal companies in this region. In the southeast coastal area, despite deeper water depths, the average berth depth is shallow due to the large number of container terminals concentrated in shallow water areas.

3.2.2 Classification of container terminal enterprises

《China Ports Yearbook 2020》identifies five types of container terminals in China. State-owned terminals are owned and controlled by the government, while joint venture terminals are formed by multiple partners, including Hong Kong, Macau, Taiwan, and domestic partners. Joint-stock enterprises have a shareholding structure, and Chinese-foreign joint ventures involve partnerships between China and foreign countries. The final type is wholly foreign-owned enterprises, which are fully controlled by foreign companies. These diverse ownership structures reflect the complex business and investment environment for container terminals in China.

Table 3.5 Ownership structure of container terminal

Nature of business	Number
State-owned enterprises	6
Joint venture (Hong Kong, Macau, Taiwan and domestic)	10
Joint Stock	2
Sino-foreign joint venture	4
Wholly Foreign Owned	1

3.2.2 The operation process of container terminal

When a container ship arrives at a terminal, it first docks at its berth where tasks such as berthing and mooring the vessel are performed. The terminal operator communicates with the captain and crew to confirm vessel information and cargo manifests to ensure all containers are accurately recorded and handled.

Using a large container crane, the terminal operator lifts the containers from the ship and stacks them on the container yard on deck. Containers are then transported to the yard by container cranes or trailers where operators sort and organize them according to cargo manifests and destinations to maximize the use of yard space.

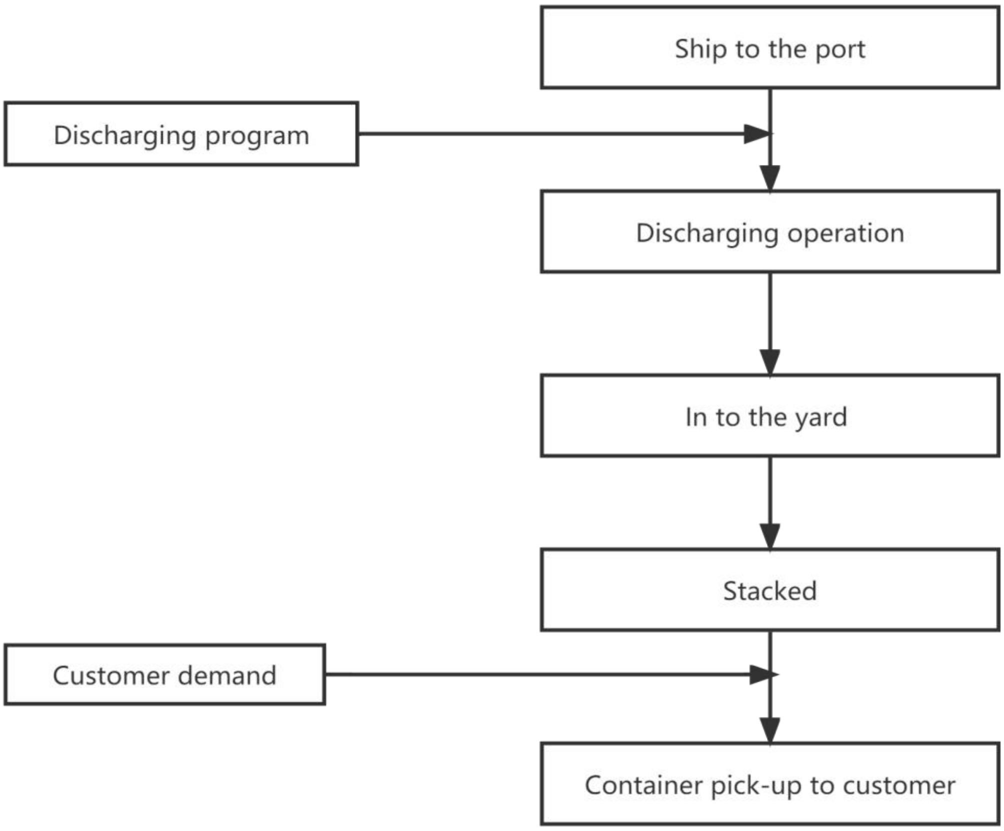


Figure 3.2 Simplified inbound process of container terminal

When a customer needs to pick up their cargo, they provide the bill of lading information to the freight forwarder, who coordinates with the terminal operator to arrange for the pickup of the cargo. The freight company issues pickup instructions to the terminal operator, instructing them to locate the designated container in the yard and move it to the pickup area on the terminal.

The entire process requires sophisticated logistics planning to ensure that the goods move efficiently and reach their destination in a timely manner.

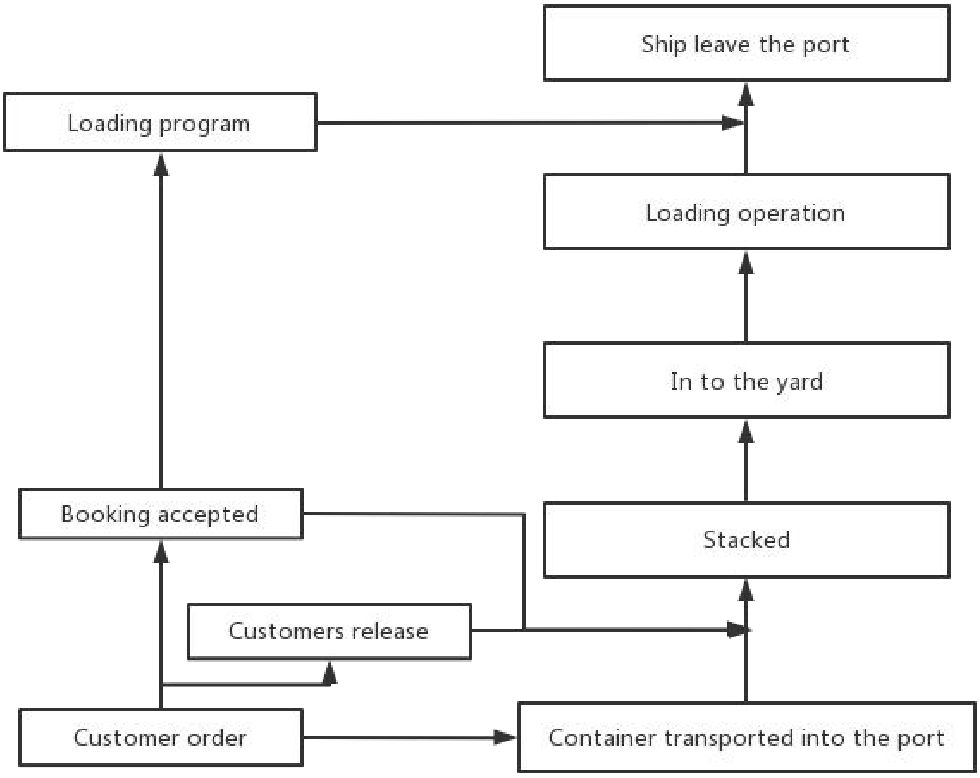


Figure 3.3 Simplified outbound process of container terminal

In the export process, booking the ship date is the earliest step, export goods need to book the ship date in advance, in order to determine the time of shipment of goods, and arrange the subsequent loading, transportation and other operations. Next is the customs clearance procedures, export goods need to complete customs and export inspection and quarantine procedures, including declaration, inspection and other processes. After the completion of customs clearance procedures, the goods need to be boxed in the terminal operation, the boxing process needs to be operated in accordance with the specifications of the container and loading requirements to ensure the safe and stable transportation of goods.

After the cargo container, the container needs to be transported from the terminal to the import port, usually need to be transported by trailer, train and other means. In the transportation process, need to ensure the safety of the container to avoid damage or loss of goods. After the container arrives at the import port, it needs to be loaded onto the ship, usually through cranes and other equipment for handling operations. The loading process needs to be operated in accordance with the ship's specifications and loading requirements to ensure the safety and stability of the goods. Finally, the container needs to complete the loading procedures, including bill of lading issuance, etc.

3.2.3 Hardware and software conditions of container terminals

As for coastal terminals, the facility inputs of container terminals are mainly concentrated in areas with fewer ports and larger ports, such as Guangzhou Nansha, Ningbo Meishan Island and Chiwan Container Terminal, which have respectively facility inputs of 343, 247 and 425 pieces of handling equipments and yard areas of 106, 970 and 1,182,000 square meters respectively. In addition, some medium-sized coastal terminals, such as Xiamen International Container Terminal and Yingkou New Century Port, facility investment and yard area are also relatively large.

As for inland river terminals, the scale of the terminals is relatively small due to the limitation of geographical location, so the facility investment and yard area are also smaller. The inland river terminals in Shanghai region occupy a larger share of facility input and yard area, such as Shanghai Mingdong Terminal and Shanghai Hudong Terminal, with 173 and 125 units of handling equipment, respectively, and 1,479,200 and 980,000 square meters of yard area, respectively. The facility input and yard area of other inland river ports are relatively small, such as Guangzhou Container Terminal and Dongguan Port International Terminal, both with facility input of no more than 120 units and yard area of no more than 300,000 square meters.

Therefore, it can be seen that the facility input and yard area of coastal terminals are mainly concentrated in the areas with larger port size, while the facility input and yard area of inland river terminals are relatively small.

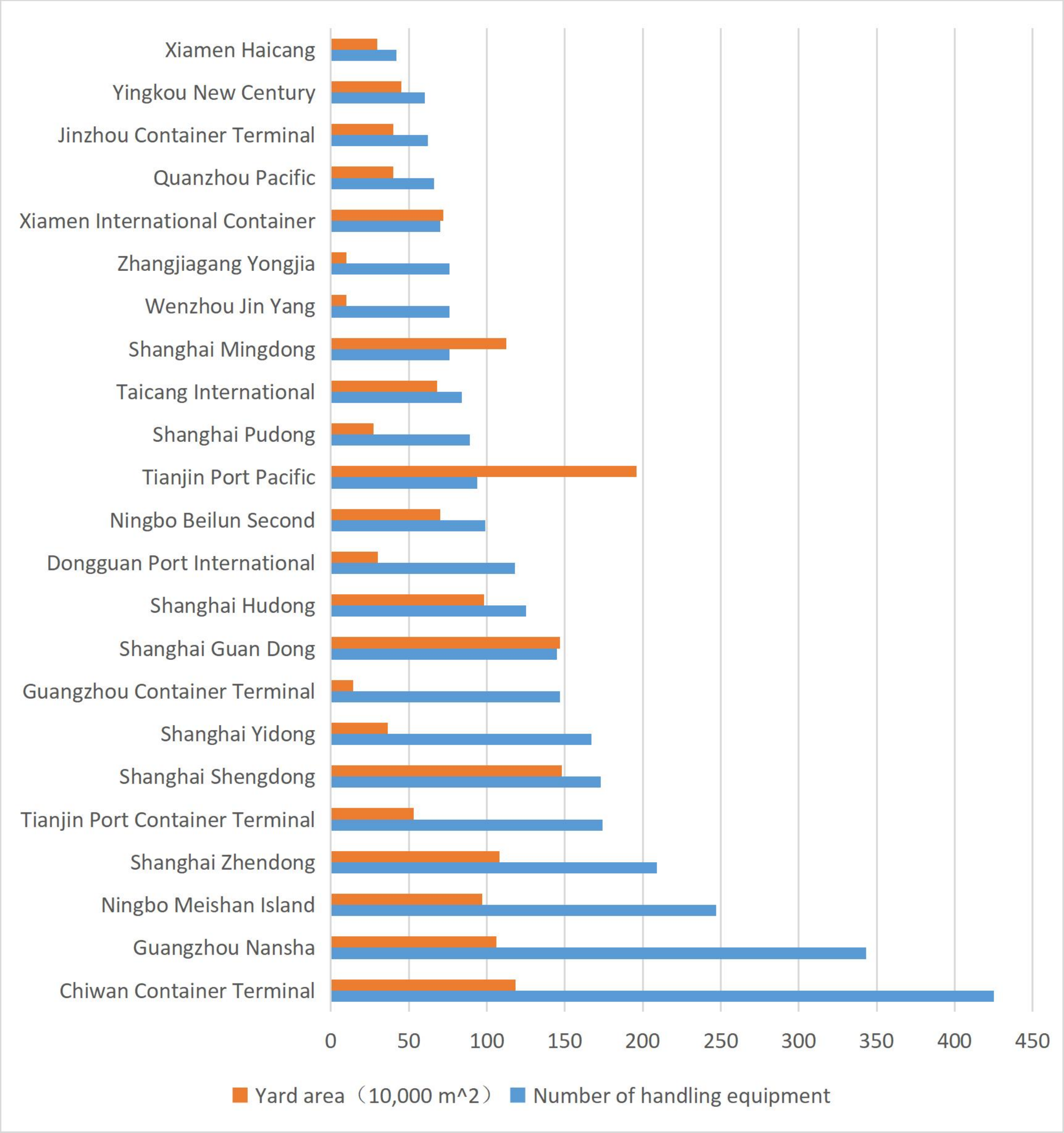


Figure 3.4 Statistics of yard area and handling equipment of main container terminals

3.2.4 Container throughput of major container terminal enterprises in China

The throughput classification of 24 container ports in China in 2019, including 7 terminals with throughput greater than 50 million TEUs, 12 terminals with throughput between 10 million and 50 million TEUs, and 4 terminals with throughput less than 10 million TEUs.

It can be found that most of Chinese container terminals are in the middle scale of throughput, of which 12 terminals have throughput between 10 million and 50 million TEUs, accounting for more than half of the total. The number of terminals with throughput of more than 50 million TEU is relatively small, with only 7 terminals,excluding Taiwan terminal. In addition, there are fewer terminals with throughput less than 10 million TEU, only 4.

This shows that the number of large container ports in China is relatively small, but the throughput of these large ports is very large and has an important supporting role for the development of logistics and trade of the whole country.

Table 3.6 Classification of container throughput of main container terminal

Container throughput	Number
>5000 Thousand TEU	7
1000~5000 Thousand TEU	12
<1000 Thousand TEU	4

The terminals in South China performed outstandingly: Taicang International Terminal, an ocean-going container terminal in Shenzhen, ranked first with an average container handling capacity of 127.6 TEU/Hr per hour and a throughput of 8.94 million TEU. Meanwhile, Guangzhou Nansha Port, Shantou Port, Shenzhen West Port and other terminals are also in the list, with container throughput above 1 million TEU.

The performance of terminals in the northern region is average: the only one ranking in the list is Tianjin Port Pacific International Container Terminal, with an average of 104.4 TEU per hour, ranking fifth in terms of throughput.

