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WORLD MARITIME UNIVERSITY

Shanghai, China

RESEARCH ON SUPPLY AND DEMAND OF CONTAINER PORT HANDLING CAPACITY—TAKING YANGSHAN HARBOR AREA OF SHANGHAI PORT AS AN EXAMPLE

By

CHEN LIANGXI

China

A research paper submitted to the World Maritime University in partial Fulfillment of the requirements for the award of the degree of

MASTER OF SCIENCE

INTERNATIONAL TRANSPORT AND LOGISTICS

2021

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DECLARATION

I certify that all the material in this dissertation that is not my own work has been identified, and that no material is included for which a degree has previously been conferred on me.

The contents of this dissertation reflect my own personal views, and are not necessarily endorsed by the University.

Signature: Chen Liangxi

Date: 2021.07.01

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Supervisor's affiliation: Shanghai Maritime University

ACKNOWLEDGEMENT

Time flies, the graduate study is close to the end. In this year's study life, I not only got the care and help of teachers and classmates, but also learned a lot of knowledge and skills. Here, I want to express my inner gratitude.

First and foremost, I would like to extend my deepest gratitude to Professor Liu Wei, my supervisor, who has provided me constant encouragement and insightful guidance in every stage of research and writing of this thesis. Without his consistent and illuminating instruction, I could not have imagined accomplishing this thesis.

My sincere thanks also goes to the professors and staffs from World Maritime University and Shanghai Maritime University whose lectures and guidance helped me to make academic progress during the two years.

Finally, I am very grateful to my friends and family for all the supports and understanding that you have given which inspire me to face and fight against the difficulties to strive towards my goal.

ABSTRACT

Title of the thesis: Research on Supply and Demand of Container Port Handling Capacity—Taking Yangshan Harbor Area of Shanghai Port as an Example.

Degree: Master of Science in International Transport and Logistic

This paper studies the supply and demand of container handling capacity of container port, taking Yangshan Harbor Area of Shanghai Port as an example. The supply and demand between container handling capacity and container throughput plays a very important role in the future development and construction of the port. Yangshan Deepwater Port, as an international hub port connecting the major ports in the world, with its unique location advantages and good natural conditions and the booming economic environment of Shanghai and the Yangtze River Delta Region of China, has become the core project of Shanghai International Shipping Center.

This paper briefly expounds the background and status quo of the research, then introduces the development status of Chinese container port from several aspects, and mainly analyzes the characteristics of container transportation in China. Next，A brief overview of some common port container throughput prediction methods is presented, and the prediction characteristics and application conditions of gray model are discussed. GM(1,1) model is established by using the data of container throughput in Yangshan Harbor Area of Shanghai Port from 2006 to 2020 to predict the container throughput in Yangshan Harbor Area in the next five years, and the accuracy of the results is tested. At the same time, the prediction results are also tested by three exponential smoothing method to ensure their correctness. Then, the throughput capacity of Yangshan Harbor Area planning is summarized and analyzed, and this paper also points out the adaptive problems of container throughput capacity, namely the elasticity of throughput capacity. Based on the above analysis, this paper studies the supply and demand of container throughput capacity in Yangshan Harbor Area, draws the conclusion that supply is less than demand, and expounds the possible serious consequences.

Finally, countermeasures and suggestions are put forward for the insufficient supply of container handling capacity in Yangshan Harbor Area. The study on the supply and demand of container throughput capacity in Yangshan Harbor Area of Shanghai Port will provide some help for the development of port planning and construction and port production adjustment.

KEYWORDS: Container port; Container throughput; Throughput capacity; Supply and demand; Adaptability; Gray model; Yangshan Harbor Area

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LIST OF ABBREVIATIONS

TEU	Twenty feet Equivalent Unit
COSCO	China Ocean Shipping (Group)Company
DWT	Dead Weight Tonnage
SIPG	Shanghai International Port Group

1 INTRODUCTION

1.1 Research background and significance

1.1.1 Research background

Since the 1960s, container as the main means of marine transportation, has become the mainstream of global integrated transportation because of its container standardization, high-efficiency, modern management and convenient docking. And it has incomparable advantages compared with the traditional general cargo transportation. According to incomplete statistics, there are more than 100 countries and regions in the world carrying out container transportation, and some developed countries have realized full containerization of groceries. The advantages of container transportation have been recognized all over the world. The role of container transportation in international trade is becoming more and more important, and the research of container transportation has been paid more and more attention.

Since the 1980s, China's large-scale container transportation has been favored because of its high loading and unloading efficiency, fast ship turnover, less packaging costs, less cargo damage and difference, and it’s suitable for "door-to-door" logistics mode. That make it get rapid popularization and development. Nowadays, the containerization rate of Chinese ports is gradually increasing, and the development trend of port container transportation industry is fast and stable.

As an important industrial transportation base and interface of land and sea transportation, port plays a fundamental role in market allocation of resources. It is the link between production and consumption, domestic and foreign transportation. The development of port is related to the vicissitude of the cities and even the hinterlands economy, and it is also the main condition and investment environment for the country to attract foreign investment and develop export-oriented economy. Nowadays, countries all over the world attach great importance to the construction and development of ports so that they can enhance international competitiveness and promote the development of domestic economy. Without exception, China is carrying out economic construction step by step, and the construction of container ports is an important part of national economic construction.1

Port container throughput is affected by many factors, such as world economic development, domestic economic operation, industrial structure adjustment, production and consumption supply and demand, port conditions and so on. How to make more reasonable capital investment, plan the development scale of the port and formulate effective operation strategy must be based on scientific analysis and accurate judgment. Strengthening the accurate prediction of container throughput is more conducive to grasp the influencing factors of container throughput and it can find the advantages and disadvantages of port construction.

Shanghai Port is the largest port in the world, and Yangshan Harbor Area is an important part of Shanghai Port. In the past 2020, the container throughput of

Yangshan Harbor Area reached 20,222 million TEU, accounting for 46.5% of Shanghai Port. It played a major role in helping Shanghai Port maintain its container throughput first in the world for consecutive 11 years. Yangshan Deepwater Port is the core project of the International Shipping Center of Shanghai. With the change of domestic and international economic environment and the increase of uncertainty, how to further respond to the national strategic demand and the change of international environment, how to scientifically predict the container throughput, how to understand the supply and demand relationship of port container throughput capacity, and how to timely resolve bottlenecks and risks are the important strategic objectives of Yangshan Harbor Area development. Based on this, the research of this paper emerges and also puts forward suggestions for the development of container port.

1.1.2 Research significance

At present, the world economy is in a stage of sluggish growth, international economic and trade frictions have intensified, and downward pressure on the domestic economy has increased. As a smart and efficient container hub port and an International Shipping Center with global influence, the container throughput in Shanghai Port is an important indicator of port construction capacity and international competitiveness. The accurate forecast of container throughput will help ports to allocate resources reasonably and achieve efficient and high-quality port activities.

The construction scale of the port can only be determined after scientific investigation and evaluation of port throughput. If the port is built too much and exceeds the market demand, it will cause the port equipment to be idle, resulting in a waste of financial and material resources invested in port construction. If the throughput capacity of the port is less than the actual throughput, the port will be overloaded. It will also bring about a backlog of goods and severe wastage of port resources, making the port's transportation in passive situation, which is very detrimental to port operations. Reasonable planning for the future development of the port will greatly improve the port's future container throughput and port operation efficiency, which will help reduce port operating costs and promote the sustainability of port economic development.

Yangshan Harbor Area of Shanghai Port is located on the rugged islands outside the mouth of Hangzhou Bay, only 45 nautical miles away from international routes. It is a deep-water container port area of Shanghai International Shipping Center and is also the core port area for Shanghai Port to participate in international competition. In recent years, the container throughput of Yangshan Harbor Area has been growing steadily, ranking first in Shanghai Port and helping Shanghai Port lead the world in container throughput for 11 consecutive years. Under the current situation, how does the Yangshan Harbor Area adapt to the development of container throughput and the needs of sustained economic development, maintain its own good competitiveness, improve the operational efficiency of port logistics, and continuously improve its comprehensive strength to develop the port. This is the first issues to be considered in the future development of Yangshan Harbor Area of Shanghai Port.

A reasonable and accurate forecast of port throughput will play a guiding role in the development of the port. This article will predict the future development of the port's container throughput by establishing a reasonable and correct port container throughput prediction model, and analyze the supply and demand of the port's container throughput capacity. On this basis, this article puts forward the relevant thinking and countermeasures for the future development of the port, and provides guidance and reference for the future research of the port's throughput capacity.

The Practical significance of this article lies in:

a) With the continuous modernization of port construction, more and more attention has been paid to the development of port container throughput. The port has continuously increased investment and construction in the development of container throughput, and has continued to plan and develop the port container throughput operation system. However, with the rapid development of port container throughput, some problems have gradually emerged. For example, the port infrastructure configuration failed to meet the development needs of port container throughput, the repeated construction of throughput logistics facilities, and the development plan formulated by the port could not adapt to the development of the port. Therefore, in order to make full use of the existing resources of the port and ensure the sustainable development of the port, the blindness of development should be avoided. Therefore, it is necessary to reasonably predict the future throughput development of the port, and put forward thoughtful suggestions on the development of the port on the basis of forecast analysis.

b) The forecast of port container throughput provides the government and enterprises with key information so that the government and enterprises can fully understand the development of the port and timely understand the future development trend of the port. From the perspective of the government, this will be more conducive to its promotion of the development of logistics supporting industries, including logistics personnel training, logistics equipment industry, logistics consulting industry, etc.

c) Accurate prediction of container throughput and analysis of the supply and demand of container throughput provide guidance for deciding the direction of port development, provide certain direction and help for the government and port investors to invest and make decisions and avoid blindness in investment. In the meanwhile, it has important practical guiding significance for operators to optimize and adjust port production. In addition, the forecast of port container throughput also provides a theoretical basis for the future planning and layout of the port.

1.2 Research status

The research on container port at home and abroad mainly focuses on the following aspects:

First of all, the researches on the economic management of container port. *Port Economics* authored by J. O. Jansson and D. Shneerson (1982), applied modern economic theory to discuss port economic problems, especially the pricing problem of ports in the case of congestion. E. Bennathan and A.A.Walters (1981) made a detailed discussion on port investment and port pricing in their book *Pricing and Investment Policy for Developing Countries*. Luo Fang (2012) made a scientific design on the governance mechanism of adverse competition in the Yangtze River Delta port group. It mainly talked about the main variables and the mechanism model of bad competition among ports, and the implementation measures of governance mechanism, etc. Li Hongbing (2015) found the origin and development of the port industry and the status and role of the port industry in the national economy by clearly defining the port industry. On this basis, the paper further analyzed the security threats and their causes in the development of China's port industry.