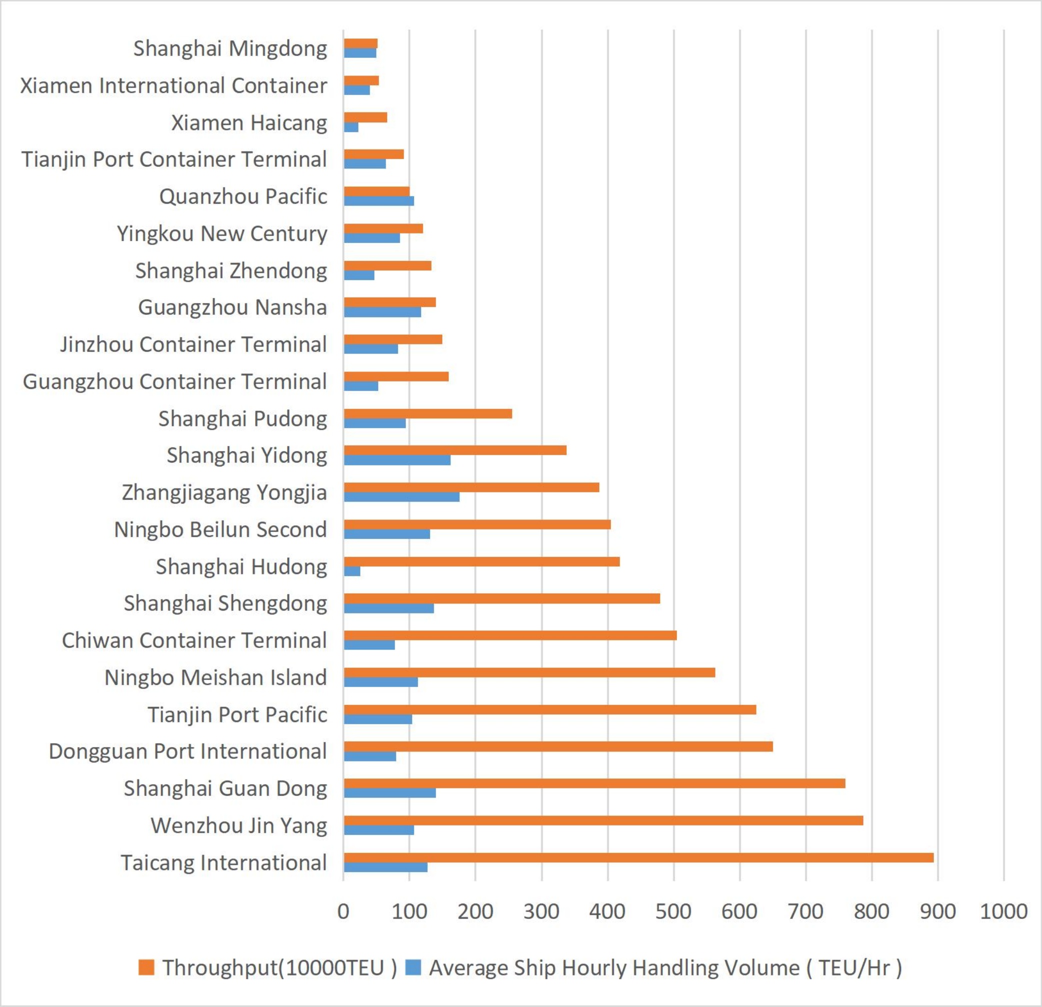


Figure 3.5 Statistics of throughput and hourly handling volume of main container terminals

Terminals with high loading efficiency usually have more handling equipment, and larger yard areas to store more cargo. It can be observed that the top five terminals in terms of cargo handled per hour all have over 100 pieces of equipment, while lower-ranked terminals typically have fewer than 50. The top ten terminals in terms of throughput all have a yard area of 900,000 square meters or more, while lower-ranked terminals have yards below 500,000 square meters.

Overall, the number of handling equipment and yard area of a terminal are key factors in determining loading efficiency and throughput. Terminals with more equipment and larger yard areas can typically handle more cargo and improve efficiency, resulting in higher throughput.

3.3 Factors affecting the efficiency of container terminals

3.3.1 Port facilities and personnel input

Terminal equipment plays a crucial role in handling capacity and coping with peak periods, but excessive equipment can increase costs and affect terminal economics. Having more equipment typically increases efficiency, enabling terminals to handle more cargo simultaneously and reducing handling times.

Qualified personnel can better handle complex and changing operational demands, increasing efficiency and safety. Experienced operators can operate equipment more accurately and quickly, reducing errors, damage, and increasing productivity. For example, a good shore bridge operator requires professional skills, including lifting, moving, and placing containers.

In summary, terminal efficiency depends on the quantity and level of automation of equipment, as well as the quality of personnel. All these factors should be considered and balanced in a practical context.

3.3.2 Hinterland economic factors

Increased economic prosperity in the surrounding areas of a port can lead to improved port efficiency in several ways. Firstly, it can increase the mobility of people and logistics, improving the port's operations. Secondly, it can lead to increased demand for port goods, boosting port operations and efficiency. Finally, it can attract more investment into the area, providing more resources and financial support for the development of the port, and improving its efficiency.

For instance, the port of Shenzhen in Guangdong Province, China, has benefited from the region's prosperous economy and its status as a global center for electronic manufacturing. The port's efficiency has been enhanced by the high freight demand and investment from the area.

The hinterland economy refers to the level of economic development in the surrounding area of a city or region, including agriculture, manufacturing, and service industries. A city's GDP per capita can serve as an indicator of the hinterland economy's development level. A city located in a more economically developed hinterland region may see an increase in its GDP per capita. The urban population and industries' proliferation in the city's periphery can also impact the surrounding areas' economic development level.

3.3.3 Hinterland resources

Inland resource factors that impact container terminal efficiency can be grouped into two main aspects. Firstly, geographical advantage, such as being located at the intersection of land transportation arteries and shipping routes, can attract more cargo and transportation demand, resulting in higher throughput and more transportation mode options. Secondly, network and transportation infrastructure, including the quality, speed, and traffic flow of transportation infrastructure like roads, railroads, and waterways in the areas surrounding the port, directly impact inland traffic and logistics transportation efficiency.

A port's international transit volume reflects its good geographical location as it is usually located at the intersection of sea routes and land logistics transport trunk lines, enabling efficient cargo transit. High water-to-water and water-to-rail transport volumes reflect the advantages of container ports in multimodal transportation and inland logistics. Such ports are often located in rivers, bays, or inland waters with good waterway transport conditions and convenient water and land intermodal transport conditions. They usually have a perfect inland logistics network to provide efficient and fast inland logistics services and facilitate multimodal transportation and cargo transshipment.

3.3.4 Terminal competition

Intense competition among container ports can improve efficiency and service levels by promoting mutual learning and reference. Competition drives terminal operators to enhance service quality and operational efficiency to attract more customers and cargo flows. This can lead to reduced handling costs, improved handling efficiency, increased capacity, and better service quality, ultimately increasing terminal efficiency.

To attract more large ships or container ships, container ports may adopt various competitive strategies. These include expanding ports by increasing facilities, such as quays and embankments, to improve handling efficiency and operational capacity, and utilizing resources such as beaches and waters to expand the port's size. Ports may also reduce port fees, offer preferential policies such as high-quality storage services and faster terminal operations, and diversify services to enhance comprehensive port services and increase customer loyalty.

3.3.5 Enterprise system structure

An enterprise's ownership system influences its efficiency, with state-owned enterprises, Sino-foreign joint ventures, and wholly-owned enterprises categorized by their degree of privatization. A higher degree of privatization means a smaller percentage of shares held by the government, and more responsibility for operation and management lies with the private sector.

Privatization promotes market competition by allowing more private enterprises to enter the market, leading to increased efficiency and reduced costs to meet market demand. However, state-owned enterprises face unique challenges that may affect management decision-making efficiency. These include policy and regulatory constraints, slow decision-making processes, and centralized decision-making. The degree of privatization has a significant impact on both investment and management decision-making efficiency, ultimately impacting production volume and efficiency.

Charpter 4 Efficiency evaluation methods, indicators and models

4.1 Concept of container production efficiency

4.1.1 The concept of efficiency

The concept of efficiency is not unified, based on the Pareto optimal state theory, it can be understood as the proportional relationship between input and output. By reasonably allocating resources, enterprises can maximize output with limited input resources, or produce a certain amount of output with minimum input resources, or consider from both directions, that is, they can obtain maximum output with minimum resource input, all three cases represent that enterprises are efficient at this time. Improve the management level and promote organizational innovation can make the enterprise resource allocation continuously optimized, and the enterprise efficiency is improved.

4.1.2 Relevant concepts of productivity in terminal enterprises

When the concept of efficiency is combined with enterprise related research, enterprise efficiency often represents its relative advantage in controlling operating costs, expanding output acquisition, and rational allocation of resources.

The efficiency of a terminal enterprise can be examined in terms of the organizational functions of the enterprise. Terminal enterprise organization can generally be divided into two kinds of internal and external organizations, and according to the organizational functions can be divided into external and internal efficiency, where external efficiency includes market efficiency, etc., while internal efficiency includes production efficiency, etc.

On the terminal production efficiency / specifically can be referred to in the unit of time, the terminal to complete the handling operations and the number of terminal equipment ratio. In a broader sense, container terminal productivity refers to the ratio of the amount of containers completed by the terminal to the input of production factors of the terminal in a unit of time. Factors of production include the number of equipment involved in the production of terminal operations, external conditions, operational processes, the quality of the workforce and other factors. For example, TEU/hour: refers to the number of standard 20-foot containers that the terminal can handle per hour. Turnaround time: This indicator refers to the total time from the arrival to the departure of a container at the terminal, usually measured in hours. In short, there is no fixed standard to measure the productivity of the terminal, but the core is able to show the terminal enterprise using the factors of production, in the unit of time to transfer into output, that is, the ability to handle containers.

This production capacity can be evaluated from the perspective of cost efficiency, configuration efficiency, and overall efficiency. The cost efficiency of the terminal enterprise mainly refers to the minimum cost of the terminal enterprise to obtain the scale of output under the condition of a certain scale of output and the ratio of the actual cost, representing the effective degree of the terminal enterprise control cost minimization. The allocation efficiency of the terminal enterprise refers to the ability of the terminal enterprise to effectively allocate and optimize the combination of resources to increase output and improve efficiency under the premise of a certain scale of inputs, which is a measure of the degree of reasonable allocation of resources within the terminal enterprise. In other words, the allocation efficiency of a terminal enterprise represents the ability of the terminal enterprise to allocate each input in an appropriate proportion.

In this paper, we choose to measure the total efficiency and sub-stage efficiency of terminal enterprises based on the perspective of inputs and outputs. The term "terminal enterprise efficiency" refers to the ability of a terminal enterprise to reasonably control the level of inputs while achieving the optimal output, and is a measure of how effectively a terminal enterprise can minimize inputs while maximizing outputs.

4.1.3 DEA efficiency evaluation model

In the DEA (Data Envelopment Analysis) model, efficiency refers to the extent to which output is maximized with a fixed level of input resources. Specifically, the DEA model evaluates whether the unit is able to maximize output given the limited input resources each uses. If the unit maximizes output and is more efficient than other units under the same conditions, the unit is an efficient unit under the DEA model.

The concept of efficiency in the DEA model is relative, i.e., each unit is evaluated relative to other units for its efficiency. At the same time, DEA-BCC model can also assess the pure technical efficiency(PTE) and scale efficiency (SE)of each unit.

Pure technical efficiency refers to the level of management or technology that the enterprise itself has, under the same resources, on the magnitude of output improvement, and is also a measure of the reasonableness of the enterprise's inputs and outputs.

Scale efficiency is the ratio of the change in total output to the change in total factors of production after all factors of production have been proportionally adjusted.

The DEA-Malmquist model can also be used to determine the change in productivity of an enterprise. The core idea of the Malmquist Productivity Index (ML index) method is to use the optimal input-output combination of the DEA model to compare the productivity of an enterprise between two different points in time. The core idea of the Malmquist Productivity Index method is to use the optimal input-output combination of the DEA model to compare the productivity of a firm between two different time points. Specifically, the method reflects the Technological change (TC) of the enterprise by calculating the distance between the DEA technical efficiency of two time points, and also reflects the Technical efficiency change(EC) of the enterprise.

Technical efficiency change EC refers to the increase in productivity brought about by the enterprise's replacement of old equipment and introduction of new production equipment, improvement of production processes, research and development, construction of a new management framework, and change of production processes, etc.

TC refers to the efficiency change resulting from the change in the allocation of production resources of the enterprise, which can be further decomposed into Pure Technical Efficiency Change (PTE) and Scale Efficiency Change (SEC).

ML=TC*EC

EC=PTE*SEC

4.2 Sample selection and data sources

Since the port is operated by several container terminals, evaluating the efficiency of container terminal enterprises can help the port improve efficiency more effectively, so this paper takes container terminal enterprises as the research object.

And this paper involves the static and dynamic efficiency of container ports. Therefore, the data of several consecutive periods and years are needed, so after screening, 23 container terminal enterprises are selected as the screening sample. And the above container terminal enterprises cover the main port clusters in China, including Yangtze River Delta region, Pearl River Delta and Bohai Sea Rim region, which increases the regional diversity of the research object.

Based on the above screening principles and data availability, 23 container terminal enterprises were finally screened, and the data were all obtained from 《Chinese Port Yearbook》 from 2017 to 2020,which includes major Chinese container terminal companies.

Table 4.1 Descriptive statistics of evaluation units

Indicators	Max	Min	Mean	Standard deviation
Quay shoreline length (m)	3457	630	1470	781
Quay front water depth (m)	19	11	14	2
Number of berths (Units)	10	2	5	2
Yard area (10000 m^2)	299	0	78	55
Number of bridge cranes or other cranes (units)	45	3	16	11

Number of tire crane and other vehicles	558	26	127	98
Average ship handling quantity hourly	176	18	88	40
Average handling quantity of bridge crane hourly	106	21	38	11
Number of ships arriving at port	30275	2	5405	6102
Average time of container stayed in yard	23	0	6	4
Throughput TEU	8936308	376000	3224411	2407686

4.3 Model construction of efficiency evaluation of container terminals

Usually the evaluation of container terminal or port enterprises is often carried out according to direct inputs and direct outputs. That is, the container terminal enterprise is treated as a whole to build an input-output index system for evaluation, as shown in Figure 4.1 below.

Figure 4.1 Simple evaluation model for container terminal enterprises

However, this evaluation system is too general and ignores the inner operational processes of container terminal enterprises. Therefore, the whole input-output process can be subdivided into two sub-processes, and intermediate outputs can be added to further, refine the evaluation index system. The evaluation model can be made more consistent with the operation process of container terminals.

From the perspective of container terminal operation, the ship approaches the port and needs to carry out preliminary container handling operations at the front of the terminal. And then transported to the rear yard of the terminal through the container truck, through the yard handling equipment for yard handling operations.

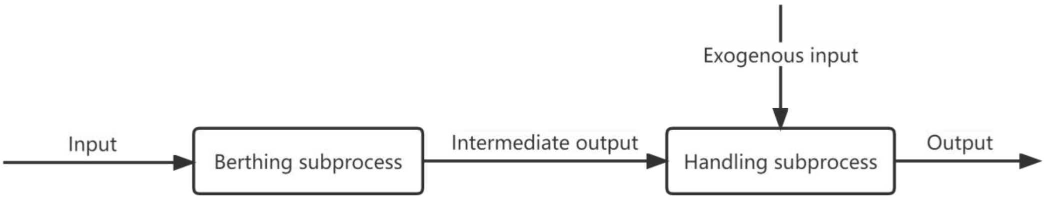


Figure 4.2 Research on the efficiency evaluation model of container terminal enterprises

According to Table 2.1 in the literature review, the evaluation indexes of container terminal enterprises are divided into two ways of direct and indirect evaluation. The number of berths and container throughput are usually used as input-output indicators in the direct evaluation index, and a few financial indicators are used as evaluation indicators. In this paper, the following efficiency evaluation indexes are selected from the perspective of equipment, berthing, handling handling conditions, etc. in conjunction with the actual operation of container terminals.

Input indicators: 1) Quay shoreline length: the length of the quay shoreline determines the number of berths at the quay, the longer the shoreline, the greater the number of ships that can be accommodated and the larger the size of the ships that can be accommodated, thus affecting the berthing efficiency of the ships. 2) Quay front water depth: this determines the size of the container ships that can berth, which is a key factor limiting the berthing of large container ships. 3) Number of berths: berths are an important part of the quay. The number of berths: berths are an important part of the terminal, insufficient berths will affect the waiting time of ships at anchor, the more berths, the more ships can be handled at the same time, thus improving berthing efficiency. 4) Number of bridge cranes or other cranes: the number of bridge cranes determines the number of operating roads that can handle the same container. The more the number of bridge cranes, the more flexible it is to coordinate the handling operation paths and significantly improve the handling efficiency.

Intermediate output: 1)Average handling quantity of bridge crane in hour: This is a comprehensive response to the berthing efficiency of the ship, the bridge crane handling speed directly affects the berthing time of the ship, and is also the result of the superposition of the above factors. 2)Yard area: It refers to the area where the goods are temporarily stored and stacked in the terminal, providing cargo handover, custody and storage services. The larger the yard area, the more containers can be accepted, is an important factor affecting the container throughput. 3) Number of tyre crane and other vehicles : this includes the tire crane / stacker / container front crane / forklift / collector truck and other major handling equipment involved in yard operations, these are important input elements of handling operations. 4) Number of ships arriving at port: this is also a comprehensive berthing conditions and handling conditions of the terminal. 5) Average time of container stayed in yard: this affects the turnaround time of the terminal box, the shorter the container turnaround time of the terminal, the more compactly arranged the berthing plan of the ship, giving the container terminal more space for handling, thus improving efficiency.

Output indicators: 1) Average ship handling quantity in hour: also on average berthing ship per hour handling of cargo tons, the greater the ship time handling, the higher the berthing efficiency of the ship, which is also a comprehensive reflection of the berthing and loading efficiency of the terminal, the unit is TEU / h. 2)Throughput TEU: container throughput is a measure of the basic indicators of container terminal output, the unit of measurement is TEU (20-foot container unit).

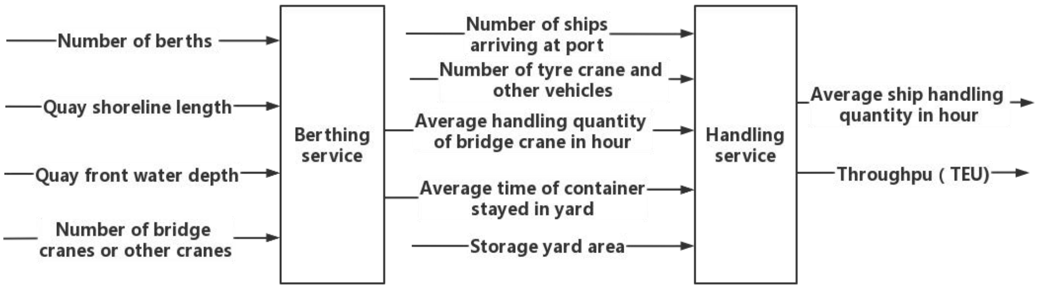


Figure 4.3 Network model for evaluating the efficiency of container terminal enterprises

Based on the main processes of container terminal operations, this paper proposes a network model for evaluating the efficiency of container terminal enterprises as well as input, output and intermediate variables.

4.4 Methods for evaluating the efficiency of container terminal enterprises

4.4.1 DEA model

DEA model: DEA is the abbreviation of "Data Envelopment Analysis", which is a non-parametric linear programming method used to measure relative efficiency and compare multiple combinations of inputs and outputs. The model was originally proposed by American scholars Charnes, Cooper and Rhodes in 1978 to assess the efficiency of production units.

In the DEA model, each container terminal is considered as a production unit and the input and output metrics can be quantified as numerical values and used as constraints and objective functions. Using these constraints and objective functions, the DEA model can determine the efficiency of each container terminal and the difference in efficiency between them.

Equation: Set the input vector for each decision unit as X_j and the output vector as Y_j.

$$X_j = (X_j^1, X_j^2, \ \dots \ , X_j^n)^T > 0, \ j = 1, 2, \ \dots \ , n$$

$$Y_j = (Y_j^1, Y_j^2, \ \dots \ , Y_j^n)^T > 0, \ j = 1, 2, \ \dots \ , n$$

Suppose the weight of the input vector is v_j and the weight of the output vector is u_j.

$$v_j = (v^1, v^2, \ \dots \ , v^n)^T$$

$$u_j = (u^1, u^2, \ \dots \ , u^n)^T$$

Then the j_0 efficiency evaluation model of the first one is

$$\begin{cases} \dfrac{\sum_{r=1}^{p} u_r y_{rj}}{\sum_{i=1}^{m} v_i x_{ij}} \le 1, j = 1,2,\dots,n \end{cases}$$

$$\max h_{j0} = \frac{\sum_{r=1}^{p} u_r y_{rj0}}{\sum_{i=1}^{m} v_i x_{ij0}}$$

$$v_i, u_r \geq 0, \quad i = 1,2, \ldots, m; r = 1, 2, \ldots, p$$

In the above model x_{ij}、y_{rj} are known numbers and v_i、u_r are variables. To simplify the formula, it is transformed into the duality form and then into the vector form.

$$\begin{cases} \sum_{j=1}^{n} \lambda_j x_j + s^- = \theta x_0 \\ \sum_{j=1}^{n} \lambda_j y_j - s^+ = y_0 \\ s^- \geq 0, s^+ \geq 0, \lambda_j \geq 0, \\ \theta \end{cases}$$

Where θ is the technical efficiency of DMUj_0 and $s+$、$s-$ is the slack variable. Assume that the optimal solution is λ^*, $s^*{-}$, $s^*{+}$, θ^*. If $\theta^* < 1$, then DMUj0 is inefficient DEA. DMUj_0 is weakly efficient if θ *=1, and s*-,s*+is not equal to 0. If $\theta^* = 1$, and $s^*{-} = 0$, $s^*{+} = 0$, then DMUj_0 is valid.

Let k=DMUj_0, denote λ_j^* the sum of optimal solutions, the more the value of k* the scale benefit is smaller. When k*> l, denotes decreasing scale benefit. When, indicates constant returns to scale. When k*=1, indicates increasing returns to scale.

4.4.2 Malmquist model

Suppose there exist n DMUs and each DMU obtains s outputs with m inputs in period k. $X_j$is the amount of inputs and $Y_j$is the amount of outputs.

$$X_j = (X_j^1, X_j^2, \ldots, X_j^n)^T$$

$$Y_j = (Y_j^1, Y_j^2, \ldots, Y_j^n)^T$$

Assuming constant payoffs of scale, let the distance function of (x_k，y_k) in period k be Dkc（x_k，y_k）, and by analogy, the distance function in period k+1 be Dk+1c（x_k，y_k）; the distance function of（x_{k+1}，y_{k+1}）in period k be Dkc（x_{k+1}，y_{k+1}）, and the distance function in period k+1 be D_{k+1}（x_{k+1}，y_{k+1}）.

Assuming that the technical conditions of period k are obeyed, the magnitude of the change in technical efficiency from the expiration of period k to k+1 is

$$M^{t} = \frac{D_{C}^{k}(x^{k+1}, y^{k+1})}{D_{C}^{k}(x^{k}, y^{k})}$$

Assuming the technical conditions obeying period k+1, the magnitude of technical efficiency change from period k to k+1 expiration is

$$M^{k+1} = \frac{D_{C}^{k+1}(x^{k+1}, y^{k+1})}{D_{C}^{k+1}(x^{k}, y^{k})}$$

Calculating the above total factor productivity index using the geometric mean, the change in efficiency from period k to k+1 period can be obtained.

$$M(x^{k}, y^{k}, x^{k+1}, y^{k+1}) = (M^{k} * M^{k+1})^{1/2} = (\frac{D_{C}^{k}(x^{k+1}, y^{k+1})}{D_{C}^{k}(x^{k}, y^{k})} * \frac{D_{C}^{k+1}(x^{k+1}, y^{k+1})}{D_{C}^{k+1}(x^{k}, y^{k})})^{1/2}$$

When $M < 1$, total factor productivity decreases, and when $M > 1$, total factor productivity increases. M can be decomposed into a technological efficiency change and a technical progress change index to perform the analysis of dynamic change efficiency values.

Charpter 5 Empirical analysis of evaluation of major container terminals

5.1 Efficiency evaluation results of container terminals

In this paper, DEAP 2.1 is used to analyze and evaluate the overall efficiency, sub-process efficiency and ML index of container terminal enterprises.

Example of the calculation process for 2017 Overall efficiency

Listing of Data File 2017OE.DTA

Table 5.1 Name of Input and Output

Output1	Average ship handling quantity in hour
Output2	Throughput TEU
Input1	Quay shoreline length
Input2	Quay front water depth
Input3	Number of berths
Input4	Number of bridge cranes or other cranes

Table 5.2 Name of DUM

DMU	**Container terminal**	**DMU**	**Container terminal**
1	Chiwan Container Terminal	**13**	Shanghai Mingdong
2	Dongguan Port International	**14**	Shanghai Pudong
3	Guangzhou Nansha	**15**	Shanghai Shengdong
4	Guangzhou Container Terminal	**16**	Taicang International
5	Jinzhou Container Terminal	**17**	Tianjin Port Container Terminal
6	Ningbo Meishan Island	**18**	Tianjin Port Pacific
7	Ningbo Beilun Second	**19**	Wenzhou Jin Yang
8	Quanzhou Pacific	**20**	Xiamen International Container
9	Shanghai Guan Dong	**21**	Xiamen Haicang
10	Shanghai Yidong	**22**	Yingkou New Century
11	Shanghai Zhendong	**23**	Zhangjiagang Yongjia
12	Shanghai Hudong		

Table 5.3 Listing of Data File 2017OE.DTA

DUM	**Output1**	**Output2**	**Input1**	**Input2**	**Input3**	**Input4**
1	34.87	7.82	3428	16	10	45
2	46	6.27	687	14.3	2	6
3	36.3	8.2	1400	15.5	4	30
4	33.6	0.44	867	12.5	3	3
5	32.5	5	677	16.5	2	4
6	59.33	7.34	1800	18	5	20
7	36.32	5.68	1258	15	4	18
8	35.8	8	1350	15.1	5	11
9	30.97	8.18	2600	17.5	7	30
10	26.18	4.26	1641	10.5	7	15
11	47.35	6.59	1984	13.7	6	10
12	44.4	5.69	1250	12.5	6	17
13	45.72	0.54	2068	12.8	7	28
14	42.86	4.7	940	12.5	3	11
15	30.26	3.5	3000	16	9	35
16	27.26	6.56	930	12	4	4
17	36	3.57	1240	16	4	14
18	45.1	6.3	2300	16.5	6	23
19	22.1	7.6	867	12.5	3	3
20	47.86	6.85	1086	15.4	3	11
21	42.34	4.76	754	13.5	2	6
22	53.8	3.5	680	17	2	6
23	32.96	20.29	722	10.8	3	5

Listing of Instruction File 2017OE.INS

```
2017OE.DTA       DATA FILE NAME
2017OE.OUT       OUTPUT FILE NAME
23               NUMBER OF FIRMS
1                NUMBER OF TIME PERIODS
2                NUMBER OF OUTPUTS
4                NUMBER OF INPUTS
0                0=INPUT AND 1=OUTPUT ORIENTATED
1                0=CRS AND 1=VRS
0                0=DEA(MULTI-STAGE), 1=COST-DEA,
                 2=MALMQUIST-DEA, 3=DEA(1-STAGE), 4=DEA(2-STAGE)
```

Listing of Output File 2017OE.OUT

```
Results from DEAP Version 2.1
Instruction file=2017OE.ins
Data file =2017OE.dta
Input orientated DEA
Scale assumption:VRS
Slacks calculated using multi-stage method
```

Explanation of parameter settings:

Data file name:Original data file name

Output file name:Calculation result file name

Number of firms:The number of companies includes the selected 23 Chinese container terminal companies.

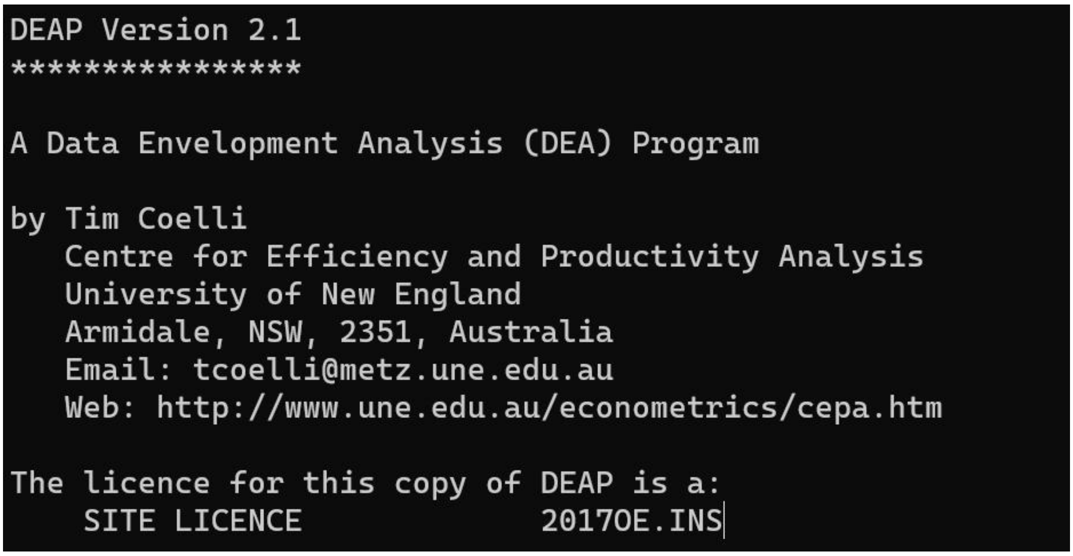
Number of time periods: The selected example is the overall efficiency value of 2017, so there is only one time period.