Second, the researches of container port planning. Yang Bo, Liu Yu and Yang Zhenglong (2020) constructed a multi factor dynamic generation coefficient method with Logistic-model. It gives full play to the advantages of the model in dealing with complex system behavior. Wang Tiantian (2019) constructed the SVR model based on Ant Colony Optimization algorithm, and selected the monthly container throughput data of Ningbo-Zhoushan port for empirical analysis. The model was compared and analyzed with SVR model, ARIMA model, GM(1,1) model and Bayesian optimized SVR model. The results showed that the prediction accuracy of the SVR model based on Ant Colony Optimization is higher. It provided a theoretical basis for port construction. Sun Jiaqing and Wei Yuqi (2020) established the port adaptability evaluation model, and calculated the carrying capacity index of the main ports in the Pearl River Delta region by using the data envelopment analysis (DEA), which can get the supply and demand adaptability of the ports in the Pearl River Delta region. In addition, the adaptability of the port is evaluated and some suggestions are put forward, which is helpful for the further development of the port.

Third, analyses based on time series. In the studies of time series analyses, Zhao Yiqi (2018) took the construction of the product season model as the starting point, took the port cargo throughput as the test model, and then predicted the port throughput. Pang and Gebka (2016) used the seasonal differential auto-regressive moving average model as one of the time series prediction analysis methods. Rashed and Meersman (2017) used ARIMA model and monthly data of total container throughput of Antwerp Port from January 1995 to March 2015. This paper forecasts the future container throughput and explores the impact of container throughput on local economic activities. Han-Chao W and others (2012) introduced the quartet exponential smoothing prediction into the grey GM(1,1) model for individual prediction. The model achieved high prediction accuracy and good reliability. On the basis of the former, Hou, J. and others (2015) integrated Pearl Curve Model and GM(1,1) model on the basis of exponential smoothing to form a comprehensive model, which greatly improved the prediction accuracy. Jiang Ruhan (2019) built a grey GM(1,1) model to predict the container throughput of Qingdao port. This paper studied the prediction of container throughput of Qingdao port, which is helpful to the development of port planning and construction and port production adjustment. Gamassa and others (2017) sorted out and analyzed the data of Abidjan port container throughput over the years, and finally determined the double exponential smoothing model as the optimal scheme. Wu Chen (2019) analyzed the change trend characteristics of time series. Then he selected ARIMA model to predict according to the characteristics of the original sequence. The results showed that the relative error between the predicted value and the actual value was basically controlled within 10%. This reflected the reliability and accuracy of the model. Ee, YJC and others (2014) applied ARIMA and exponential smoothing method to predict port throughput. This paper provided decision support for port infrastructure capacity construction through the prediction results.

Fourth, forecast based on econometric model. From the perspective of port cargo composition, Kuang Haibo (2009) carried out cluster analysis on the premise of fully considering the internal relationship between important cargoes. This paper solved the problem of insufficient port information mining. He built the VAR (Vector Auto Regression) throughput prediction model of China's coastal ports. Tian Xin et al. (2009) added the seasonal time series model based on the former. He used radial basis function neural network technology, took Hong Kong container throughput as an example, adopted the quantitative method of irregular events, and constructed a comprehensive integrated prediction model. At the same time, the paper pointed out the close relationship between the coastal ports and the development of Hong Kong, and put forward suggestions on regional competition and cooperation. After analyzing the diversification of the formation mechanism factors, Guang-Quan K et al. (2011) established a model to forecast the demand of foreign trade containers. Farhan et al. (2018) established a seasonal auto-regressive integrated moving average model, and demonstrated that the model is more suitable for nonlinear medium and short-term forecasting. This provided the shipping companies and port operators with the assistance of medium and short-term strategy formulation. Xie et al. (2013) proposed three hybrid prediction methods based on minimum support vector regression model. In this paper, the three methods are compared and verified with other methods. It was concluded that the hybrid method had better prediction accuracy for seasonal and nonlinear changes. Xiong Jian (2005) used the method of system dynamics to study the supply and demand balance of China's container transport capacity. This paper pointed out that the fluctuation of container transport capacity was inevitable, and put forward some suggestions to minimize the loss caused by the fluctuation of transport capacity.

Lastly, prediction based on artificial intelligence model. Le Meilong et al. (2003) introduced the concept of genetics, summarized the rule of container throughput changing with time, and established the prediction model. The model had the characteristics of automation, simplicity and high prediction accuracy. But the convergence of the model was poor. Shih-Huang et al. (2009) compared genetic algorithm model, decomposition model and seasonal auto-regressive integrated moving average algorithm model. This paper demonstrated that the genetic algorithm model had more advantages in prediction. GOSASANGV et al. (2011) compared the traditional prediction method and neural network model prediction method on the platform of Bangkok port. Liu Bingchun and Zhang Peng (2021) predicted the port container throughput in the next month through machine learning. The experimental results showed that the machine learning prediction model had good performance, and it was found that macroeconomic changes had a more positive impact on the prediction results of port container throughput. Niu et al. (2018) based on the hybrid decomposition and integration model, predicted the low frequency components, which produced high prediction accuracy for container throughput.

To sum up, the research status of container transport capacity at home and abroad shows that most of the literature focuses on the prediction of container throughput, that is, the demand for container throughput is predicted. And there is no quantitative or qualitative analysis of container throughput capacity. What's more, it has no clear quantitative analysis of the gap between supply and demand of container ports in the future.

1.3 Research contents and technology roadmap

1.3.1 Research contents

This paper aims to analyze the supply and demand of container handling capacity in Yangshan Harbor Area of Shanghai Port, and put forward some constructive suggestions for the future development of Yangshan Harbor Area. The analysis is divided into two aspects. One is the demand for container throughput, that is, the forecast of the future container cargo throughput. The other is the supply of container throughput, that is, the planned container throughput capacity. Especially means the planned container throughput of Yangshan Harbor Area in this paper. According to the basic principles of economics, it is the demand that affects the supply, and the planning of throughput capacity should depend on the throughput demand.

This paper intends to reasonably forecast the container throughput of Yangshan Harbor Area in the next five years. Then, according to the planning level of container port in Yangshan Harbor Area, the relationship between supply and demand of container throughput capacity and container throughput is explored, so as to determine whether the capacity of Yangshan Harbor Area is excessive or insufficient, and put forward reasonable suggestions for the future development of Yangshan Harbor Area.

In addition, the adaptability of container handling capacity is considered in the supply analysis of container handling capacity. Because in reality, the actual throughput capacity of the container port will be higher than the designed handling capacity of the container. At the same time, modern handling equipment and information system are also considered to improve the container handling capacity of the port, which makes the actual handling capacity of the port container greater than the designed.

Therefore, the factors which contribute to the container handling capacity is considered too. Correctly grasp, judge and study the development of China's container port and container transportation, predict the changes of container throughput in Yangshan Harbor Area in the next five years, analyze and predict the new situation, new problems and development trend that may appear in the development process, and put forward reasonable countermeasures and suggestions for the future development and construction of Yangshan Harbor Area of Shanghai Port. This is the research value of this paper. It’s the research value of this paper to correctly grasp, judge and study the development of China’s container ports and container transportation; to predict the changes of container throughput of Yangshan Harbor Area in the next five years; to analyze and predict the new situations, new problems and development trends that may appear in the process; to put forward reasonable countermeasures and suggestions for the future development and construction of Yangshan Harbor Area of Shanghai Port.

The main contents of this paper are as follows:

Chapter 1: Introduction. This part mainly expounds the research background and significance. This part analyzes the value of port throughput prediction according to the background and content, and summarizes the research status of container throughput at home and abroad, and then explains the main contents of this paper.

Chapter 2: Analysis of The Current Situation of China's Container Port Development. Firstly, this paper summarizes the emergence and development of container transportation. Then it explains the development status of China's container ports. Finally, the characteristics of China's container transportation development are summarized and analyzed.

Chapter 3: Demand Forecasting of Container Throughput—Taking Yangshan Harbor Area of Shanghai Port as an Example. First of all, the paper systematically compares all kinds of prediction methods. Then it summarizes and analyzes the gray prediction model, and introduces the gray prediction model. Secondly, taking Yangshan Harbor Area as an example, the grey prediction model is established to predict the container throughput demand of Yangshan Harbor Area in the next five years. What's more, the error analysis and accuracy test of the model are carried out. Finally, a reasonable prediction result is obtained.

Chapter 4: Supply and Demand Analysis of Container Port Throughput

Capacity—Taking Yangshan Harbor Area as An Example. Firstly, according to the development plan of Yangshan Harbor Area, this paper summarizes and analyzes the container handling capacity of it in the future. Secondly, based on the adaptability of container handling capacity, this paper makes an elastic analysis of the designed handling capacity of Yangshan Harbor Area. Finally, according to the previous chapter of Yangshan Harbor Area of container throughput demand forecast data results, this paper analyzes the supply and demand of container handling capacity in Yangshan Harbor Area, and quantifies the gap.

Chapter 5: Analysis on the countermeasures for the construction and development of Yangshan Harbor Area of Shanghai Port. Based on the analysis and conclusions of the previous chapters, this paper puts forward some reasonable suggestions for the future development of Yangshan Harbor Area, such as improving the port infrastructure and strengthening the construction of the collection and distribution system; speeding up the construction of intelligent port and improving the service level of port; speeding up the development process of the north side of Xiaoyangshan and relieving the pressure of the deep-water wharf on the south side of it; promoting the cooperation of Port Alliance and realizing the complementary advantages of resources; transferring part of the domestic transit container goods to the surrounding ports, etc.

Chapter 6: Conclusion and Prospect. This part summarizes the main contents of this paper, and points out the shortcomings of this paper, as well as the direction of further research in the future.

1.3.2 Technology roadmap

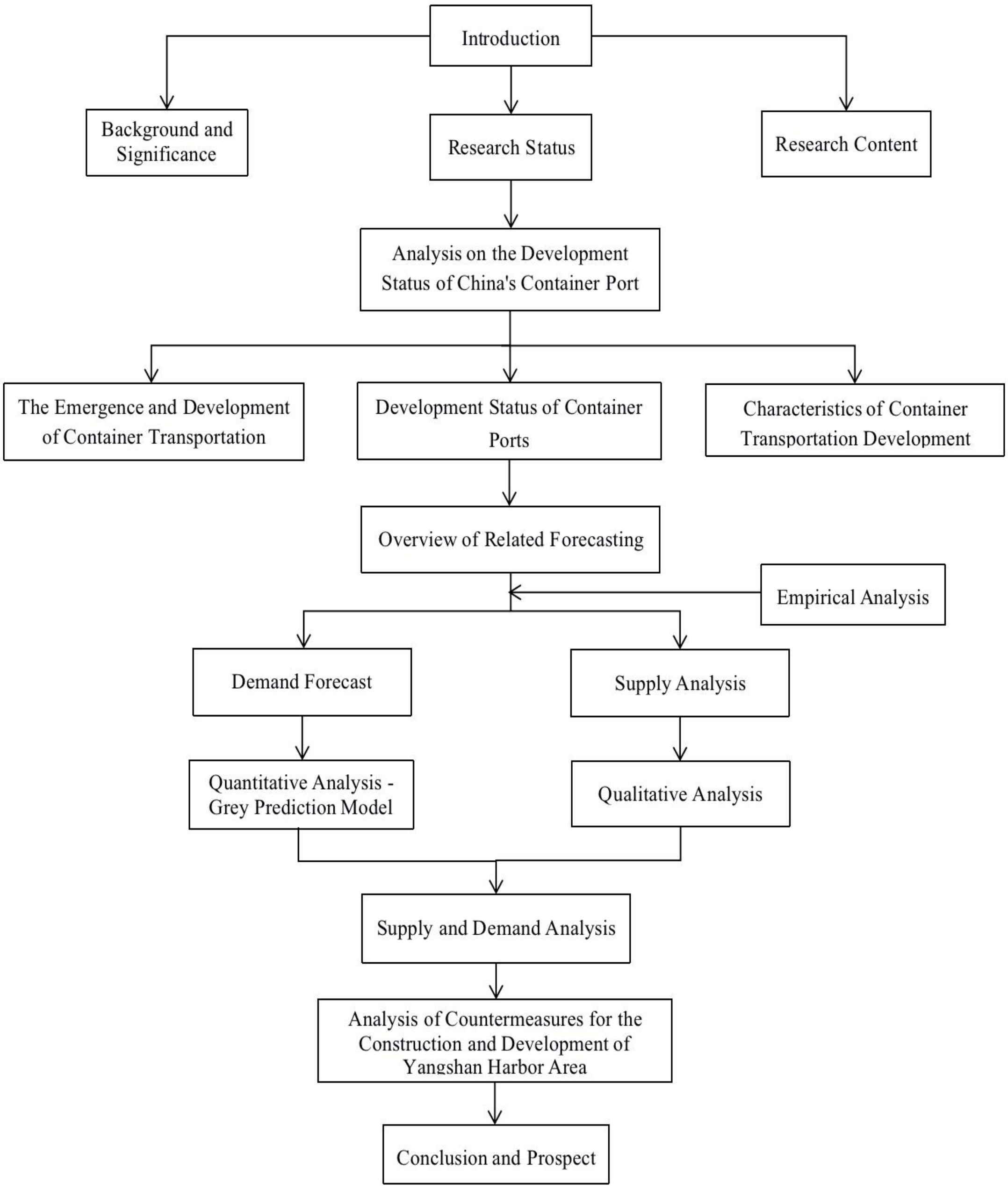


Fig 1 The Technology Roadmap

2 ANALYSIS OF THE CURRENT SITUATION OF CHINA'S CONTAINER PORT DEVELOPMENT

2.1 The emergence and development of container transportation

As early as the early 19th century, Dr. James Anderson, a British, had the idea of loading goods into containers for transportation. In 1830, a kind of container for loading coal first appeared on the railway in England. At the same time, the large container was used to carry groceries on the railway. However, because it was still in the early stage of industrialization, this method of transporting goods in large containers was restricted in many ways, and then it was forced to suspend.

It was at the beginning of the 20th century that containers were formally used to transport goods. In 1900, containers were first used for transport on British Railways. Later, container transport was successively spread to the United States, Germany, France, Japan and Italy. In the mid-1950s, the success of the U.S. maritime container transportation experiment marked the beginning of the world's modern container transportation. Although container transportation had made some progress before 1966, the development of container transportation at this stage was limited to some advanced European and American countries. At the same time, container transportation was mainly used in highway, railway and domestic coastal transportation.

In 1966, Sea-Land Service opened the transatlantic container route. At the same time, the Australia Europe route also began to open. This indicated that the sea container transportation had entered the international stage, and the pace of container transportation was further accelerated. 1966-1983 was the key period for the world transportation to enter the era of containerization. In this period, more and more people realized the superiority of container transportation, and the international container transportation dominated by sea transportation developed rapidly. By 1970, the total capacity of the world's container fleet was about 200,000 TEU, and the total number of containers was about 500,000 TEU. By the 1970s, the annual growth rate of container throughput of the world's major ports had reached 15%. After the 1970s, in addition to developed countries, shipping companies in the Middle East and East Asia began to participate in container transportation. By 1983, the world's container reserves had increased to 4.4 million TEU, and the number of special container berths had increased to 983. The container ship type had changed from refitted ship to the first and second generation of small or medium full container ships. The container carrying capacity of the whole world's container fleet had also expanded rapidly.

With the continuous development of container ports, the scale of container ports and container ships continued to expand. In this context, a new type of container routes began to take shape. In 1984, American liner companies used the world's largest Panamax at that time to open the eastbound global route. This indicated that containerization had entered a new stage of development, which was the stage when containerization spreads to China, central and South America. Container ports all over the world had developed rapidly. The total throughput of port containers was 55.79 million TEU in 1985 and 84.22 million TEU in 1990. By 1995, it had reached 142 million TEU, and the container throughput of world ports had increased by 7.13 times in 20 years. The growth rate of container throughput was much faster than that of the world's total shipping volume.

After the mid-1990s, with the arrival of the era of integrated logistics and the acceleration of the process of global economic integration, the combination and merger of container liner companies had accelerated. At the same time, the status and role of container transportation in the global transportation system were further strengthened, and container transportation had entered a new stage of development. Container transportation by sea had penetrated into every corner of the world. Container ports on major continents, including the African continent, had developed rapidly. The era of global containerization had come. The separation of hub port from feeder port and trunk flight was further intensified.

At present, the containerization degree of general cargo transportation in developed countries has exceeded 80%. According to statistics, by 1998, there were more than 6,800 container ships of various types in the world, with a total carrying capacity of 5.79 million TEU. In 2000, there were more than 2000 special berths in the world's container terminals, and the container throughput reached 218.67 million TEU. In 2020, the total transport capacity of the global fleet will be 2.06 billion DWT, and the global container trade scale was 143 million TEU.[1] Container transportation has spread all over the world. With the container transportation entering the mature stage, containerization of world sea freight has become an irresistible trend.

As the most important part of sea transportation, container port plays a more and more important role in the world transportation system. So far, container port has become the most important part of the complex in the era of network economy.

2.2 Development status of container ports in China

2.2.1 Construction of container port

In September 1973, the "Bohai No.1" general cargo ship arrived at Tianjin Port with small containers from Kobe, Japan, making Tianjin Port the first port in China to engage in container transportation. At this time, China's container transportation had just started. However, in the initial stage, when China National Transportation Corporation opened the first international container liner line, China did not have a specialized container port, and its economic construction and foreign trade development were relatively slow. It was not until a few years after the opening of container routes that China began to invest in the construction of specialized container ports. With the construction of China's specialized container ports, the port container throughput also began to grow rapidly. From 1978 to 1980, the average annual growth rate of China's container throughput was as high as 60%. By 1980,

[1] Source: The latest *2020 Global Maritime Development Review Report* released by the United Nations Conference on Trade and Development (UNCTAD) in January 2021

China's first container terminal was built in Tianjin, marking the development of China's container port into a specialized stage.

Since then, China's port container throughput had grown at an average annual rate of 30%. By the end of the 6th Five-Year period, it had increased from 32,900 TEU in 1979 to 580,000 TEU. By the end of the 7th Five-Year period, China's container port throughput had reached 1.56 million TEU. At this time, there were 28 ports carrying out container import and export business in China, with 19 special container berths, and the annual design capacity had reached 1.45 million TEU. The containerization rate of ports also increased from 3.2% in 1980 to 33% in 1990.

In the 1990s, the pace of China's container port construction was further accelerated, and a large number of foreign capital and private capital were introduced. The sources of container port construction funds were increasingly diversified. By 2000, 202 container terminals had been built in China, and the designed container handling capacity had reached 18.71 million TEU. In 2002, the container throughput of Chinese mainland ports reached 37 million 210 thousand TEU. It was the first time in the world that it had been the first in the world for 46 consecutive years, ranking first in the world. China's container terminals were developing in the direction of specialization and large-scale, which met the requirements of large-scale ships and greatly improved the handling efficiency. By 2008, China's port container throughput had reached 126 million TEU. By 2020, the total container throughput of Chinese ports was 260 million TEU, an increase of 1.2% over the same period in 2019. [2]

Among the top 10 container ports in the world, Chinese ports occupied 7 seats. See Table 1 for details. Despite the influence of COVID-19, China's port throughput is still growing steadily, showing that China's economic growth is growing stronger. With the sharp decline of global port throughput, the global ranking of Chinese ports is still rising.

Tab 1 The rank of top 10 container port of the world in 2020

Rank	Port Name	Country	2020	2019	Growth %
1	Shanghai	China	4350	4331	3.1%
2	Singapore	Singapore	3687	3720	1.6%
3	Ningbo-Zhoushan	China	2872	2753	4.5%
4	Shenzhen	China	2655	2577	0.1%
5	Guangzhou	China	2317	2283	5.7%
6	Qingdao	China	2201	2101	8.8%
7	Busan	South Korea	2181	2191	1.1%