Number of outputs: Outputs includes average ship handling quantity in hour and throughput TEU so there are two.

Number of inputs: Inputs includes quay shoreline length/quay front water depth/number of berths/number of bridge cranes or other cranes so there are four.

Input or output orientation: This paper studies in the perspective of assuming constant output.

CRS/VRS:CRS represents the assumption of constant returns to scale which means DEA-CCR model is used, and VRS represents the assumption of variable returns to scale which means DEA-BCC model is used.



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DEAP Version 2.1
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A Data Envelopment Analysis (DEA) Program

by Tim Coelli
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Figure 5.1 DEA2.1 Program running interface

Table 5.4 Output in 2017 OE.OUT file

Firm	Crste	Vrste	Scale	Return of scale
1	0.599	0.793	0.755	irs
2	0.877	0.877	1.000	irs
3	1.000	1.000	1.000	-
4	0.419	0.448	0.936	irs
5	0.467	0.467	1.000	irs
6	0.617	0.892	0.691	irs
7	0.861	0.948	0.908	irs
8	0.287	0.391	0.735	irs
9	1.000	1.000	1.000	-
10	0.642	0.642	1.000	drs
11	1.000	1.000	1.000	-
12	0.948	0.948	1.000	irs
13	0.982	0.982	1.000	irs
14	0.957	0.957	1.000	irs
15	1.000	1.000	1.000	-
16	0.237	0.261	0.906	irs
17	0.696	0.900	0.773	irs
18	0.597	0.807	0.740	irs
19	0.194	0.212	0.917	irs
20	0.818	0.929	0.881	irs
21	0.638	0.638	1.000	irs
22	1.000	1.000	1.000	-
23	0.274	0.274	1.000	irs
Means	0.700	0.755	0.924	

Crste：Overall efficiency from CRS DEA

Vrste：Technical efficiency from VRS DEA

Scale：Scale efficiency (drs：decreasing returns to scale；-：constant returns to scale；irs：increasing returns to scale)=Crste/Vrste

5.1.1 Static efficiency analysis

Overall efficiency analysis

The overall efficiency values of the 23 container terminal enterprises in 2017-2020 are obtained by solving with DEAP2.1, as shown in Table 5..5.

Table 5.5 Overall static efficiency

Year DMU	2017	2018	2019	2020	Average
Chiwan Container Terminal	0.599	0.615	0.694	0.574	0.621
Dongguan Port International	0.877	1.000	1.000	1.000	0.969
Guangzhou Nansha	1.000	0.803	0.867	0.842	0.878
Guangzhou Container Terminal	0.419	0.501	0.478	0.443	0.460
Jinzhou Container Terminal	0.467	0.505	0.509	0.575	0.514
Ningbo Meishan Island	0.617	0.613	0.814	0.794	0.710
Ningbo Beilun Second	0.861	0.945	0.947	1.000	0.938
Quanzhou Pacific	0.287	0.325	0.377	0.620	0.402
Shanghai Guan Dong	1.000	1.000	1.000	0.957	0.989
Shanghai Yidong	0.642	0.659	0.743	0.737	0.695
Shanghai Zhendong	1.000	1.000	1.000	0.891	0.973
Shanghai Hudong	0.948	1.000	1.000	1.000	0.987
Shanghai Mingdong	0.982	1.000	0.979	0.968	0.982
Shanghai Pudong	0.957	1.000	0.950	0.807	0.929
Shanghai Shengdong	1.000	1.000	1.000	1.000	1.000
Taicang International	0.237	0.232	0.214	0.402	0.271
Tianjin Port Container Terminal	0.696	0.708	0.743	1.000	0.787
Tianjin Port Pacific	0.597	0.838	0.539	1.000	0.744
Wenzhou Jin Yang	0.194	0.313	0.271	0.293	0.268
Xiamen International Container	0.818	0.708	0.787	0.741	0.764
Xiamen Haicang	0.638	0.776	0.808	0.790	0.753
Yingkou New Century	1.000	1.000	1.000	0.822	0.956
Zhangjiagang Yongjia	0.274	0.318	0.321	0.194	0.277
Average	0.700	0.733	0.731	0.759	0.733

As can be seen from table 5.5, from 2017 to 2020. Chinese major container companies mainly show a year-by-year upward trend. Among them, the remaining six terminals in Shanghai terminals, except Yidong Terminal, are on the production front surface. From the overall trend of change, except for Tianjin Pacific as well as Tianjin Container, which achieved a huge efficiency increase in 2020, the magnitude of change in the efficiency of each container terminal did not increase significantly.

According to the efficiency performance of each container terminal, Shanghai Shengdong terminal four years of container efficiency are effective, Shanghai Zhendong 2017-2019 are effective, the average value of efficiency is located in the second. In addition to the Yangtze River Delta terminal remaining Tianjin container, as well as Dongguan International's terminal efficiency in the forefront. The efficiency performance of these ports is related to the geographical location of the terminal. These ports are mostly in Shanghai Guangzhou and other areas of Chinese more developed economic development, as well as the Port of Tianjin as one of the hub ports in the Bohai Rim, with a rich hinterland resources .

(2) Analysis of berthing process efficiency

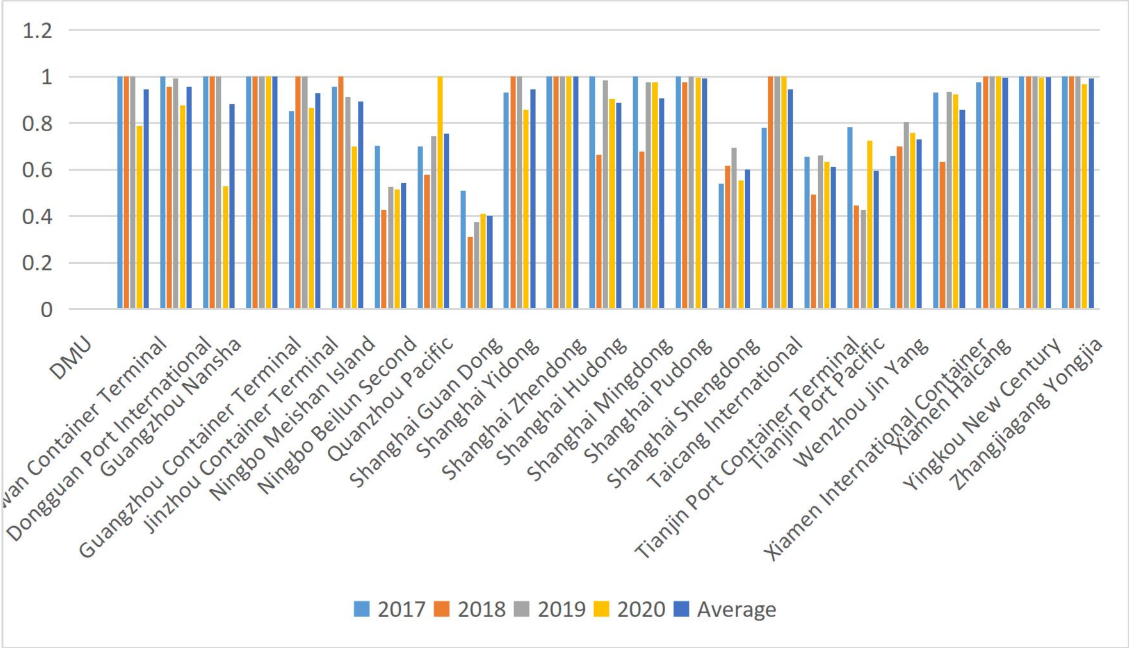
Right Table 5.6 can be seen berthing sub-process When Guangzhou Container and Shanghai Zhendong efficiency is 1, relatively effective , the rest of the terminal companies are relatively ineffective . From the overall average value of the highest efficiency year is 2019, the lowest efficiency year is two 018, the overall 2017 to 2020 overall efficiency fluctuations in about 0.84.

Table 5.6 Berthing static efficiency

Year DMU	2017	2018	2019	2020	Average
Chiwan Container Terminal	1.000	1.000	1.000	0.788	0.947
Dongguan Port International	1.000	0.958	0.993	0.877	0.957
Guangzhou Nansha	1.000	1.000	1.000	0.530	0.883
Guangzhou Container Terminal	1.000	1.000	1.000	1.000	1.000
Jinzhou Container Terminal	0.853	1.000	1.000	0.865	0.930
Ningbo Meishan Island	0.956	1.000	0.912	0.699	0.892
Ningbo Beilun Second	0.703	0.427	0.525	0.515	0.543
Quanzhou Pacific	0.700	0.579	0.743	1.000	0.756
Shanghai Guan Dong	0.509	0.312	0.375	0.411	0.402
Shanghai Yidong	0.931	1.000	1.000	0.856	0.947
Shanghai Zhendong	1.000	1.000	1.000	1.000	1.000
Shanghai Hudong	1.000	0.665	0.984	0.905	0.889
Shanghai Mingdong	1.000	0.678	0.975	0.976	0.907
Shanghai Pudong	1.000	0.975	1.000	0.995	0.993
Shanghai Shengdong	0.541	0.616	0.695	0.555	0.602
Taicang International	0.780	1.000	1.000	1.000	0.945
Tianjin Port Container Terminal	0.656	0.493	0.662	0.635	0.612
Tianjin Port Pacific	0.783	0.445	0.426	0.725	0.595
Wenzhou Jin Yang	0.658	0.701	0.804	0.758	0.730
Xiamen International Container	0.932	0.635	0.934	0.924	0.856
Xiamen Haicang	0.975	1.000	1.000	1.000	0.994
Yingkou New Century	1.000	1.000	1.000	0.995	0.999
Zhangjiagang Yongjia	1.000	1.000	1.000	0.967	0.992
Average	0.869	0.804	0.871	0.825	0.842

From the perspective of container terminal enterprise efficiency,Guangzhou Container and Shanghai Zhendong berthing efficiency of 1, reached the effective. The third and fourth places are Yingkou New Century and Xiamen Haicang, and the top four places are from four different port groups. The annual throughput of both Yingkou New Century and Xiamen Haicang is less than 1.5 miilion, and the investment in frontier equipment is at a low level, but their berthing efficiency is higher, which may be due to the improvement of efficiency brought by technology. The berthing efficiency of Quanzhou Pacific reached effective in 2020, because Quanzhou Pacific reduced half of the terminal frontage inputs in 2020, but the output volume did not decrease, which represents the obvious progress of production technology.

Figure 5.2 Berthing static efficiency



(3) Efficiency analysis of handling process

In 2017 there were 12 container terminal companies with a handling sub-process efficiency of 1, at the front side of production , with the lowest efficiency being Taicang International and Zhangjiagang Yongjia . Unlike 2018, the efficiency of Tianjin container did not reach relatively effective, because the average loading hourly volume of Tianjin container has decreased. In 2019, the distribution of handling sub-efficiencies is roughly the same as in 2017. 2020, Yingkou New Century and Shanghai Hudong do not achieve effective handling sub-efficiencies because Shanghai Hudong's throughput decreases in 2020 and the average container time on site increases by one day. The average loading time decreases by 30% and its throughput decreases by 1/6, which represents a decrease in technical efficiency.

Table 5.7 Handling static efficiency

Year / DMU	2017	2018	2019	2020	Average
Chiwan Container Terminal	0.716	0.642	0.742	0.621	0.680
Dongguan Port International	1.000	1.000	1.000	1.000	1.000
Guangzhou Nansha	1.000	0.809	0.831	0.806	0.862
Guangzhou Container Terminal	1.000	0.688	0.691	1.000	0.845
Jinzhou Container Terminal	0.745	0.690	0.663	0.548	0.662
Ningbo Meishan Island	0.619	0.607	0.788	0.787	0.700

Ningbo Beilun Second	1.000	1.000	1.000	1.000	1.000
Quanzhou Pacific	0.455	0.355	0.428	0.498	0.434
Shanghai Guan Dong	1.000	1.000	1.000	1.000	1.000
Shanghai Yidong	1.000	1.000	1.000	0.815	0.954
Shanghai Zhendong	0.932	0.832	0.800	0.582	0.787
Shanghai Hudong	0.904	0.846	0.876	0.763	0.847
Shanghai Mingdong	1.000	1.000	1.000	1.000	1.000
Shanghai Pudong	1.000	1.000	1.000	1.000	1.000
Shanghai Shengdong	1.000	1.000	1.000	1.000	1.000
Taicang International	0.452	0.346	0.332	0.482	0.403
Tianjin Port Container Terminal	1.000	0.963	1.000	1.000	0.991
Tianjin Port Pacific	1.000	1.000	1.000	1.000	1.000
Wenzhou Jin Yang	0.724	0.878	0.768	1.000	0.843
Xiamen International Container	0.865	0.807	0.709	0.718	0.775
Xiamen Haicang	0.823	0.665	0.682	0.853	0.756
Yingkou New Century	1.000	1.000	1.000	0.907	0.977
Zhangjiagang Yongjia	0.406	0.254	0.260	0.717	0.409
Average	0.854	0.799	0.807	0.830	0.823

The lowest handling sub-efficiencies are in Taicang International and Quanzhou Pacific, but in 2020 Zhangjiagang Yongjia's handling efficiency tripled due to the reduction of inputs by more than half with no change in output, especially the reduction in yard area by 75%, representing a significant increase in technical efficiency.

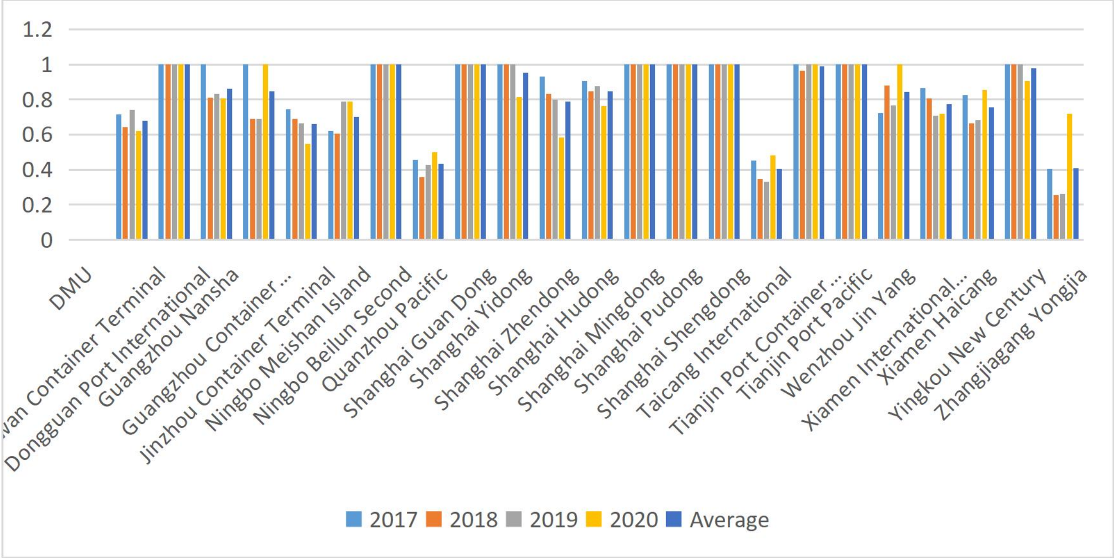


Figure 5.3 Handling static efficiency

On the whole, Table 5.3 shows that the highest handling efficiency is 0.854 in 2017 and the lowest is 0.799 in 2018. nearly half of the container terminal enterprises have a handling efficiency of 1, including Ningbo Meishan/Dongguan International/Guan Dong/Sheng Dong/Yidong/Zhentong, most of the terminals with effective handling efficiency are concentrated in the Yangtze River Delta.