[2] Source: Ministry of Transport of China

8	Tianjin	China	1835	1730	8.1%
9	Hong Kong	China	1796	1836	-6.3%
10	Rotterdam	Netherlands	1434	1481	2.1%

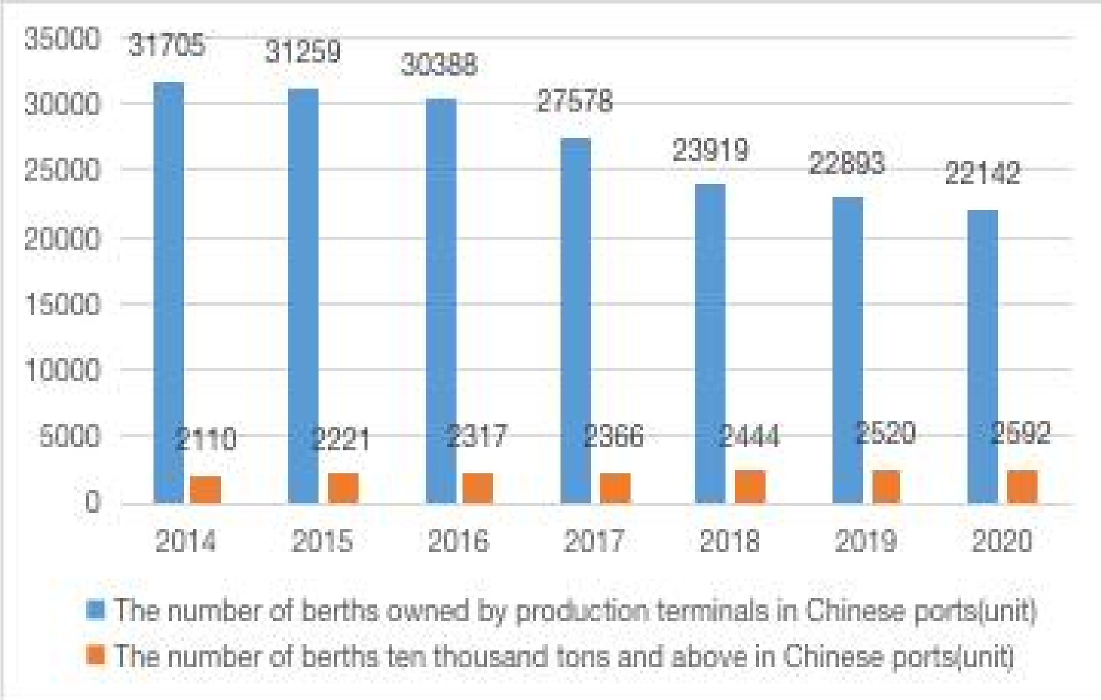
Source: International containerization

China has formed five port groups around the Bohai Sea, Yangtze River Delta, South-East Coastal, Pearl River Delta and South-West Coast, and eight transportation systems layout, including coal, oil, iron ore, container, grain, commercial vehicles, land island roll on loading and passenger transportation. Due to the adverse effects of the port construction approaching saturation, excess industrial capacity and insufficient investment of local government, the overall market growth space is limited, and the market investment in coastal traditional water transport construction projects continues to grow negatively. According to the data of Ministry of Transport of China, since 2013, China's coastal construction investment has shown a downward trend, and the number of new berths has also declined year by year. At the same time, with the continuous deepening of the integration of various types of ports, in recent years, although the total number of berths in China's ports has decreased, the number of berths above 10,000 tons still maintained a momentum of continuous growth.

By the end of 2020, China's ports had 22,142 berths for production, 751 less than last year. See Figure 1 for details. Among them, there were 2,592 berths of 10,000 tons and above, an increase of 72 over the previous year, and the proportion of berths of 10,000 tons and above increased from 6.7% in 2014 to 11.7% in 2020. Among the berths of ten thousand tons and above in China, there were 592 general bulk cargo berths, 415 general cargo berths and 1,371 specialized berths, including 87 crude oil berths, 147 product oil berths, 239 liquefied chemical berths, 39 bulk grain berths, 265 coal berths and 354 container berths.[3] Among the specialized berths of 10,000 tons and above in China, the proportion of container berths was the largest, and it was gradually increasing, reaching 25.8% in 2020, indicating the strong momentum of China's container terminal construction and development in recent years.

While continuously reducing the intensity of port investment, port infrastructure investment presents the trend of intelligence, information and integration. What’s more, intelligent transformation is becoming a common direction for port enterprises to cope with the industry downturn. It can also deal with their own excess supply capacity and enhance their core competitiveness.

[3] Source: China Port Yearbook



Source: China Port Yearbook

Fig 2 Statistics on the number of berths owned by production terminals, ten thousand tons and above in Chinese ports from 2014 to 2020

2.2.2 Completion of container throughput

2.2.2.1 Overall container throughput

Over the past 40 years of reform and opening up, China's port container transportation has achieved the leap forward development of ranking first in the world for 11 consecutive years with an annual growth rate of 35%, which is rare in the world. It has become one of the fields with the highest level of opening up and the best integration into the international market. The global port container throughput increased by nearly 200% from 1998 to 2008, while it took only 34 years for China's mainland port container throughput to reach 100 million TEU from 1973. In the first half of 2008, China's port container throughput still maintained a rapid growth, reaching 61.63 million TEU. The outbreak of the global financial crisis in September 2008 had a serious impact on the development of China's container ports. The growth rate of port container throughput declined rapidly. In 2009, the impact of the financial crisis was fully revealed. In 2009, the container throughput of the port was only 122 million TEU, showing a negative growth compared with 2008, and the coastal inland ports had a drop and a rise. Among them, coastal ports completed 110 million TEU, a decrease of 5.6% compared with 2008, and inland ports completed 122 million TEU, an increase of 5.4% compared with 2008.

As a derivative market of the world economy and trade, the shipping market had also been affected by the subprime crisis due to trade diffusion, resulting in the decline of shipping demand, as well as the serious imbalance between supply and demand in the shipping market, and the significant decline of market freight and volume. China's Yangtze River Delta and Pearl River Delta were greatly affected by the financial crisis, which was equivalent to other big ports in the world. Dalian Port, Tianjin Port and Qingdao Port around Bohai Bay were relatively less affected. In 2010, the world economy picked up, especially China's economy showed a restorative rise. The port container throughput of China was 145 million TEU, an increase of 18.85% over the previous year. See Table 2.

Unexpected COVID-19 in early 2020 had had a serious impact on China's port production. China's port production in the whole year showed an obvious trend of low in the front and high in the back. The cargo throughput increased slightly, and the container throughput increased slightly. In February, the container business volume of China's ports decreased by 16.5%. After March, with the effective containment of the epidemic, the decline rate had narrowed significantly. However, in the second quarter, with the outbreak of the epidemic in Europe and the United States, countries around the world had taken restrictive measures of blockade, which led to the reduction of orders of Chinese import and export enterprises. International liner companies cut the number of voyages one after another, and the recovery of port container business was weak. It was not until June that it returned to the same level in 2019. In the second half of 2020, European and American countries restarted their economies one after another.

Under the premise of China's steady promotion of normalized epidemic prevention and control, Chinese enterprises sped up the resumption of production and work, and the port production and operation were fully restored. At the same time, the demand for shipping was strong, the container freight rate was rising sharply, and the port container business volume was growing and the growth rate was accelerating. Especially in the fourth quarter, under the influence of stocking on Christmas Eve, China's port container throughput grew rapidly, especially in October and November, with the growth rate exceeding 7%.[4]

[4] Source: China Ports Association Container Branch

Tab 2 China's container throughput from 2000 to 2020

Year	Container throughput（Ten thousand TEU）	Growth %
2000	2061.60	32.19%
2001	2470.00	19.81%
2002	3382.10	36.93%
2003	4454.90	31.72%
2004	5656.70	26.98%
2005	6988.80	23.55%
2006	8563.40	22.53%
2007	10456.00	22.10%
2008	12600.00	20.50%
2009	12200.00	-3.17%
2010	14500.00	18.85%
2011	16400.00	13.10%
2012	17700.00	7.93%
2013	19000.00	7.34%
2014	20200.00	6.32%

2015	21200.00	4.95%
2016	22000.00	3.77%
2017	23800.00	8.18%
2018	25100.00	5.46%
2019	26107.00	4.01%
2020	26430.00	1.24%

Source: China Ports Association

2.2.2.2 Completion of container throughput by regions

Since the reform and opening up, China has formed five major urban economic circles: Pearl River Delta Economic Circle, Yangtze River Delta Economic Circle, Bohai Rim Economic Circle, South-East Coastal Economic Circle and South-West Coastal Economic Circle. They will drive the rapid development of China's economy in an all-round way. However, due to the differences in economic development, foreign trade development, own conditions and other aspects of each region, there are great differences in the completion of container throughput and the growth rate of port container throughput. The Yangtze River Delta Region, which is mainly Shanghai Port and Ningbo-Zhoushan Port, is the largest container port group in China.

Shanghai Port is located at the intersection of China's coastline and the "golden waterway" of the Yangtze River. In 2003, Shanghai Port completed container throughput of 112 million and 820 thousand TEU, and Shanghai Port was the first Chinese mainland to break through the 10 million TEU port. By 2008, the container throughput of Shanghai Port had reached 28 million TEU, ranking second in the world. For the first time, Shanghai Port surpassed Singapore Port by 28.4308 million TEU with 29.069 million TEU, ranking first in the world. In 2020, the container throughput of Shanghai Port was 43.5 million TEU, ranking first in the world for 11 consecutive years. Among them, the container throughput of Yangshan Harbor Area exceeded 20 million TEU for the first time in 2020, ranking first in Shanghai Port, helping Shanghai Port to lead the world in container throughput for 11 consecutive years. Ningbo-Zhoushan Port was also an important hub of comprehensive transportation system in Yangtze River Delta. In 2020, Ningbo-Zhoushan Port followed Shanghai Port with 28.72 million TEU container throughput, ranking second in China.

The main ports in the Pearl River Delta Economic Circle are Shenzhen Port and Guangzhou Port. The Pearl River Delta Economic Circle is the leading area of China's reform and opening up. It is an important economic center in China, and plays a prominent leading role and strategic position in the process of China's economic development. Moreover, Shenzhen Port is an influential container port in South China. In 2020, the container throughput of Shenzhen Port was 26.55 million TEU, ranking the third in China. When it comes to Guangzhou Port, it is the largest foreign trade port in South China. It is connected with more than 100 ports in China, and it has more than 300 ports in more than 80 countries and regions. By 2020, the container throughput of Guangzhou Port had reached 23.17 million TEU, ranking the fourth in China.

The main ports in Bohai Rim are Dalian Port, Tianjin Port and Qingdao Port. Among them, Qingdao Port has the largest throughput of container ports. Qingdao Port is an important international trade port on the west coast of the Pacific Ocean, and also a maritime transport hub. It has a history of nearly 120 years. In 2020, the container throughput of Qingdao Port was 22.01 million TEU, ranking the fifth in China. Tianjin Port is closely followed. It is the largest artificial port in China, ranking the sixth in China with 18.35 million TEU. There are more than 400 ports in more than 200 countries and regions that trade with Tianjin Port in the world. With 5.11 million TEU container throughput, Dalian Port lags behind Qingdao Port and Tianjin Port, ranking tenth in China. Among the top ten ports in China, the above three port groups occupy nine seats. Among the ports in southeast coastal areas and southwest coastal areas, only Xiamen Port ranked in the top ten with 11.41 million TEU, ranking seventh temporarily.

Tab 3 China ' s top 10 ports container throughput in 2020

Rank	Port Name	Container throughput（Ten thousand TEU）	Growth %
1	Shanghai	4350	0.4
2	Ningbo-Zhoushan	2872	4.3
3	Shenzhen	2655	3.0
4	Guangzhou	2317	1.5
5	Qingdao	2201	4.7
6	Tianjin	1835	6.1
7	Xiamen	1141	2.5
8	Suzhou	629	3.0
9	Yingkou	565	3.1
10	Dalian	511	-41.7

Source: China Port Yearbook

2.3 The development characteristics of container transportation in China

2.3.1 Increasingly reasonable container port layout

With the development of China's economy and the needs of international trade, the layout of China's container ports is becoming more and more reasonable. At present, five port groups have been formed, including Bohai Rim, Yangtze River Delta, Southeast Coast, Pearl River Delta and Southwest Coast. As the main bridge for China to participate in the economy, it is an important gateway for China to enter the economic globalization.

The ports around Bohai Sea are mainly Dalian Port, Tianjin Port and Qingdao Port. Dalian Port is an important gateway to the sea in Northeast China; Qingdao Port has good water depth, no freezing all the year round, and sufficient supply of goods in the hinterland; Tianjin Port is located at the innermost end of Bohai Bay. Due to its favorable location in Beijing, Tianjin and Tangshan economic zones, Tianjin Port has abundant sources of goods.

Relying on Shanghai International Shipping Center, the ports in the Yangtze River Delta mainly include Shanghai Port, Ningbo Port and Lianyungang Port, giving full play to the role of Zhoushan, Wenzhou, Nanjing, Zhenjiang, Nantong, Suzhou and other coastal and lower Yangtze River ports to serve the economic and social development of the Yangtze River Delta and the regions along it. Shanghai Port, with its superior hinterland and strong economic development momentum, has become an important shipping center in China and one of the international container transit ports; Ningbo Port is one of the most excellent ports in China. The 2,138m long container berth can accommodate the sixth-generation container ships. Ningbo Port, together with Shanghai and Jiangsu Ports, forms the Yangtze River Delta group.

The port group of Pearl River Delta is composed of ports in East Guangdong and Pearl River Delta. Relying on the advantages of Hong Kong's economy, trade, finance, information and international shipping center, the port group of the region consolidates Hong Kong's position as an international shipping center. At the same time, it mainly develops ports of Guangzhou, Shenzhen, Zhuhai and Shantou, and correspondingly develops ports of Shanwei, Huizhou, Humen, Maoming and Yangjiang to serve parts of south China and southwest China. What's more, it can strengthen exchanges between Guangdong Province, inland areas and Hong Kong and Macao.

The southeast coastal port group is mainly composed of Xiamen Port and Fuzhou Port, including Quanzhou Port, Putian Port and Zhangzhou Port, which have active trades with Taiwan. Although the development is generally late and the throughput base is small, the income growth is fast.

Zhanjiang Port, Fangcheng Port and Haikou Port are the main ports in the southwest coastal area, and Beihai Port, Qinzhou Port, Yangpu Port, Basuo Port and Sanya Port are developed accordingly. Relying on the southwest and facing Southeast Asia, it will benefit from the development of the West and the cooperation of ASEAN Free Trade Area.

2.3.2 Significantly improved container throughput

In the past 40 years, China's national economy and foreign trade have developed rapidly. The gross domestic product and foreign trade have continued to grow and maintained a high growth rate. At the same time, China has a huge shipping fleet, which provides the basic conditions for the rapid development of China's port container transportation. Since the development of container transportation in China, the port container throughput has maintained a high-speed development. From 2001 to 2008, the compound growth rate of China's port container throughput was 23.8%. According to the data of 2007, the container throughput of China's ports accounts for 22% of the world's total, surpassing that of all European ports and 2.5 times that of the United States.

Since China started container transportation, port container throughput has been developing at a high speed. From 1990 to 2007, the average container throughput of China's ports increased by 28.4%, from 1.56 million TEU in 1990 to 113 million TEU in 2007, an increase of nearly 70 times in 17 years. By the end of 2020, Chinese mainland Shanghai Port, Ningbo-Zhoushan Port, Shenzhen Port, Guangzhou Port, Qingdao Port and Tianjin harbor ranked first, third, fourth, fifth, sixth and eighth respectively. The container throughput of Shanghai Port is 43.5 million tons TEU, ranking the first in the world for 11 consecutive years.

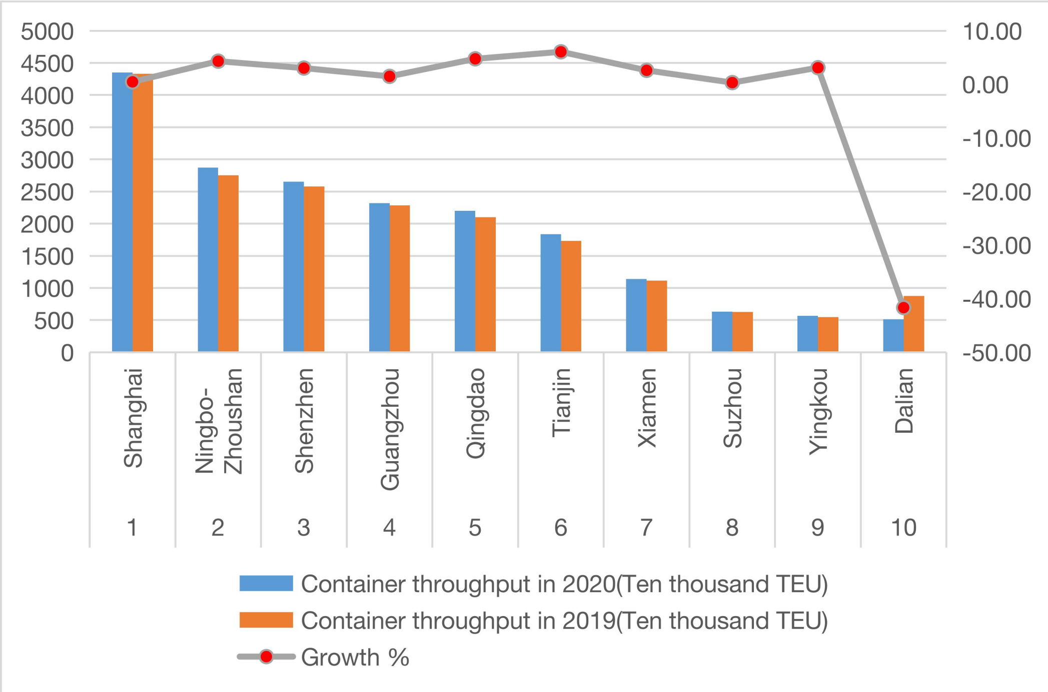


Fig 3 Container throughput of China's ports in 2020

2.3.3 High efficiency of port container transportation

Compared with the traditional mode of transportation, container transportation has the advantages of high mechanization, less loading and unloading links, high labor productivity, high loading and unloading rate, fast ship turnover and so on. At the same time, due to the less impact of climate, the container handling time is shortened, which greatly shortens the berthing time of ships in the port. Therefore, the navigation rate is greatly improved, and the ship's productivity and transportation capacity are also improved.

2.3.4 Container port networking

The large-scale container ship is a basic trend of the development of container transportation. This trend makes the operating cost of single container transportation increased. If the ship is too tight in the case of scattered port, the container will be packed for a short time, which will not meet the requirements of container location and cannot be guaranteed transportation. However, if the time interval is increased, it is difficult to meet the requirements of the owner and is not conducive to the high market share. Based on this, liner company can only select a few large ports in the world to hang on board, which will break the traditional maritime transportation network, making the container ports begin to differentiate. At the same time, the main and branch lines of maritime container transportation will begin to form.

The port differentiation is manifested in the separation of hub port and branch port. Those ports, which are located on the trunk transportation routes of containers, with developed hinterland economy, sufficient supply of goods, superior natural conditions, strong logistics foundation and open policies, stand out and develop into hub ports. However, the surrounding small ports have become feeder ports, also known as feeder ports. The difference between trunk network and branch network is that trunk flights are formed by connecting hub ports with large vessels, while branch flights are formed by connecting hub ports with branch ports with small and medium vessels. Therefore, container ports form a container transportation network composed of ports of different levels and scales.

2.3.5 Continuous improvement of container port information level

The facilities and equipment of container terminals in China's major ports have been further improved, some of which are at the leading level in the world. The construction of China ' s port container terminal adopts the internationally accepted tender system, project legal person system, construction supervision and contract responsibility system. The design and construction are in line with international standards, and there is a design and construction team up to international standards. In terms of handling machinery and equipment configuration, China's port container terminals aim at the international advanced level. They adopt the advanced technology and means, and base themselves on the reality in China, and try to improve the practicability, reliability and advancement of the equipment. In addition, they also strengthen the condition inspection and maintenance of equipment, insist on carrying out on-the-job technical training, and constantly improve the performance of large machinery and equipment and the mechanized operation level of port containers.

At present, the port information technology has been widely used in port enterprise management, production scheduling and operation control, port clearance and other aspects. For example, in recent years, Xiamen, Qingdao and Shanghai have successively built fully automatic container terminals. The automated terminal highly integrates intelligent control, information management, communication and navigation, big data, cloud computing and other technologies. The computer system automatically generates operation instructions, and the port handling machinery automatically completes related tasks. The terminal business process is fully automated, which greatly improves the production efficiency and port logistics efficiency of the terminal.

Fig 4 Yangshan Phase IV fully automated container terminal

The new generation-5G communication technology has the characteristics of large bandwidth and low delay. Among them, the bandwidth is 100 times of 4G network, reaching 10GB per second, and the delay is one-fiftieth of 4G network, which is about 1 millisecond. It is very suitable for the application of container terminal in data, voice, video and other aspects, as well as the application of gantry crane remote control and truck driver-less which require high time delay. 5G communication technology has broad application prospects in container terminals.

With the continuous improvement of port information level and the construction of smart port, port enterprises' understanding of big data is also gradually improved. Massive data is one of the most valuable assets of the terminal. With data resources as the core, through continuous innovation and improvement of solutions, the data in the actual production process of the port is stored and classified, and then through data analysis, the management and operation process are optimized, the convenient and fine services are provided, the intelligent terminal is supported, and the decision-making of port enterprises is provided with reference.

3 DEMAND FORECASTING OF CONTAINER THROUGHPUT — TAKING YANGSHAN HARBOR AREA OF SHANGHAI PORT AS AN EXAMPLE

3.1 Selection of prediction methods

Port container throughput forecasting belongs to economic forecasting. Economic forecasting is a science that studies the development trend of objective economic process in a certain period in the future. With the help of scientific methodology and technical means, according to the historical evolution and development rules of objective economic process, it describes and analyzes the trend and situation of economic development in a certain period of time in the future. Its purpose is to obtain the impact on future economic activities through the discussion of the historical rules of objective economic phenomena and the research on the present. The quality of economic prediction depends on the understanding of objective economic phenomena and the scientificity of the prediction methods adopted. It also contains the attention and absorption of experience judgment.