However, the four-year average handling sub-efficiency is smaller than the berthing sub-efficiency, which represents a serious uneven distribution of the handling efficiency of Chinese container terminals.

The lowest efficiency is Taicang International and Zhangjiagang Yongjia, the two enterprises belong to the inland river smaller scale terminals. That in addition to the Chiwan Container Terminal and Quanzhou Pacific although both belong to the coastal terminal, but also inefficient. Chiwan container in the Pearl River estuary east coast, there is a very strong geographical advantage, but also the port of Shenzhen is one of the very important container terminal. Similar to the Chiwan container terminal throughput is Guangzhou Nansha, but Guangzhou Nansha, the number of ship arrivals and the length of the quay shoreline input, are half of the Chiwan container, but the Chiwan container handling sub-efficiency is much lower than Guangzhou Nansha, it can be seen that its handling efficiency needs to be improved.

5.1.2 Dynamic efficiency analysis

(1) Overall ML index analysis

Looking at the change in Malmquist Index from 2017 to 2020 , it can be seen that total factor productivity is declining first and then rising. From the decomposition factor of ml, the technical efficiency index is greater than one in 2017 to 2020, and only the index from 2018 to 2019 is less than the previous year. But the technical progress index has a value greater than one only from 2019 to 2020, representing that the rise in total factor productivity is due to the rise in technical progress.

In 2017-2018, total factor productivity increased in 65% of the container terminal companies, 19 of which had an increase in technical efficiency, but 17 of which had a technological regression . Among them, the total factor productivity of Wenzhou Jinyang is the highest and its technical efficiency increase is also the highest.

From 2018 to 2019 14, or 60% of the container terminal enterprises had an increase in total factor productivity, of which 17 had an increase in technical efficiency but the same 60% had a regression. Among them, Ningbo Meishan has the highest technical efficiency, although it has a near technical regression but it has little impact on its total factor productivity increase.

From 2019 to 2020, 73% of the container terminal enterprises have improved their total factor productivity, but only 40% of the enterprises have improved their technical efficiency in this year. 2019 to 2020, the increase in total factor productivity mainly comes from the technological progress of 78% of the container terminal enterprises. Five of the enterprises have improved their technical efficiency and technological progress, and three terminal enterprises have exceeded 2. including Tianjin Pacific Quanzhou Pacific as well as Tianjin Container.

Table 5.8 Overall dynamics efficiency

ML DMU	2017-2018			2018-2019			2019-2020		
	EC	**TC**	**ML**	**EC**	**TC**	**ML**	**EC**	**TC**	**ML**
Chiwan Container Terminal	1.026	1.060	1.088	1.129	1.000	1.128	0.827	1.008	0.834
Dongguan Port International	1.141	1.036	1.182	1.000	0.994	0.994	1.000	0.929	0.929
Guangzhou Nansha	0.803	0.877	0.705	1.080	0.998	1.078	0.971	1.080	1.048
Guangzhou Container Terminal	1.195	0.909	1.086	0.953	1.012	0.965	0.927	1.186	1.099
Jinzhou Container Terminal	1.082	0.927	1.003	1.006	0.994	1.000	1.130	0.999	1.129
Ningbo Meishan Island	0.995	0.924	0.919	1.326	0.996	1.321	0.976	1.225	1.196
Ningbo Beilun Second	1.098	0.895	0.982	1.003	0.963	0.966	1.056	1.157	1.221
Quanzhou Pacific	1.132	0.899	1.018	1.159	0.995	1.154	1.645	1.245	2.048
Shanghai Guan Dong	1.000	1.049	1.049	1.000	1.012	1.012	0.957	1.072	1.027
Shanghai Yidong	1.027	1.126	1.156	1.129	0.986	1.113	0.992	1.052	1.044
Shanghai Zhendong	1.000	1.107	1.107	1.000	0.986	0.986	0.891	1.084	0.965
Shanghai Hudong	1.054	0.992	1.045	1.000	1.020	1.020	1.000	1.007	1.007
Shanghai Mingdong	1.019	1.069	1.089	0.979	0.980	0.960	0.988	1.025	1.013
Shanghai Pudong	1.045	0.936	0.978	0.950	0.972	0.923	0.850	1.176	0.999
Shanghai Shengdong	1.000	1.042	1.042	1.000	0.997	0.997	1.000	1.008	1.008
Taicang International	0.980	0.978	0.958	0.923	1.021	0.943	1.878	1.042	1.956
Tianjin Port Container Terminal	1.018	0.935	0.952	1.048	0.980	1.028	1.347	1.488	2.005
Tianjin Port Pacific	1.404	0.924	1.297	0.643	1.003	0.645	1.856	1.239	2.299
Wenzhou Jin Yang	1.611	0.954	1.537	0.865	1.012	0.875	1.082	0.965	1.044
Xiamen International Container	0.865	0.972	0.841	1.112	1.016	1.130	0.941	0.988	0.930
Xiamen Haicang	1.216	0.873	1.062	1.041	0.982	1.022	0.978	1.127	1.102
Yingkou New Century	1.000	0.886	0.886	1.000	1.003	1.003	0.822	0.907	0.746
Zhangjiagang Yongjia	1.162	0.929	1.079	1.008	1.003	1.011	0.604	1.356	0.819
Average	1.081	0.970	1.046	1.015	0.997	1.012	1.075	1.103	1.194

A look at the change in Malmquist Index for container terminal companies from 2017 to 2020 shows that total factor productivity is decreasing and then increasing but total factor productivity from 2017 to 2019 are less than one and only in 2019-2020 is greater than one. Because in 2017 to 2019 there is a regression in both technical efficiency and technical progress, only in 2019 to 2020 both technical progress and technical efficiency are greater than one .

Specifically from 2017 to 2018, only 30% of the companies have ML index greater than one, 50% of the companies have technical efficiency decrease, and 52% of the companies have technical progress, but this cannot compensate for the substantial technical efficiency decrease. Among them, Tianjin Pacific has the biggest contrast between technical efficiency and technical progress, and the technical efficiency and technical progress of Tianjin Pacific are in the last place and the first place respectively, because its input quantity such as the length of the quay line and the number of berths/bridge cranes have not changed but its loading time and average container presence time have improved. Among them, Guangzhou Container has the most obvious technological regression.

From 2018 to 2019, only 20% of container terminal companies have ml index greater than 1. The reason is that except for Shanghai Yidong, all other container terminal companies have technical decrease. Among them, Chiwan Container has the most obvious decline in technical efficiency and technological progress index.

There are 65% of container terminal enterprises with MI index greater than one from 2019 to 2020, among which Tianjin Pacific and Taicang International have great contributions to technical efficiency and technical progress, respectively. It is the technical efficiency of Guangzhou Nansha that regressed the most significantly leading to the decline in its ML index.

Table 5.9 Berthing dynamic efficiency

ML DMU	2017-2018			2018-2019			2019-2020		
	EC	**TC**	**ML**	**EC**	**TC**	**ML**	**EC**	**TC**	**ML**
Chiwan Container Terminal	1.000	1.131	1.131	0.519	0.664	0.344	1.517	0.998	1.514
Dongguan Port International	0.958	0.917	0.878	1.037	0.968	1.004	0.883	0.950	0.838
Guangzhou Nansha	1.000	0.827	0.827	1.000	0.984	0.984	0.530	0.946	0.501
Guangzhou Container Terminal	1.000	0.681	0.681	1.000	0.969	0.969	1.000	1.154	1.154
Jinzhou Container Terminal	1.172	0.879	1.031	1.000	0.894	0.894	0.865	0.988	0.854
Ningbo Meishan Island	1.046	1.640	1.716	0.912	0.624	0.569	0.766	1.049	0.803
Ningbo Beilun Second	0.606	1.306	0.792	1.230	0.764	0.939	0.983	1.048	1.030
Quanzhou Pacific	0.828	1.233	1.021	1.282	0.790	1.013	1.346	1.096	1.476
Shanghai Guan Dong	0.613	1.334	0.818	1.202	0.794	0.953	1.095	1.034	1.132
Shanghai Yidong	1.074	0.904	0.971	1.000	1.006	1.006	0.856	0.958	0.820
Shanghai Zhendong	1.000	0.862	0.862	1.000	0.959	0.959	1.000	1.001	1.001
Shanghai Hudong	0.665	1.467	0.975	1.480	0.663	0.982	0.920	1.070	0.985
Shanghai Mingdong	0.678	1.496	1.014	1.438	0.687	0.987	1.001	1.013	1.014
Shanghai Pudong	0.976	1.001	0.976	1.025	0.935	0.958	0.995	1.064	1.059
Shanghai Shengdong	1.139	1.109	1.263	1.129	0.889	1.003	0.798	1.095	0.874
Taicang International	1.282	0.730	0.936	1.000	0.869	0.869	1.000	1.978	1.978
Tianjin Port Container Terminal	0.751	1.343	1.009	1.344	0.739	0.993	0.958	1.051	1.007
Tianjin Port Pacific	0.568	1.649	0.937	0.958	0.604	0.578	1.702	1.062	1.808
Wenzhou Jin Yang	1.066	0.755	0.805	1.147	0.951	1.090	0.943	1.503	1.417
Xiamen International Container	0.681	1.240	0.844	1.471	0.806	1.186	0.989	1.033	1.022
Xiamen Haicang	1.026	0.970	0.995	1.000	0.984	0.984	1.000	0.952	0.952
Yingkou New Century	1.000	0.846	0.846	1.000	0.912	0.912	0.995	1.008	1.003
Zhangjiagang Yongjia	1.000	0.892	0.892	1.000	0.827	0.827	0.967	1.490	1.441
Average	0.919	1.096	0.966	1.095	0.838	0.913	1.005	1.110	1.117

Looking at the total factor productivity from 2017 to 2020, except for 2018-2019, the total factor production index is greater than one in the remaining two periods , ergo the ML index from 2017 to 2018 improves the most significantly.

Specifically from 2017 to 2018, 73% of container terminal companies had ml indexes greater than one, with Shanghai Pudong, Yingkou New Century and Shanghai Mindong showing outliers. Their technical progress index is greater than 4 due to the drastic reduction in the number of ship arrivals at Yingkou New Century and the zeroing out of yard space at Shanghai Pudong International, and a significant reduction in the total volume of other instruments at Shanghai Mindong, which on the contrary increased its throughput by 10%, while other inputs and outputs remained unchanged.

From 2019 to 2020 there are 56% of container terminal enterprises with ml index efficiency greater than one 1, of which 60% of terminal enterprises with technical efficiency and technological progress index greater than 1. Among them Zhangjiagang Yongjia and Shanghai Pudong have anomalous values. The second reason is that Zhangjiagang Yongjia has a significant reduction in yard area with little change in the amount of other inputs and outputs, while on the contrary Shanghai Pudong has a significant increase in yard area.

Table 5.10 Handling dynamic efficiency

ML **DMU**	**2017-2018**			**2018-2019**			**2019-2020**		
	EC	**TC**	**ML**	**EC**	**TC**	**ML**	**EC**	**TC**	**ML**
Chiwan Container Terminal	0.896	1.058	0.948	1.481	0.919	1.361	0.654	1.241	0.811
Dongguan Port International	1	1.302	1.302	1	0.961	0.961	1	0.92	0.92
Guangzhou Container Terminal	0.688	0.728	0.501	1.005	0.926	0.93	1.447	1.35	1.952
Guangzhou Nansha	0.809	1.003	0.812	1.026	1.026	1.053	0.971	1.154	1.12
Jinzhou Container Terminal	0.926	1.042	0.965	0.961	1.007	0.967	0.827	0.952	0.787
Ningbo Beilun Second	1	1.13	1.13	1	1.018	1.018	1	1.23	1.23
Ningbo Meishan Island	0.981	1.09	1.069	1.298	0.955	1.241	0.999	1.285	1.283
Quanzhou Pacific	0.78	1.319	1.029	1.208	0.968	1.169	1.163	1.189	1.383
Shanghai Guan Dong	1	1.34	1.34	1	0.965	0.965	1	1.324	1.324

Shanghai Hudong	0.936	1.136	1.063	1.036	1.01	1.047	0.871	1.117	0.972
Shanghai Mingdong	1	4.75	4.75	1	0.954	0.954	1	1.052	1.052
Shanghai Pudong	1	5.639	5.639	1	0.998	0.998	1	0.18	0.18
Shanghai Shengdong	1	1.237	1.237	1	1.018	1.018	1	0.961	0.961
Shanghai Yidong	1	1.14	1.14	1	1.087	1.087	0.816	1.661	1.354
Shanghai Zhendong	0.893	1.231	1.099	0.962	1.037	0.998	0.727	1.341	0.975
Taicang International	0.766	1.308	1.002	0.958	1.015	0.972	1.453	0.977	1.421
Tianjin Port Container Terminal	0.963	1.054	1.015	1.038	0.995	1.033	1	1.373	1.373
Tianjin Port Pacific	1	1.314	1.314	1	1.146	1.146	1	1.308	1.308
Wenzhou Jin Yang	1.213	1.374	1.667	0.874	0.975	0.852	1.302	0.835	1.087
Xiamen Haicang	0.808	1.15	0.93	1.025	0.968	0.992	1.251	0.912	1.141
Xiamen International Container	0.932	1.094	1.019	0.879	1.072	0.942	1.014	0.891	0.903
Yingkou New Century	1	5.03	5.03	1	0.06	0.06	0.907	0.824	0.748
Zhangjiagang Yongjia	0.626	1.544	0.967	1.021	0.952	0.971	2.758	1.034	2.853
Chiwan Container Terminal	0.896	1.058	0.948	1.481	0.919	1.361	0.654	1.241	0.811
Average	0.900	1.132	0.987	1.139	0.850	0.954	0.920	1.022	0.942

5.1.3 Difference analysis of efficiency of container terminal enterprises in different regions

In this paper, the study will be divided into two categories of coastal enterprises and inland river enterprises according to geography to compare and analyze the overall efficiency of the two types of enterprises and the differences in the efficiency values of their berthing sub-process handling sub-processes, as shown in Table 5.11.