At present, there are many economic forecasting methods. And also there are sixty or seventy kinds of commonly used methods, mainly including intuitive forecasting technique, Delphi forecasting method, judgment and prediction method, technical forecasting method (matrix analysis, life cycle, envelope curve and morphological analysis, etc.), regression analysis forecasting method, growth curve forecasting method, econometric model forecasting method, time series analysis forecasting method (sliding average method and exponential smoothing method), random time series forecasting method, system dynamics model, simulation forecasting method, Markov forecasting method and grey forecasting model. There are so many methods, and various methods have corresponding characteristics and application scope.

In port container throughput prediction, qualitative analysis and quantitative prediction are usually combined. Quantitative prediction methods mainly include time series forecasting method, regression analysis prediction method and elastic coefficient method. In recent years, neural network forecasting method has been introduced. Usually we choose several different forecasting methods to analyze and compare from many aspects in order to obtain better forecasting results. The following briefly introduces several types of key models.

3.1.1 Regression model

Regression model prediction is to establish the regression equation between variables on the basis of analyzing the correlation between independent variables and dependent variables of market phenomena. At the same time, the regression equation as a prediction model, according to the number of independent variables in the prediction period to predict the relationship between dependent variables are mostly related.

Regression prediction method is widely used in the prediction of container throughput. It is a reliable method for prediction based on the causal relationship of changes in things. The main models are linear regression model, multiple linear regression model, nonlinear regression model, etc.

3.1.2 Artificial Neural Network model

Artificial Neural Network (A.N.N) is an engineering system which simulates the structure and intelligent behavior of human brain based on the understanding of human brain structure and operation intelligence. Artificial neural network has developed into dozens of different models. It is usually classified from the following five principles: according to the structure of the network, there are forward network and feedback network; according to the way of learning, there are supervised learning and unsupervised learning networks; according to the network performance, there are continuous and discrete neural networks, deterministic and stochastic neural networks; according to the synaptic properties, there are first-order linear correlation neural network and high-order nonlinear correlation neural network; according to the hierarchical simulation of biological nervous system, there are neuron hierarchical model, combinatorial model, network hierarchical model, nervous system hierarchical model and intelligent model. The interconnection structure of neural network is usually considered.

Generally speaking, the neural network has four kinds of structures: forward network (feed-forward network), feedback network (feed-forward network with feedback in the input layer), interconnected network (feed-forward network in the layer), hybrid network (fully interconnected feedback network). Sensor, BP network and RBF network belong to the forward network model. Neocognitron belongs to the feedback network model. Hopfield and Boltzmann machines belong to the fully interconnected feedback network model.

3.1.3 Time series prediction

Time series prediction is a method based on the development process and regularity of social and economic phenomena to extrapolate and predict its development trend. Common models are: moving average method, exponential smoothing method and trend extrapolation method.

According to the numerical changes of port container throughput over the years, it can be seen that with the passage of time, container throughput shows certain regularity. Therefore, this paper tends to choose time series model to predict container throughput. However, this paper selects the generally applicable grey prediction model with low raw data requirements but high prediction accuracy to predict the port container throughput.

There are many factors that affect the throughput of the port, but the principle of the impact of specific factors on throughput is not clear. The traditional prediction methods have high requirements for data quantification, and the sample data of port container throughput prediction can be collected are less, which makes the selection of prediction methods more inclined to use the grey system prediction method. Therefore, this paper chooses to establish GM(1,1) model to predict the container throughput of Shanghai Yangshan Harbor Area.

3.2 Grey system theory and grey prediction model

The grey system theory was first proposed by Professor Deng Julong in 1982 and has taken an extremely important step in the field of prediction. Its research significance is mainly in the case that the number of information is difficult to predict the results of the study and the research data is difficult to collect. Through the correct information known and obtained, the valuable information is extracted, and the evolution law and effective monitoring system behavior are analyzed. The grey system model does not have strict time data requirements, and has been recognized and widely used in most research fields.

3.2.1 Basic theory of grey system

The random variables are controlled in a specific experimental range, and the grey quantity results obtained in the process of grey quantity change in the study period are established by manually processing the correct part of the collected information and adding a specific time series. The principle of the system is that no matter how complex and scattered the objective information has been collected, there are rules that always can make it connected and attached. After analysis, the relevant and orderly parts are excavated, and the rules between data can effectively characterize the system characteristics.

After strict manual processing, the data is sorted into orderly “module”. Its geometric meaning refers to the general term of the continuous curve and its bottom given by the generated sequence data on the time and data two-dimensional plane. The data module is divided into white module and grey module by known or predicted sources.

The grey theory of differential equations needs to be established according to the following concepts, principles and methods:

a) Random quantity is regarded as a grey quantity which changes in a certain range. Random process is regarded as a grey process which changes in a certain range and a certain time zone.

b) Irregular raw data after processing become more regular generated sequence. Therefore, the GM modeling is actually a model established by using the generated sequence, which is different from the general modeling.

c) The data obtained after GM model processing are not the final results. It must be restored.

d) The modeling of grey theory is aimed at a class of sequences which meet the condition of smooth discrete function. Usually, smooth discrete function can be obtained after processing the original data sequence, and the common method is cumulative generation.

e) The grey system considers that the differential equation is a combination (linear or nonlinear) of the background and each derivative (grey derivative).

f) Grey model can adjust and correct the accuracy, which is usually completed by adding grey number, data and different levels of residual model.

g) For systems that are not first-order, the state equation can be generated by GM model group and then solved.

3.2.2 GM(1,1) Model

Grey system theory provides a number of methods that can be used for prediction, among which GM(1,1) model is a common one in grey model. Relatively speaking, GM(1,1) model is a dynamic prediction model with less modeling data, simple calculation and reliable results.

3.2.3 Test of original data sequence

Whether the high-precision level of GM(1,1) can be judged by the level of the original sequence $x^{(0)}$ and the size of $\sigma^{(0)}(k)$ and its interval.

Consider the class ratio $\sigma^{(0)}(k)$ as follows:

$$\sigma^{(0)}(k) = \frac{x^{(0)}(k-1)}{x^{(0)}(k)} \tag{3.1}$$

If:

$$\sigma^{(0)}(k) \in (e^{-\frac{2}{n+1}}, \quad e^{\frac{2}{n+1}}) \ (k = 2,3,\dots n) \tag{3.2}$$

Then the original sequence $x^{(0)}$ can be considered as GM(1,1) modeling. If the original sequence is not satisfied, the level ratio can be dropped into the range by translation.

Next, consider the sliding sequence $y^{(0)}$ as follows:

$$y^{(0)}(k) = x^{(0)}(k) + c, k = 1,2,\dots,n \tag{3.3}$$

And we compute the ratio of $y^{(0)}$ as follows:

$$\varphi^{(0)}(k) = \frac{y^{(0)}(k-1)}{y^{(0)}(k)} \in (e^{-\frac{2}{n+1}}, e^{\frac{2}{n+1}}), k = 2,3,\dots,n \tag{3.4}$$

3.2.4 Modeling process of GM(1,1)

To establish GM(1,1), the original sequence should be accumulated and generated to show a strong regularity. Secondly, construct the first-order differential equation, and the least square method is used for parameter estimation. Then the time response function is obtained by solving the differential equation, and the time response sequence is obtained, which is the fitting value of the cumulative sequence. Finally, the fitting values of the original sequence and the model are obtained by the cumulative reduction process.

The modeling process is as follows:

Consider the initial sequence for a time series, $X^{(0)} = (X^{(0)}(1), X^{(0)}(2), \ldots, X^{(0)}(n))$. The next sequence $X^{(1)}(k)$ is generated from the accumulated generating operation of $X^{(0)}$. Specifically,

$$x^{(1)}(k) = \sum_{i=1}^{k} x^{(0)}(i), k = 1,2, \ldots, n \quad (3.5)$$

Applying the mean value generating operation to $X^{(1)}$, we obtain $Z^{(1)} = (Z^{(1)}(1), Z^{(1)}(2), \ldots, Z^{(1)}(n))$. Then,

$$z^{(1)}(k) = \frac{1}{2}[x^{(1)}(k) + x^{(1)}(k-1)], \quad k = 2,3, \ldots, n \quad (3.6)$$

If parameter columns are $\hat{a} = [a, \mu]^T$, and

$$Y = \begin{bmatrix} x^{(0)}(2) \\ x^{(0)}(3) \\ \dots \\ x^{(0)}(n) \end{bmatrix}, \quad B = \begin{bmatrix} -Z^{(1)}(2) & 1 \\ -Z^{(1)}(3) & 1 \\ \dots & \\ -Z^{(1)}(2) & 1 \end{bmatrix} \tag{3.7}$$

Then the least squares estimation parameters of the grey differential equation $x^{(0)}(k) + az^{(1)}(k) = b$ satisfy $\hat{a} = (B^T B)^{-1} B^T Y$.

Suppose the original sequence $X^{(0)}$ is a non-negative sequence, then $x^{(1)}$ would represent a grey index pattern in the 1-AGO, and $Z^{(1)}$ would be the adjacent generating sequence. If $[a, \mu]^T = (B^T B)^{-1} B^T Y$, we specify a whitening equation (shadow equation) for GM(1,1) as follows:

$$\frac{dx^{(1)}}{dt} + ax^{(1)} = \mu \tag{3.8}$$

Thus,

a) The solution of whitening equation $\frac{dx^{(1)}}{dt} + ax^{(1)} = \mu$ is time response function

$$x^{(1)}(t) = \left(x^{(1)}(1) - \frac{\mu}{a}\right) e^{-at} + \frac{\mu}{a} \tag{3.9}$$

b) The time response sequence is

$$\hat{x}^{(1)}(k+1) = \left(x^{(0)}(1) - \frac{\mu}{a}\right) e^{-ak} + \frac{\mu}{a}, k = 1,2,\dots,n \tag{3.10}$$

c) The reducing value is

$$\hat{x}^{(0)}(k+1) = (1 - e^{a}) \left(a - \frac{\mu}{a}\right) e^{-ak}, k = 1,2,\dots,n \tag{3.11}$$

where a is development grey number, which reflects the development trend of $X^{(1)}$ and $X^{(0)}$; μ is endogenous control grey number, which reflects data change relationships.

3.2.5 Test of GM(1,1)

Whether GM(1,1) model is applicable can be tested through residual error, correlation degree and back-check error.