Table 5.11 Coastal and inland river container terminal division

Category	Name of the container terminal
Costal terminal（15）	Chiwan Container Terminal Dongguan Port International Guangzhou Nansha Jinzhou Container Terminal Ningbo Meishan Island Ningbo Beilun Second Quanzhou Pacific Shanghai Guan Dong Shanghai Shengdong Tianjin Port Container Terminal Tianjin Port Pacific Wenzhou Jin Yang Xiamen International Container Xiamen Haicang Yingkou New Century
Inland river terminal（8）	Guangzhou Container Terminal Shanghai Yidong Shanghai Zhendong Shanghai Hudong Shanghai Mingdong Shanghai Pudong Taicang International Zhangjiagang Yongjia

As shown in table 5.12 the overall efficiency mean of coastal terminal companies from 2017 to 2020 is 0.753 The efficiency mean of inland river areas is 0.697. and each year the efficiency mean of coastal terminal companies is greater than the overall efficiency mean of inland river, which is in line with the traditional perception.

Table 5.12 Overall efficiency of inland and coastal area

Year / Category	2017	2018	2019	2020	Average
Coastal terminal enterprises	0.710	0.743	0.757	0.801	0.753
Inland river terminal enterprises	0.682	0.714	0.711	0.680	0.697

As shown in table 5.13, the berthing efficiency of inland river container terminals from 2017 to 2020 are greater than coastal container terminals, with four-year average values of 0.780 and 0.959 respectively. The difference in efficiency between the two enterprises is relatively obvious. The reason is that the inland river terminals, most of which belong to Shanghai terminals, such as Shanghai Yidong/Shanghai Mingdong, and the rest of the terminals are Zhangjiagang Yongjia as well as Guangzhou Container, which are inland river terminals but are in coastal cities with the same very advantageous location, high throughput and high efficiency values.

Table 5.13 Berthing efficiency of inland and coastal area

Year / Category	2017	2018	2019	2020	Average
Coastal terminal enterprises	0.818	0.744	0.805	0.752	0.780
Inland river terminal enterprises	0.964	0.915	0.995	0.962	0.959

Unlike berthing sub-efficiency, as shown in table 5.14 from 2017 to 2020, the handling sub-efficiency of coastal container terminals are greater than inland container yards, with four-year average values of 0.845 and 0.781, respectively.

Table 5.14 Handling efficiency of inland and coastal area

Year / Category	2017	2018	2019	2020	Average
Coastal terminal enterprises	0.863	0.828	0.841	0.849	0.845
Inland river terminal enterprises	0.837	0.746	0.745	0.795	0.781

5.2 Analysis of the external factors influencing the efficiency of container terminals

5.2.1 Sample selection and data sources

In order to investigate the factors influencing the efficiency of container terminal enterprises, competition/ownership structure/hinterland economy/maximum berthing capacity and multimodal transport were selected as explanatory variables, and Tobit model was chosen to analyze the factors influencing the efficiency of container terminal enterprises.

Table 5.15 Interpretation and measurement of variables

Explanatory variables	Measurements	Units
Skill	Number of middle and senior employees	Number
Competition	Distance to the nearest terminal	1 Km
Economics	Hinterland GDP Per Capita	RMB
Berthing	The maximum tonnage of ship calling the terminal	10000 Ton
Multimodal transport	Containers transported by intermodal transport at terminals (including water to rail, water to water, international transhipment)	TEU

The variable descriptions of the influencing factors are referred to in Section 3.3.

Table 5.16 Descriptive statistics of variables

Variable	Min	Max	Mean
Skill	43.000	398.000	185.174
Distance	0.400	130.000	18.604
Hinterland GDP	7.160	15.680	12.850
Berthing capacity	2.500	20.000	11.304
Multimodal transport	1689.000	524967.000	126027.467
Overall efficiency	0.268	1.000	0.733
Berthing efficiency	0.402	1.000	0.842
Handling efficiency	0.391	0.982	0.769

In this statistical variable the number of multimodal transport shows a large difference. The minimum distance is very close to the competition because some container terminals are clustered in concentrated ports, and the efficiency values are calculated by de A model so that the values are in the range [0, 1].

Table 5.17 Results of correlation analysis of variables

Variable	OS	Skill	Distance	Hinterland GDP	Berthing capacity	Multimodal transport
OS	1					
Skill	-0.153*	1				
Distance	0.117	-0.396	1			
Hinterland GDP	-0.118	0.299**	-0.116*	1		
Berthing capacity	-0.203	0.161**	-0.105*	0.241	1	
Multimodal transport	-0.385*	0.177**	-0.273	0.190**	0.367	1
* p<0.05 ** p<0.01						

After conducting Pearson correlation analysis on the independent variables it was concluded that there was no multicollinearity between the independent variables.

5.2.2 Model construction of Tobit model

DEA efficiency values range from 0 to 1 and are truncated, meaning they can only be observed for a random sample of individuals and are constrained by a certain value. Since efficiency values are not fixed, using the least squares method to study factors affecting efficiency is inappropriate. To avoid large deviations, this paper mainly uses the Tobit model proposed by economist Tobit in 1958, which has been widely used. The Tobit regression model uses static efficiency values of ports as main variables, and the model is as follows:

$$T=\begin{cases} T^{*} = a + BX + \epsilon, T > 0 \\ 0, \ T^{*} \leq 0 \end{cases}$$

Where T denotes the vector of efficiency values, T denotes the truncated dependent variable term, X denotes the corresponding independent variable, a

denotes the intercept term vector, B denotes the correlation coefficient term, and the error term e~N(0, δ^{2}). According to the construction principle of Tobit model and the selected variables of interest, the model is constructed as follows: $T_i = C + a_1X_1 + a_2X_2 + a_3X_3 + a_4X_4 + a_5X_5 + a_6X_6 + \epsilon$ where T_i denotes the efficiency value corresponding to the ith container terminal, the constant term C, a_1、a_2、a_3、a_4、a_5、$a_6$the coefficient corresponding to the influencing factor, and ϵ is the error term.

5.2.3 Calculation of regression results of influencing factors

In this paper, the data of 23 major container terminals in China in 2020 were analyzed by using Stata/MP 16 software, and Overall efficiency, Berthing efficiency and Handling efficiency of container terminals were selected as the explanatory variables, and Skill, Distance, Hinterland GDP, Berthing capacity and Multimodal transport as explanatory variables, which are noted as OH, BE, HE, OS, Skill, Dis, GDP, BC and MT, respectively.

Table 5.18 Results of regression model

Variables	**OE**		**BE**		**HE**	
	Coef	**Std.Err**	**Coef**	**Std.Err**	**Coef**	**Std.Err**
Constants	0.988**	0.095	0.847**	0.114	0.962**	0.065
OS	0.03	0.066	0.058	0.079	0.043	0.045
Skill	0.264*	0.115	-0.015	0.139	0.215**	0.079
Dis	-0.959**	0.127	-0.081	0.153	-0.740**	0.087
GDP	-0.318	0.127	0.222*	0.153	-0.203	0.087
BC	-0.195	0.095	-0.218	0.114	-0.192**	0.065
MT	0.264	0.129	-0.288*	0.155	0.105	0.088
Remarks:	***p<0.01	**p<0.05	* p<0.1			

According to the empirical results the skill level of employees of container terminal enterprises has a significant positive relationship on the handling efficiency. This shows that senior employees can improve the handling efficiency of the terminal. This is because container terminals have a higher technical threshold compared to other service industries and require a higher level of mastery of the operation and processes of handling equipment. Skilled employees can make the rapid transfer of containers, reduce the container stacking cycle and increase the circulation.

The degree of competition among firms has a significant negative relationship with the overall efficiency of the container terminal and the efficiency of the handling sub-processes. Since the measure of competition in this paper is distance, it is understandable that when competition becomes very intense, port operators may lower prices to attract more vessels, which may lead to overcrowding at the port, increasing the time and efficiency of operations such as handling. And to remain competitive, port management may reduce investment, resulting in poorly updated port facilities and equipment and thus reduced efficiency.

The economic GDP of the inland hinterland has a significant positive relationship with the berthing sub-process. Because most of the goods transported in containers belong to industrial semi-manufactured goods, unlike bulk goods transported in bulk, which are low-value goods. So the container transported goods are mostly received in the final consumer goods, the higher economic level of payment represents the rich per capita consumption level the higher demand for goods and trade demand is also very high, so the higher economic level of the hinterland can affect the number of ship arrivals, thus improving the berthing efficiency of the container terminal.

The maximum berthing capacity of container terminals has a significant negative relationship with the handling sub-process. Board larger berthing capacity on behalf of the container terminal can be able to accept the largest container ship tonnage higher, large container plant ships can carry more containers, so the container terminal on the yard's rapid response requirements will be higher. Too much at one time to accept a large number of containers will be a huge burden on the container terminal yard handling, thus reducing the handling efficiency.

Multimodal transport has a significant negative relationship with the berthing process of container terminals, as this indicator includes water-to-water transfer, international transfer, and rail-to-water transfer, which usually involves multiple transfer points and multiple transfer operations, which means that the cargo needs to be unloaded and reloaded at the transfer point, and these operations will increase the dwell time of the cargo at the terminal, thus reducing the berthing efficiency of the container terminal.

In addition, intermodal transport involves the coordination and connection of multiple modes of transport, which may take longer to coordinate the connection between the modes, thus leading to longer time for cargo to reach the container terminal and affecting the overall operational efficiency of the container terminal.

5.3 Summary of this chapter

This chapter mainly analyzes the static efficiency as well as dynamic efficiency of container terminal enterprises. Firstly, the research sample of this paper is selected to collect relevant data, then DEAP Version 2.1 software is used to solve the static efficiency and dynamic efficiency and analyze the calculation results, and finally the efficiency of coastal container terminal and inland container terminal enterprises are compared and analyzed.

Based on the results of the first half of the calculation, the influencing factors such as Skill, Distance, Hinterland GDP, Berthing capacity and Multimodal transport were selected considering the availability of data and the characteristics of the enterprises. The efficiency influencing factors of container terminal enterprises were analyzed using Tobit regression model by Stata/MP 16 and relevant conclusions were drawn.

Charpter 6 Suggestions for efficiency improvement of container terminals

6.1 Efficiency Analysis of Container Terminals

6.1.1 Overall efficiency analysis

In order to show the efficiency difference of individual terminals more intuitively, this paper combines Quadrant Matrix, based on the pure technical efficiency (PTE) and scale efficiency (SE) of the sample for scatter depiction as shown in Figure 6.1, with SE and PTE as the horizontal and vertical coordinates respectively.

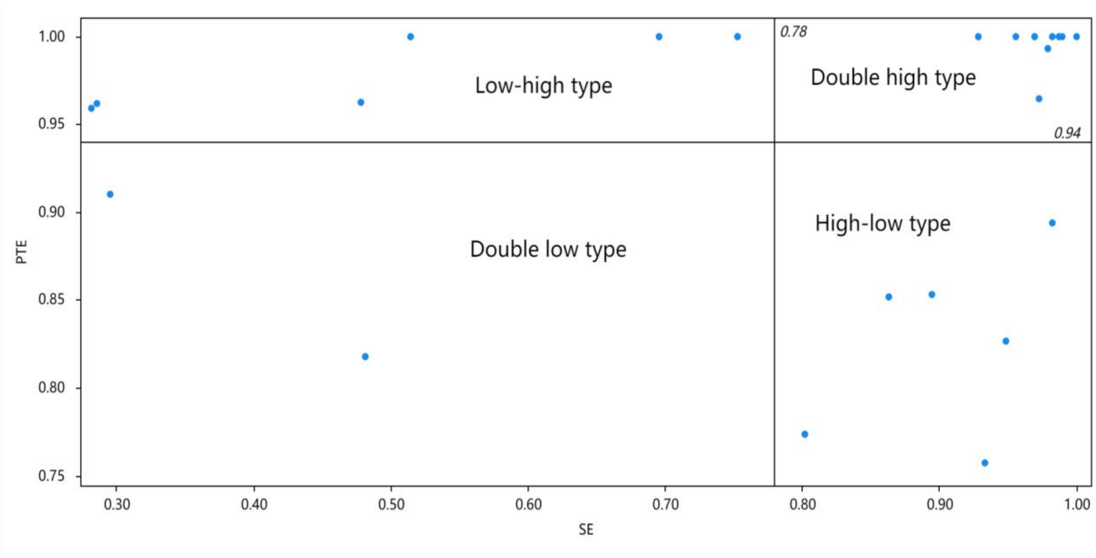


Figure 6.1 2017-2020 Pure technical efficiency and Scale efficiency

The mean value of the decomposition term is used to divide the four areas: Double high area, High-low area, Low-high area and Double low area. GuanDong, Shanghai Hudong, Shanghai Mingdong, Shanghai Zhendong, Ningbo Beilun Second, Dongguan Port International, Yingkou New Century, Shanghai Pudong, which accounts for 40% of the total sample, is a relatively ideal operation state.

High-low type terminal enterprises include six Xiamen Haicang, Shanghai Yidong, Jinzhou Container Terminal, Guangzhou Container Terminal, Zhangjiagang Yongjia, Taicang International, these enterprises have high pure technical efficiency, but the scale efficiency has not reached the average value, and there is still much room for improvement. 5 enterprises of low-high type are: Guangzhou Nansha, Tianjin Port Container Terminal, Ningbo Meishan The scale efficiency of these enterprises is high, but the pure technical efficiency is low, and the lag of technology will lead to the hindrance of sustainable development of the enterprises. There are two types of terminal enterprises, one is Quanzhou Paciffic,Wenzhou Jin Ynag, and these two enterprises have low operational efficiency, which is the problem to be solved.

6.1.2 Berthing and loading efficiency analysis

As shown in the Figure 6.2, there are 7 container terminals located in double high area, namely Shanghai Pudong, Dongguan Port International, Shanghai Mingdong, Yingkou New Century,Shanghai Yidong, Guangzhou Nansha, Shanghai Hudong, Guangzhou Container Terminal, the handling and berthing efficiency of these terminals have reached the ideal state.

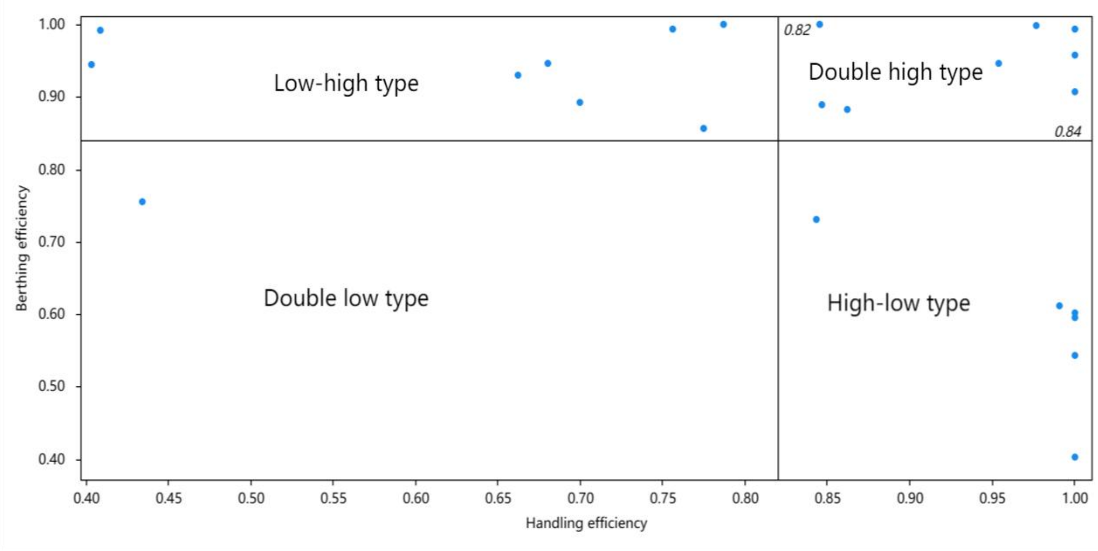


Figure 6.2 2017-2020 Berthing and loading efficiency analysis

Next is the low-high type, a total of six container terminals. They are: Shanghai Shengdong, Tianjin Port Pacific, Ningbo Beilun Second, Shanghai Guan Dong, Tianjin Port Container Terminal, Wenzhou Jin Yang, the handling efficiency of these terminals is relatively low.There are seven terminals of high-low type, namely Shanghai Zhendong, Xiamen International Container, Xiamen Haicang, Ningbo Meishan Island, Chiwan Container Terminal Jinzhou Container Terminal, Zhangjiagang Yongjia, Taicang International, which have lower berthing efficiency.There is only one double low type company, Quanzhou Pacific, whose berthing efficiency and handling efficiency are below the average and need to be solved.

6.2 Suggestions for container terminals

6.2.1 Suggestions for container terminals at the edge of the port group

1）Efficiency Analysis

As shown in Figure 5.5, the overall efficiency of container terminals at the edge of the port cluster is the lowest: listed as Wenzhou Jinyang, Zhangjiagang Yongjia, Taicang International and Jinzhou Container. These four types of container terminals wind up on the edge of the Yangtze River Delta and Pearl River Delta port groups respectively, and their overall efficiency is below 0.4, much lower than the average value of 0.73. Since these terminals are farther away from the central port, this will lead to an increase in logistics and transportation costs, as well as an increase in cargo transportation time and waiting time, thus affecting the overall efficiency. Smaller terminals at the edges are smaller and cannot carry large vessels and large volumes of cargo, so their throughput will be limited.

2）Efficiency improvement suggestions

Wenzhou Jinyang is a relatively small container terminal that mainly serves the local and surrounding areas. It faces challenges in accommodating larger container vessels due to the shallow water depth and outdated equipment and technology. The following suggestions can be considered to improve its efficiency: Increase water depth, invest in the terminal, and increase the frequency of silt excavation to accommodate larger vessels. Introduce modern equipment and technology to improve handling efficiency and precision, and reduce manual operation. Develop multimodal transportation system to interconnect with other means of transportation to improve freight transport efficiency and coverage.

Zhangjiagang Yongjia Terminal is a large comprehensive port serving the Yangtze

River basin and maritime trade. The terminal is located in a favorable location with relatively complete equipment and technical conditions. The following suggestions can be considered to improve its efficiency: Strengthen information management with modern information systems for intelligent scheduling and monitoring. Introduce automatic container handling equipment and technology to reduce manual operation workload and error rate and improve efficiency and safety. Promote green environment protection by adopting clean energy and low-carbon equipment to reduce carbon and pollutant emissions and improve the environmental protection image and sustainable development ability of the port.

Taicang International Terminal is a comprehensive port for container and bulk cargo, serving international trade such as the Yangtze River Delta region and Southeast Asia. It has an advantageous location close to Shanghai. The following suggestions can be considered to improve its efficiency: Enhance logistics support by strengthening logistics support facilities around the terminal, such as developing logistics parks and expanding freight stations. Develop an intelligent port by introducing intelligent logistics and information technology, such as logistics information platform and intelligent yard. Promote safety management by strengthening the safety inspection of the terminal and implementing dangerous cargo management to improve the safety and reliability of the port and reduce the risk of freight transportation.

6.2.2 Suggestions for inland container terminals

1）Efficiency Analysis

According to Figure 5.12, the handling efficiency of inland river terminals is smaller than that of coastal terminals. First, the positioning and functions of inland river terminals and coastal terminals are different. Inland river terminals are generally built along inland rivers or lakes, mainly serving inland water transport logistics, and their goods mainly come from inland manufacturing enterprises or goods imported through inland waterways. The coastal terminal is built on the coastline, mainly serving marine transportation and international trade, and its goods mainly come from marine transportation and foreign trade import and export.

Secondly, the handling efficiency of inland river terminals is smaller than that of coastal terminals, mainly due to the following reasons: 1. The scale of vessels is different. Most of the vessels in inland waterway terminals are small and the loading capacity is relatively small, while coastal terminals tend to have larger cargo ships and container ships, and the loading capacity is much higher than that of inland waterway terminals. 2. The channel conditions are different. Inland river terminals are generally located in narrower waterways, slower currents, and relatively shallow water depths. 3. differences in handling equipment. Coastal terminals are equipped with large cranes, handling equipment, etc. are more advanced, while inland terminals are equipped with mostly smaller and more rudimentary equipment.4. The relatively small scale of inland terminals is also determined by their positioning and function. The service area of inland river terminal is smaller, so its scale is relatively small, while the coastal terminal service area is more extensive, radiating to the whole economic hinterland, so the scale will be larger.

2）Efficiency improvement suggestions

In order to improve the efficiency of inland river container terminals. Among other things, private capital is encouraged to enter the inland river port investment sector, and incentives such as tax breaks, government loans and investment promotion are provided. Support the automation and information technology construction of inland river terminals by providing funding and technical advice, such as the Wuhan Port's comprehensive automated container handling equipment upgrade project launched in 2019. Require inland river terminals to follow a series of management and service standards, such as Shanghai Port Group has put forward a series of standards for the management and services of inland river terminals to ensure that the inbound, handling and settlement processes are operated according to standardized processes. Support inland river terminals to build logistics parks and provide supporting services, with reference to Nanchang Port's 2 billion RMB investment in building inland river port logistics parks. Encourage inland river terminals to strengthen international cooperation and exchange and introduce advanced management and technology experience, for example, Ningbo Zhoushan Port cooperates with Malaysia Port Authority to carry out inland river shipping business and promote the development and cooperation of ports in both countries. These policy proposals will promote the development of inland waterway terminals and improve the competitiveness of inland waterway terminals.

6.2.3 Suggestions for the southeast coastal terminals

1）Efficiency Analysis

According to Table 5.5 and Table 5.7, the average container terminal on the southeast coast has the lowest overall efficiency and handling efficiency, which are 0.639 and 0.701 respectively.These include Quanzhou Pacific, Xiamen International, Xiamen Container Terminal. The problem of old equipment in Xiamen container terminal may be manifested in the following aspects: First, the number of cranes in the terminal is low, only about 10, and most of them are old models, which cannot meet the needs of modern container terminals. Road traffic congestion is serious, and the above terminals are located in the city, which affects the efficiency of goods entering and leaving the terminal, and needs to strengthen the construction of traffic infrastructure.

2）Efficiency improvement suggestions

For Xiamen port container business, foreign trade container terminal enterprises to give incentives to support, encourage foreign trade shipping enterprises to develop container routes, expand the container international transit and empty box transfer business, support the "Silk Road Shipping" and key customers, etc., to enhance the port radiation and service capacity, bigger and stronger Xiamen port container business.

For Quanzhou should build "Two ports, two shores and one center" port system, namely, Quanzhou port and Zhangzhou port as the core, build two ports, Anxi port and Jinjiang port, build a new highland for the development of port industry in Fujian (Quanzhou) Pilot Free Trade Zone, form diversified business of container, liquid chemical and petrochemical products, further improve the container processing efficiency of Quanzhou port. To promote the high-quality development of Quanzhou port industry.

Encourage Quanzhou port to develop international shipping line business, and enhance the port service capacity and competitiveness. Specific policies include financial subsidies, free use of port facilities, preferential charges, etc. Quanzhou Port Group is also required to optimize the service process, improve cargo handling efficiency and promote the development of container transshipment business in Quanzhou Port.

Charpter 7 Conclusions and Outlook

7.1 Research conclusions

In this paper, DEA model and Malmquist productivity index is used to measure the overall efficiency of container terminal enterprises from both static and dynamic levels and compare and analyze the differences in efficiency of container terminal enterprises in inland and coastal areas and even in different port groups.

(1)The berthing sub-efficiency is the highest, the handling sub-efficiency is the next, and the overall efficiency is the lowest. From the evaluation results, the handling sub-efficiency and the overall efficiency show the same trend of change, that is, usually the higher the efficiency of the handling sub-process, the higher the overall efficiency of the container terminal.

The handling efficiency of container terminals in China has geographical differences, from the overall efficiency ranking, firstly, the Yangtze River Delta region is the highest, followed by the Bohai Rim and Pearl River Delta regions, and finally, the southeast coastal region. The overall efficiency of the container terminals at the edge of the port group is the lowest.

Comparing the overall efficiency of coastal terminals and inland river terminals, the overall efficiency of coastal terminals and handling efficiency is greater than that of inland river terminals.

(2)The average overall total factor productivity of enterprises in Chinese container terminals is in a state of increasing year by year, and the increase in the ML index of most of them is caused by technological progress. The trend of ML index of berthing sub-process is similar to the trend of overall ML index. However, the ML index of the handling sub-process decreases year by year, which is caused by the decrease of technical efficiency change year by year.

(3)The level of competition in container terminals reduces the overall efficiency of the terminal and the efficiency of the berthing sub-process. Urban GDP in the inland hinterland has a positive impact on the berthing sub-process. Maximum berthing capacity has a negative impact on the handling sub-process. Multimodal transport reduces the efficiency of berthing sub-process of the enterprise. However, ownership structure has no significant effect on the efficiency of container terminal enterprises.

(4)For the container terminals at the edge of the port group: such as Wenzhou Jinyang, Zhangjiagang Yongjia, Taicang International and Jinzhou Container. These ports are located far from the central port of the port group, so the construction of logistics support facilities around the terminals can be increased and strengthened, such as the development of logistics parks and expansion of freight stations, in order to improve the efficiency of inland distribution of goods. Strengthen port logistics connections: Improve the connections between ports and inland transportation networks, including railroads, highways and inland waterways. Ensure efficient logistics corridors to facilitate the rapid flow and distribution of goods.

(5)For inland container terminals:such as Zhangjiagang Yongjia, Guangzhou Container Terminal, etc. Encourage private capital to enter the inland port investment sector and provide incentives such as tax breaks and investment attraction. By deepening waterways and berths, larger vessels will be attracted to improve loading and unloading efficiency and cargo throughput.

(6)For container terminals along the southeast coast: such as Xiamen container port, the government can give incentives to support foreign trade container terminal enterprises, encourage foreign trade shipping enterprises to develop container routes, expand international container transshipment and empty container transfer business. As well as the introduction of modern loading and unloading equipment, and strengthen the construction of transport infrastructure and other measures to solve the aging equipment, road congestion and other problems.

7.2 Outlook

In this paper, when evaluating the research efficiency, ship-time handling and container throughput are used as output indicators of terminal efficiency. Considering the difficulty of data collection, there is no average ship time in port as an output indicator, because the ship time in port is divided into operating time and idle time, which are difficult to detect and collect.

As well as other factors that can be added to affect the efficiency of the terminal there are factors of container types, such as the number of handling of oversized containers, such special containers tend to spend a lot of handling time. As well as other external factors, such as the establishment of free trade zones, special customs regimes, pollution emissions, etc., subsequent data collection for specific ports can be analyzed.

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Appendix

Table1 23 Container indicator parameters in 2017 (1)

Year	Company	Quay shoreline length	Quay front water depth	Number of berths	Number of tyre crane and other vehicles	Yard area	Number of bridge cranes or other cranes
2017	Chiwan Container Termina	3428	16	10	558	113	45
2017	Dongguan Port Internationa	687	14. 3	2	100	299	6
2017	Guangzhou Nansha	1400	15. 5	4	261	105	30
2017	angzhou Container Termi	867	12. 5	3	86	12	3
2017	Jinzhou Container Termina	677	16. 5	2	39	40	4
2017	Ningbo Meishan Island	1800	18	5	222	97	20
2017	Ningbo Beilun Second	1258	15	4	212	70	18
2017	Quanzhou Pacific	1350	15. 1	5	155	71	11
2017	Shanghai Guan Dong	2600	17. 5	7	116	238	30
2017	Shanghai Yidong	1641	10. 5	7	145	36. 55	15
2017	Shanghai Zhendong	1984	13. 7	6	196	108	10
2017	Shanghai Hudong	1250	12. 5	6	106	98	17
2017	Shanghai Mingdong	2068	12. 8	7	125	112. 6	28
2017	Shanghai Pudong	940	12. 5	3	79	30. 2	11
2017	Shanghai Shengdong	3000	16	9	142	147. 9	35
2017	Taicang International	930	12	4	49	68	4
2017	njin Port Container Termi	1240	16	4	183	53. 2	14
2017	Tianjin Port Pacific	2300	16. 5	6	93	180	23
2017	Wenzhou Jin Yang	867	12. 5	3	86	12	3
2017	amen International Contai	1086	15. 4	3	54	72	11
2017	Xiamen Haicang	754	13. 5	2	26	29. 75	6
2017	Yingkou New Century	680	17	2	54	45	6
2017	Zhangjiagang Yongjia	722	10. 8	3	72	30	5

Table2 23 Container indicator parameters in 2018 (1)

Year	Company	Quay shoreline length	Quay front water depth	Number of berths	Number of tyre crane and other vehicles	Yard area	Number of bridge cranes or other cranes
2018	Chiwan Container Termina	3428	14. 75	9	475	118	45
2018	Dongguan Port Internationa	687	14. 3	2	101	29. 89	6
2018	Guangzhou Nansha	2100	15. 5	6	300	106. 48	22
2018	angzhou Container Termi	810	12. 5	4	129	14. 4	14
2018	Jinzhou Container Termina	677	16	2	40	40	4
2018	Ningbo Meishan Island	1800	18. 5	5	227	97	20
2018	Ningbo Beilun Second	1258	15	4	82	70	18
2018	Quanzhou Pacific	1350	15. 1	5	147	71	11
2018	Shanghai Guan Dong	2600	17. 5	7	115	147	30
2018	Shanghai Yidong	1641	10. 5	7	146	36. 55	16
2018	Shanghai Zhendong	1984	12. 82	6	173	108	27
2018	Shanghai Hudong	1250	12. 5	6	108	98	17
2018	Shanghai Mingdong	2068	12. 8	7	50	112. 6	26
2018	Shanghai Pudong	940	12	3	80	0	11
2018	Shanghai Shengdong	3000	16	9	106	148	15
2018	Taicang International	930	12	4	49	68	4
2018	njin Port Container Termi	1204	16	4	160	53. 2	14
2018	Tianjin Port Pacific	2300	18	6	94	195	23
2018	Wenzhou Jin Yang	867	12. 5	5	77	9. 8	4
2018	amen International Contai	1083	15. 4	3	55	72	11
2018	Xiamen Haicang	754	13. 5	2	35	29. 75	6
2018	Yingkou New Century	630	15	2	54	45	6
2018	Zhangjiagang Yongjia	722	11. 8	3	74	42. 59	5