3.2.5.1 Test of residuals

The purpose of residual test is to detect the difference between the predicted value and the actual value of the experimental model, so that a more accurate model can be obtained by residual test. We can calculate $\hat{x}^{(0)}(i+1)$ by GM(1,1), then obtain $\hat{x}^{(0)}(i)$. And we calculate absolute residual sequence of the original sequence $x^{(0)}(i)$ and $\hat{x}^{(0)}(i)$, so that we can get the average relative residual, to obtain the precision of the model. The relative calculation formula is as follows:

a) Absolute residual sequence:

$$\Delta^{(0)} = \{\Delta^{(0)}(i), i = 1,2,\cdots,n\} \tag{3.12}$$

$$\Delta^{(0)}(i) = |x^{(0)}(i) - \hat{x}^{(0)}(i)| \tag{3.13}$$

b) Relative residual sequence:

$$\emptyset = \{\emptyset_i, i = 1,2,\cdots,n\} \quad (3.14)$$

$$\emptyset_i = [\frac{\Delta^{(0)}(i)}{x^{(0)}(i)}]\ \% \quad (3.15)$$

c) Average relative residual:

$$\overline{\emptyset} = \frac{1}{n-1}\sum_{i=2}^{n}|\emptyset(i)| \quad (3.16)$$

d) Precision:

$$p^0 = (1-\overline{\emptyset}) \times 100\% \quad (3.17)$$

Generally, it requires $\emptyset_i < 20\%$, and $\emptyset_i < 10\%$ is the best. When $p^0 > 80\%$, $p^0 > 90\%$ is the best. At this time, it is considered that the accuracy of the established GM(1,1) model is satisfactory.

3.2.5.2 Test of correlation degree

The correlation degree of the model is tested by comparing the fitting degree of the predicted value curve of the model and the original sequence value curve. According to the correlation degree calculation method, the correlation coefficient between $\hat{x}^{(0)}(i)$ and the original sequence $x^{(0)}(i)$ is calculated, and then the correlation degree is calculated. In general, models with correlation degree greater than 0.6 are considered satisfactory.

3.2.5.3 Test of posterior error

The posterior error test is to test the statistical distribution law of the predicted residual distribution.

a) Average value of original sequence

$$\bar{x}^{(0)} = \frac{1}{n}\sum_{i=1}^{n} x^{(0)}(i) \quad (3.18)$$

b) Quadratic mean deviation of original sequence $X^{(0)}$

$$S_1 = \left(\frac{\sum_{i=1}^{n}[x^{(0)}(i) - \bar{x}^{(0)}]^2}{n-1}\right)^{1/2} \quad (3.19)$$

c) Mean of residual

$$\bar{\Delta} = \frac{1}{n}\sum_{i=1}^{n} \Delta^{(0)}(i) \quad (3.20)$$

d) Variance ratio

$$C = \frac{s_1}{s_2} \quad (3.22)$$

e) Small residual probability

$$P = P\{|\Delta^{(0)}(i) - \bar{\Delta}| < 0.6745S_1\} \quad (3.23)$$

If $S_0 = 0.6745S_1$, $e_i = \Delta^{(0)}(i) - \bar{\Delta}$, then $P = P\{e_i < S_0\}$.

As the discriminant parameter values of posterior difference test has been illustrated in the Table 4 below, we should properly select parameter values. When $C < C_0$, we call the mean variance ratio of the model qualified. When $P > P_0$, we call small residual probability of the model is qualified. Otherwise, we should make sure that $C_0 > 0$, $P_0 > 0$.

Tab 4 Reference table for posterior difference test

Test Index / Accuracy Class	Relative Error-q	Mean Variance Ratio-C	Small Residual Probability-P
Level 1 (Excellent)	0.01	< 0.35	> 0.95
Level 2 (Qualified)	0.05	< 0.50	> 0.80
Level 3 (Barely)	0.10	< 0.65	> 0.70
Level 4 (Unqualified)	0.20	⩾0.65	⩽0.70

3.2.6 Characteristics and application scope of GM(1,1)

3.2.6.1 Characteristics of GM(1,1)

The advantages of GM(1,1) are mainly manifested in three aspects:

a) It is suitable for data prediction with less historical data and has no special requirements for the distribution of data itself, which can effectively reduce the randomness of historical data;

b) This model can excavate the phenomenon that the change rule is not obvious in the economic system;

c) The calculation and test of the model are relatively simple and convenient, and it has good effect in the medium and short term prediction of the prediction object.

GM(1,1) also has some limitations, mainly in:

a) This model cannot accurately predict the data with large dispersion;

b) Without improvement, this model cannot conduct long-term accurate prediction.

3.2.6.2 Scope of GM(1,1) application

The application scope of GM(1,1) is closely related to its development coefficient. The prediction effect changes with ‘a’ value, and the following rules can be used as reference:

a) If $-a \leq 0.3$, the GM(1,1) model meets the medium and long term prediction requirements;

b) If $0.3 < -a \leq 0.5$, the GM(1,1) model meets the short-term prediction requirements, and should be cautiously applied to medium and long term prediction;

c) If $0.5 < -a \leq 0.8$, the GM(1,1) model may have large error in short-term prediction;

d) If $0.8 < -a \leq 1$, the accuracy of the GM(1,1) model is poor, and the residual should be corrected and then predicted;

e) When -a > 1, it is better not to use the GM(1,1) model.

3.3 Grey prediction model of container throughput in Shanghai Yangshan Harbor Area

3.3.1 Sample selection and data sources

This paper selects the container throughput data of Yangshan Harbor Area of Shanghai Port from 2006 to 2020 to establish GM(1,1) model. The data came from *China Port Yearbook*. Data on container throughput of Yangshan Harbor Area of Shanghai from 2006 to 2020 are shown in Table 5.

Tab 5 Container thr oughput of Yangshan Harbor Area of Shanghai Port from 2006 to 2020

Year	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Container throughput (Ten thousand TEU)	323.6	610.8	822.7	784.8	1010.8	1309.8	1415.0	1436.4	1520.2	1540.7	1561.6	1655.2	1842.4	1980.8	2022.2

3.3.2 Establishment of GM(1,1) prediction model

Set $X^{(0)} = (x^{(0)}(1), x^{(0)}(2), \cdots, x^{(0)}(15))$ corresponding original sequence data.

Calculate series ratio sequence $\sigma^{(0)} =$

$(0.891,0.926,1.014,0.925,0.910,0.969,0.994,0.976,0.994,0.994,0.975,0.952,0.965,0.990)$

by Formula (3.1). Then we can calculate $\sigma^{(0)}(k) \notin (0.882,1.133)$ by Formula (3.2).

Therefore, according to the Formula (3.3), (3.4), the shift conversion is carried out, that is, the shift conversion value 2022 is added on the basis of the original value, and the final test value of the data level ratio after the shift conversion is within the standard range [0.882, 1.133]. This means that the adjusted data is suitable for GM(1,1) model. When calculating the predicted value, the shift conversion value is subtracted at the same time. See Table 6 for details.

Tab 6 GM(1,1) model level ratio table

Serial Number	Original Value	Level Ratio-λ	Original Value+Shift Value(shift=2022)	The Level Ratio after conversion -λ
1	323.6	-	2345.6	-
2	610.8	0.891	2632.8	0.891

3	822.7	0.926	2844.7	0.926
4	784.8	1.014	2806.8	1.014
5	1010.8	0.925	3032.8	0.925
6	1309.8	0.910	3331.8	0.910
7	1415.0	0.969	3437.0	0.969
8	1436.4	0.994	3458.4	0.994
9	1520.2	0.976	3542.2	0.976
10	1540.7	0.994	3562.7	0.994
11	1561.6	0.994	3583.6	0.994
12	1655.2	0.975	3677.2	0.975
13	1842.4	0.952	3864.4	0.952
14	1980.8	0.965	4002.8	0.965
15	2022.2	0.990	4044.2	0.990

The first order cumulative sequence $X^{(1)}(k)$ can be obtained from Formula (3.5) by translating converted data:

$$x^{(1)}(1) = 2345.6, x^{(1)}(2) = 4978.4, x^{(1)}(3) = 7823.1,$$

$$x^{(1)}(4) = 10629.9, x^{(1)}(5) = 13662.7, x^{(1)}(6) = 16994.5,$$

$$x^{(1)}(7) = 20431.5, x^{(1)}(8) = 23889.9, x^{(1)}(9) = 27432.1,$$

$$x^{(1)}(10) = 30994.8, x^{(1)}(11) = 34578.4, x^{(1)}(12) = 38255.6,$$

$$x^{(1)}(13) = 42120.0, x^{(1)}(14) = 46122.8, x^{(1)}(15) = 50167.0$$

The data matrix B and data vector Y can be constructed by calculating the sequence and Formula (3.6) and Formula (3.7).

They are respectively $Y = \begin{bmatrix} 2632.8 \\ 2844.7 \\ 2806.8 \\ \cdots \\ 4044.2 \end{bmatrix}$, $B = \begin{bmatrix} -3662.0 & 1 \\ -6400.8 & 1 \\ -9226.5 & 1 \\ \cdots & \cdots \\ -48144.9 & 1 \end{bmatrix}$.

Then $a = -0.02968, \mu = 2686.162$, the prediction model can be obtained as

$\hat{x}^{(0)}(k + 1) = 92848.0e(0.02968 * k) - 90503.0$.

3.3.3 Test of GM(1,1) model

According to the model calculation, the residual test is carried out. See Table 7.

Tab 7 Residual test table

Serial Number	$x^{(0)}(i)$	$\hat{x}^{(0)}(i)$	$\Delta^{(0)}(i)$	$\varnothing_i$	$\overline{\varnothing}$	p^0
1	2345.600	-	-	-	-	-
2	2632.800	2797.085	164.285	6.240%	6.240%	93.760%
3	2844.700	2881.348	-36.648	1.288%	3.764%	96.236%
4	2806.800	2968.149	161.349	5.749%	4.426%	95.574%
5	3032.800	3057.566	24.766	0.817%	3.524%	96.477%
6	3331.800	3149.676	182.124	5.466%	3.912%	96.088%
7	3437.000	3244.561	192.439	5.599%	4.193%	95.807%
8	3458.400	3342.305	116.095	3.357%	4.074%	95.926%
9	3542.200	3442.993	99.207	2.801%	3.915%	96.085%
10	3562.700	3546.714	15.986	0.449%	3.530%	96.470%
11	3583.600	3653.560	69.960	1.952%	3.372%	96.628%
12	3677.200	3763.625	86.425	2.350%	3.279%	96.721%
13	3864.400	3877.005	12.605	0.326%	3.033%	96.967%
14	4002.800	3993.801	8.999	0.225%	2.616%	97.384%
15	4044.200	4114.116	69.916	1.729%	2.557%	97.443%

We can calculate $\emptyset_i < 10\%$; $p^0 > 95\%$. It can be concluded that the accuracy of GM(1,1) model is satisfactory and the prediction results of throughput are credible.

We can calculate variance ratio $C = 0.2146$, small residual probability $P = 1$. Refer to Table 4, we find that the prediction level of the model is excellent, indicating that the model is very suitable for solving the container throughput prediction problem of Yangshan Harbor Area of Shanghai Port. It can be predicted that:

Tab 8 Container throughput forecast in the next five years

Year	2021	2022	2023	2024	2025
Predicted Value (Ten thousand TEU)	4238.1	4365.7	4497.2	4632.7	4772.3
Predictive value after subtracting translation transformation (Ten thousand TEU)	2216.1	2343.7	2475.2	2610.7	2750.3

In order to more intuitively observe the prediction accuracy of the model, this paper fits the predicted value (Figure 4).