Table3 23 Container indicator parameters in 2019 (1)

Year	Company	Quay shoreline length	Quay front water depth	Number of berths	Number of tyre crane and other vehicles	Yard area	Number of bridge cranes or other cranes
2019	Chiwan Container Termina	3428	14.75	9	475	118	45
2019	Dongguan Port Internationa	687	14.3	2	101	29.89	6
2019	Guangzhou Nansha	2100	15.5	6	300	106.48	22
2019	angzhou Container Termi	810	12.5	4	129	14.4	14
2019	Jinzhou Container Termina	677	16	2	40	40	4
2019	Ningbo Meishan Island	1800	18.5	5	227	97	20
2019	Ningbo Beilun Second	1258	15	4	82	70	18
2019	Quanzhou Pacific	1350	15.1	5	147	71	11
2019	Shanghai Guan Dong	2600	17.5	7	115	147	30
2019	Shanghai Yidong	1641	10.5	7	146	36.55	16
2019	Shanghai Zhendong	1984	12.82	6	173	108	27
2019	Shanghai Hudong	1250	12.5	6	108	98	17
2019	Shanghai Mingdong	2068	12.8	7	50	112.6	26
2019	Shanghai Pudong	940	12	3	80	0	11
2019	Shanghai Shengdong	3000	16	9	106	148	15
2019	Taicang International	930	12	4	49	68	4
2019	njin Port Container Termi	1204	16	4	160	53.2	14
2019	Tianjin Port Pacific	2300	18	6	94	195	23
2019	Wenzhou Jin Yang	867	12.5	5	77	9.8	4
2019	amen International Contai	1083	15.8	3	55	72	11
2019	Xiamen Haicang	754	13.5	2	35	29.75	6
2019	Yingkou New Century	630	14	2	54	40	6
2019	Zhangjiagang Yongjia	722	11.8	3	74	42.59	5

Table4 23 Container indicator parameters in 2020 (1)

Year	Company	Quay shoreline length	Quay front water depth	Number of berths	Number of tyre crane and other vehicles	Yard area	Number of bridge cranes or other cranes
2020	Chiwan Container Termina	3457	16.5	9	386	118.2	39
2020	Dongguan Port Internationa	687	14.3	2	112	29.89	6
2020	Guangzhou Nansha	2100	15.5	6	321	106	22
2020	angzhou Container Termi	810	12.5	4	132	14.1	15
2020	Jinzhou Container Termina	677	16	2	56	40	6
2020	Ningbo Meishan Island	1800	18.5	5	227	97	20
2020	Ningbo Beilun Second	1258	15	4	81	70	18
2020	Quanzhou Pacific	630	14	2	60	40	6
2020	Shanghai Guan Dong	2600	17.5	7	115	146.96	30
2020	Shanghai Yidong	1641	10.5	7	151	36.55	16
2020	Shanghai Zhendong	1984	13.7	7	175	107.88	34
2020	Shanghai Hudong	1250	12.5	6	108	98	17
2020	Shanghai Mingdong	2068	12.8	7	50	112.6	26
2020	Shanghai Pudong	940	12	3	78	27.5	11
2020	Shanghai Shengdong	3000	16	9	138	147.92	35
2020	Taicang International	930	12	4	80	67.99	4
2020	njin Port Container Termi	1204	16	4	160	53.2	14
2020	Tianjin Port Pacific	2300	16	6	71	196	23
2020	Wenzhou Jin Yang	867	15.5	5	73	9.8	3
2020	amen International Contai	1083	15.4	3	59	71.92	11
2020	Xiamen Haicang	754	13.5	2	34	29.86	8
2020	Yingkou New Century	630	15	2	54	45	6
2020	Zhangjiagang Yongjia	867	15.5	5	73	9.8	3

Table5 23 Container indicator parameters in 2017 (2)

Year	Company	Average ship handling quantity in hour	Average handling quantity of bridge crane in hour	Number of ships arriving at port	Average ship handling quantity in hour	Throughput
2017	Chiwan Container Termina	68.29	34.87	28299	7.82	5E+06
2017	Dongguan Port Internationa	110	46	431	6.27	1E+06
2017	Guangzhou Nansha	161	36.3	18821	8.2	5E+06
2017	uangzhou Container Termi	48.33	33.6	10037	0.44	1E+06
2017	Jinzhou Container Termina	65.6	32.5	550	5	376015
2017	Ningbo Meishan Island	115.32	59.33	2368	7.34	2E+06
2017	Ningbo Beilun Second	130.92	36.32	2731	5.68	4E+06
2017	Quanzhou Pacific	41.5	35.8	2410	8	1E+06
2017	Shanghai Guan Dong	123.77	30.97	6271	8.18	7E+06
2017	Shanghai Yidong	24.03	26.18	13023	4.26	3E+06
2017	Shanghai Zhendong	88.97	47.35	16000	6.59	6E+06
2017	Shanghai Hudong	121.44	44.4	2961	5.69	4E+06
2017	Shanghai Mingdong	99.97	45.72	3469	0.54	6E+06
2017	Shanghai Pudong	117.33	42.86	6210	4.7	3E+06
2017	Shanghai Shengdong	126.55	30.26	7269	3.5	8E+06
2017	Taicang International	28.12	27.26	6072	6.56	513295
2017	anjin Port Container Termi	110.19	36	1011	3.57	2E+06
2017	Tianjin Port Pacific	101	45.1	1015	6.3	3E+06
2017	Wenzhou Jin Yang	23.3	22.1	1130	7.6	490321
2017	amen International Contai	120.02	47.86	1416	6.85	1E+06
2017	Xiamen Haicang	76.51	42.34	1739	4.76	1E+06
2017	Yingkou New Century	144	53.8	592	3.5	2E+06
2017	Zhangjiagang Yongjia	21.87	32.96	7713	20.29	675061

Table6 23 Container indicator parameters in 2018 (2)

Year	Company	Average ship handling quantity in hour	Average handling quantity of bridge crane in hour	Number of ships arriving at port	Average ship handling quantity in hour	Throughput
2018	Chiwan Container Termina	70.66	38.42	30275	9.29	5E+06
2018	Dongguan Port Internationa	130	40.4	455	5.78	1E+06
2018	Guangzhou Nansha	102.5	30.34	19696	8.475	5E+06
2018	uangzhou Container Termi	47.4	33.9	10577	5.99	1E+06
2018	Jinzhou Container Termina	65	33.5	739	7	376000
2018	Ningbo Meishan Island	49.3	106.29	2958	7.33	3E+06
2018	Ningbo Beilun Second	128.94	28.11	2465	6.51	3E+06
2018	Quanzhou Pacific	44.4	36.6	2344	7.5	1E+06
2018	Shanghai Guan Dong	124.89	27.17	3402	7.4	8E+06
2018	Shanghai Yidong	24.08	27.52	12835	4.09	4E+06
2018	Shanghai Zhendong	85.1	47.83	16239	6.64	7E+06
2018	Shanghai Hudong	126.6	43.25	2926	5.6	4E+06
2018	Shanghai Mingdong	105.69	46.34	3514	0.55	7E+06
2018	Shanghai Pudong	110.67	41.17	5731	6.35	3E+06
2018	Shanghai Shengdong	127.1	34.41	6509	5	9E+06
2018	Taicang International	26.94	26.04	5542	6.8	520797
2018	anjin Port Container Termi	103.64	35.8	1021	3.75	2E+06
2018	Tianjin Port Pacific	146	46	732	5.7	3E+06
2018	Wenzhou Jin Yang	23.5	21.1	1267	7	887650
2018	amen International Contai	100.915	40.42	1102.5	4.38	1E+06
2018	Xiamen Haicang	81.12	41.24	2952.5	13.09	1E+06
2018	Yingkou New Century	122	43	1.5	4	2E+06
2018	Zhangjiagang Yongjia	21.13	30.85	7010	21.4	735920

Table7 23 Container indicator parameters in 2019 (2)

Year	Company	Average ship handling quantity in hour	Average handling quantity of bridge crane in hour	Number of ships arriving at port	Average ship handling quantity in hour	Throughput
2019	Chiwan Container Termina	87.56	28.15	3272	9	5E+06
2019	Dongguan Port Internationa	131.78	40.56	430	6.02	1E+06
2019	Guangzhou Nansha	110.245	32.01	19198	8.34	5E+06
2019	angzhou Container Termi	40.89	29.67	10770	4.97	1E+06
2019	Jinzhou Container Termina	60	30	598	4	751855
2019	Ningbo Meishan Island	109.12	57.47	2943	7.45	4E+06
2019	Ningbo Beilun Second	125.11	26.74	2159	6.35	3E+06
2019	Quanzhou Pacific	50.18	37.21	2041	7.25	2E+06
2019	Shanghai Guan Dong	133.06	23.47	5429	7.94	8E+06
2019	Shanghai Yidong	27.52	28.59	12802	4.34	4E+06
2019	Shanghai Zhendong	84.07	47.14	15383	6.36	7E+06
2019	Shanghai Hudong	129.98	42.57	2796	5.5	4E+06
2019	Shanghai Mingdong	100.47	45.65	3604	0.54	6E+06
2019	Shanghai Pudong	92.41	40.52	5229	5.23	3E+06
2019	Shanghai Shengdong	127.2	34.53	6531	4.5	9E+06
2019	Taicang International	25.41	25.18	4471	7.03	520797
2019	njin Port Container Termi	102.41	35.56	987	3.51	3E+06
2019	Tianjin Port Pacific	40.58	26.6	638	5.25	4E+06
2019	Wenzhou Jin Yang	32.8	23.03	1348	6.3	632590
2019	amen International Contai	116.77	48.53	1281	5.97	982642
2019	Xiamen Haicang	74.03	43.58	2043	4.68	1E+06
2019	Yingkou New Century	125.32	38.5	466	4	1E+06
2019	Zhangjiagang Yongjia	18.24	28.68	5313	22.68	761848

Table8 23 Container indicator parameters in 2020 (2)

Year	Company	Average ship handling quantity in hour	Average handling quantity of bridge crane in hour	Number of ships arriving at port	Average ship handling quantity in hour	Throughput
2020	Chiwan Container Termina	77.925	31.51	15785.5	8.41	5E+06
2020	Dongguan Port Internationa	117.5	34	497	6	1E+06
2020	Guangzhou Nansha	112.32	30.42	4094	8.7	6E+06
2020	angzhou Container Termi	46.76	34.26	12600	0.39	1E+06
2020	Jinzhou Container Termina	64.28	33.54	694	7	918434
2020	Ningbo Meishan Island	136.88	46.13	2631	6.81	5E+06
2020	Ningbo Beilun Second	162.04	27.54	2379	6.12	3E+06
2020	Quanzhou Pacific	52.36	38.79	2053	7.53	2E+06
2020	Shanghai Guan Dong	140.09	26.62	1498	8.48	8E+06
2020	Shanghai Yidong	25.69	33.3	2133	4.25	4E+06
2020	Shanghai Zhendong	79.61	47.98	16930	6.75	7E+06
2020	Shanghai Hudong	131.42	41.92	2845	6.21	4E+06
2020	Shanghai Mingdong	104.4	46.29	3585	0.5	6E+06
2020	Shanghai Pudong	94.23	41.64	6304	4.41	3E+06
2020	Shanghai Shengdong	127.6	32.82	7470	5.3	9E+06
2020	Taicang International	49.92	44.46	9908	4.78	520797
2020	njin Port Container Termi	107.32	35.8	3325	4.2	8E+06
2020	Tianjin Port Pacific	176	43	578	5.4	4E+06
2020	Wenzhou Jin Yang	39.91	25.26	1263	5.4	537303
2020	amen International Contai	106.48	48.47	1364	6.09	1E+06
2020	Xiamen Haicang	83.12	44.65	1938	4.46	1E+06
2020	Yingkou New Century	86	38.6	424	7	1E+06
2020	Zhangjiagang Yongjia	22.95	32.25	5355	20.28	657849

Table9 Influencing factor data in 2020

DUM	Overall efficiency	Berthing efficiency	Handling efficiency	OS	Skill	Compitetion	GDP	Capacity	Multipal transportation
Chiwan Container Terminal	0.6205	0.947	0.708875	1	296	28.6	13.53	20	229929.5
Dongguan Port International	0.96925	0.957	0.9815625	1	98	1.3	9.32	5	50521
Guangzhou Nansha	0.46025	1	0.5953125	1	103	18.8	13.53	7.5	52608
Guangzhou Container Terminal	0.878	0.8825	0.867375	0	206	1	13.53	20	232448.75
Jinzhou Container Terminal	0.514	0.9295	0.631875	1	96	25	13.93	5	3440
Ningbo Meishan Island	0.93825	0.5425	0.8569375	0	351	2	13.26	15	74190.75
Ningbo Beilun Second	0.7095	0.89175	0.8023125	0	325	2	13.26	15	91835.245
Quanzhou Pacific	0.40225	0.7555	0.5386875	1	70	36	11.48	10	62465
Shanghai Guan Dong	0.7635	0.85625	0.7869375	1	129	5.2	12.5	15	64290
Shanghai Yidong	0.753	0.99375	0.8361875	1	62	5.2	12.5	10	13828
Shanghai Zhendong	0.98925	0.40175	0.837	0	312	0.6	15.68	15	524967
Shanghai Hudong	0.987	0.8885	0.968875	1	253	0.4	15.68	10	137059
Shanghai Mingdong	0.98225	0.90725	0.959125	1	377	0.4	15.68	15	257417.25
Shanghai Pudong	0.9285	0.9925	0.9195	1	206	0.6	15.68	10	56118
Shanghai Shengdong	1	0.60175	0.9004375	0	398	0.6	15.68	15	511679.5
Taicang International	0.69525	0.94675	0.7805	1	108	6.9	15.68	5	175232
Tianjin Port Container Terminal	0.97275	1	0.9659375	1	246	0.6	15.68	10	174551.75
Tianjin Port Pacific	0.27125	0.945	0.4580625	1	172	80	10.4	5	43221
Wenzhou Jin Yang	0.78675	0.6115	0.7853125	1	250	3.7	10.11	20	35207
Xiamen International Container	0.7435	0.59475	0.7193125	1	43	3.7	10.11	20	1689
Xiamen Haicang	0.26775	0.73025	0.3905	1	45	130	7.16	2.5	35684
Yingkou New Century	0.9555	0.99875	0.9440625	0	45	2.3	8.68	5	16916
Zhangjiagang Yongjia	0.27675	0.99175	0.445875	1	68	73	12.5	5	53334