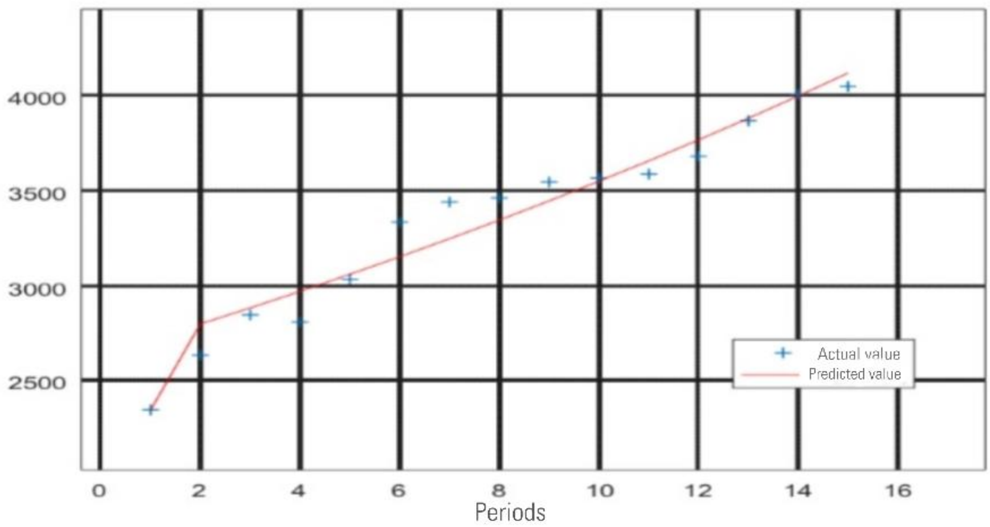


Fig 5 Fitting curve of predicted value

At the same time, in order to further increase the accuracy of prediction, this study carried out bystander detection for prediction results. According to the Comprehensive Transportation "14th Five-Year" Plan of Lingang New District, the container throughput of Yangshan Harbor Area of Shanghai Port is expected to reach 26,000,000 TEU in 2025. This is close to the prediction result, which further shows that the model prediction is credible.

3.3.4 Three exponential smoothing method test

Based on the container throughput data of Yangshan Harbor Area of Shanghai Port from 2006 to 2020, the prediction model is established. For the initial value S_0, if the number of samples is between 10 and 20, we generally take the average value of the first two periods of data as the initial value S_0. In this paper, the most reasonable alpha value is selected by comparing the root mean square error of historical data and predicted value, as shown in Table 9.

The three exponential smoothing method is the time series prediction method. When calculating the mean square deviation, the 15 data predicted by the first 15 data are used to subtract the corresponding actual data for $|Y(t) - X(t)|$. Root mean square error $RMSE = \sqrt{\frac{1}{n}\sum_{t=1}^{n}(Y(t) - X(t))^2}$, where n is number of predicted data; $Y(t)$ is predicted value; $X(t)$ is actual value.

Tab 9 Root mean square error of prediction under different alpha values

Number	S_0	alpha	Smooth type	RMSE
1	467.2	0.05	three times	476.982
2	467.2	0.10	three times	264.486
3	467.2	0.20	three times	178.351
4	467.2	0.30	three times	159.330
5	467.2	0.40	three times	155.250
6	467.2	0.50	three times	161.096
7	467.2	0.60	three times	174.494

8	467.2	0.70	three times	193.398
9	467.2	0.80	three times	216.696
10	467.2	0.90	three times	244.189
11	467.2	0.95	three times	259.643

Through the prediction calculation, the optimal alpha value is 0.4, and finally the predicted value of three exponential smoothing is obtained.

Tab 10 Three exponential smoothing method prediction

Year	2021	2022	2023	2024	2025
Container throughput (Ten thousand TEU)	2142.798	2250.158	2359.318	2470.277	2583.035

From the perspective of data comparison, the predicted values of the three exponential smoothing method are consistent with the predicted values of the modified model, which is showing a relatively stable growth trend. Therefore, we can find that the accuracy of the established GM(1,1) model is satisfactory, and the prediction results are reliable.

4 SUPPLY AND DEMAND ANALYSIS OF CONTAINER PORT THROUGHPUT CAPACITY - TAKING YANGSHAN HARBOR AREA AS AN EXAMPLE

4.1 Analysis of container design handling capacity in Yangshan Harbor Area of Shanghai Port

The construction of Yangshan Harbor Area of Shanghai Port started in June 2002. The total investment of the port construction project exceeded 70 billion yuan. And the port was officially opened on December 10, 2005. Five deep-water container berths were constructed in the first phase of Yangshan Harbor Area, the wharf shoreline is 1600 meters long and the designed annual throughput capacity is 2.2 million standard containers. Phase II project built four deep-water container berths, the length of the wharf shoreline is 1400 meters, the designed annual throughput capacity is 2.1 million standard containers, and the Phase II project was completed on December 10, 2006.Seven deep-water container berths were constructed in the third phase of the project, with the wharf shoreline length of 2600 meters and the designed annual throughput capacity of 5 million standard containers. The third phase of the project was completed on 10 December 2008. Seven deep-water container berths were constructed in the fourth phase of the project, with a shoreline length of 2350 meters. The initial design capacity was 4 million standard containers and the forward capacity was 6.3 million standard containers. The fourth phase of the project was completed on 10 December 2017.

Up to now, a total of 23 million-ton deep-water container berths have been added in Yangshan Harbor Area, the new added port container handling capacity is 14.3 million TEU, and the total length of the wharf shoreline is 7950 meters.

Tab 11 The container handling capacity in Yangshan Harbor Area from 2006-2020

Year	Container throughput (Ten thousand TEU)	Growth %	Container handling capacity (Ten thousand TEU)	Growth %
2006	323.6	-	220	-
2007	610.8	88.80%	430	95.50%
2008	822.7	34.70%	710	65.10%
2009	784.8	-4.60%	930	31.00%
2010	1010.8	28.80%	930	0.00%
2011	1309.8	29.60%	930	0.00%
2012	1415.0	8.00%	930	0.00%
2013	1436.4	1.50%	930	0.00%
2014	1520.2	5.80%	930	0.00%
2015	1540.7	1.30%	930	0.00%

2016	1561.6	1.40%	930	0.00%
2017	1655.2	6.00%	930	0.00%
2018	1842.4	11.30%	1330	43.00%
2019	1980.8	7.50%	1330	0.00%
2020	2022.2	2.10%	1430	7.50%

Source: Ministry of Transport of China

Table 11 shows that: Both container throughput and container handling capacity in Yangshan Harbor Area grow to varying degrees, but the growth rate of container throughput is significantly faster than that of container handling capacity. With the rapid growth of China 's economy and the growing prosperity of international trade, the container throughput was increasing and further widened the gap between the two. At the same time, it also increases the pressure of the collection and distribution system in Yangshan Harbor Area, and as the only channel in and out of Yangshan Harbor Area, the East Sea Bridge has overloaded operation, and relatively serious congestion has appeared in some time periods.

The container handling capacity of Yangshan Harbor Area cannot well match the continuous growth of container throughput, which makes Yangshan Harbor Area operate under overload. And the existing container handling capacity of Yangshan

Harbor Area has been unable to meet the needs of port production development to a certain extent.

4.2 Adaptability analysis of container handling capacity in Yangshan Harbor Area of Shanghai Port

Container handling capacity adaptability refers to the container handling capacity divided by the container throughput.

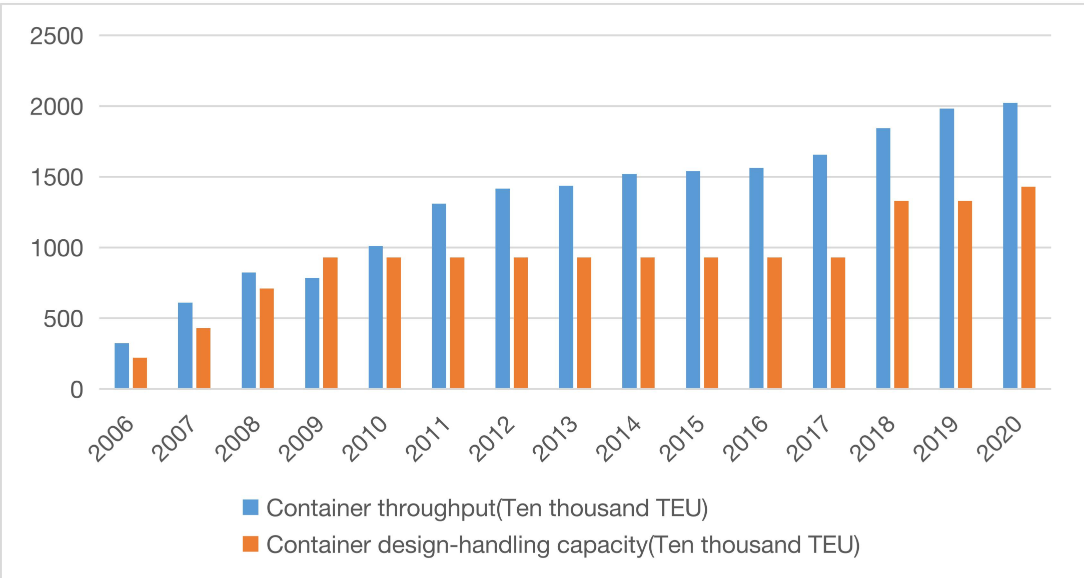


Fig 6 Container throughput and design handling capacity in Yangshan Harbor Area from 2006 to 2020

From 2006 to 2020, the adaptability of container handling capacity in Yangshan Harbor Area can be seen from Figure 5: the container throughput in Yangshan Harbor Area is basically greater than the container design handling capacity, that is, the adaptability of container handling capacity is less than 1 (Figure 6).According to the verification statistics of container handling capacity in Yangshan Harbor Area of Shanghai Port, by the end of 2020, the container handling capacity in Yangshan Harbor Area was 14.3 million TEU, and the actual container throughput was 20.22 million TEU.The port adaptability (handling capacity / throughput) was only 0.71.

The wharf space in Yangshan Harbor Area is insufficient, the handling volume of containers have long exceeded the original designed handling capacity level, and the overall wharf is insufficient. Yangshan Harbor Area has been overloaded under the high berth utilization rate, and the port congestion has appeared in some periods, affecting the overall operation efficiency of the port and the turnover efficiency of container truck. When the adaptability is close to 1, the utilization rate of port facilities in Yangshan Harbor Area will reach the maximum.

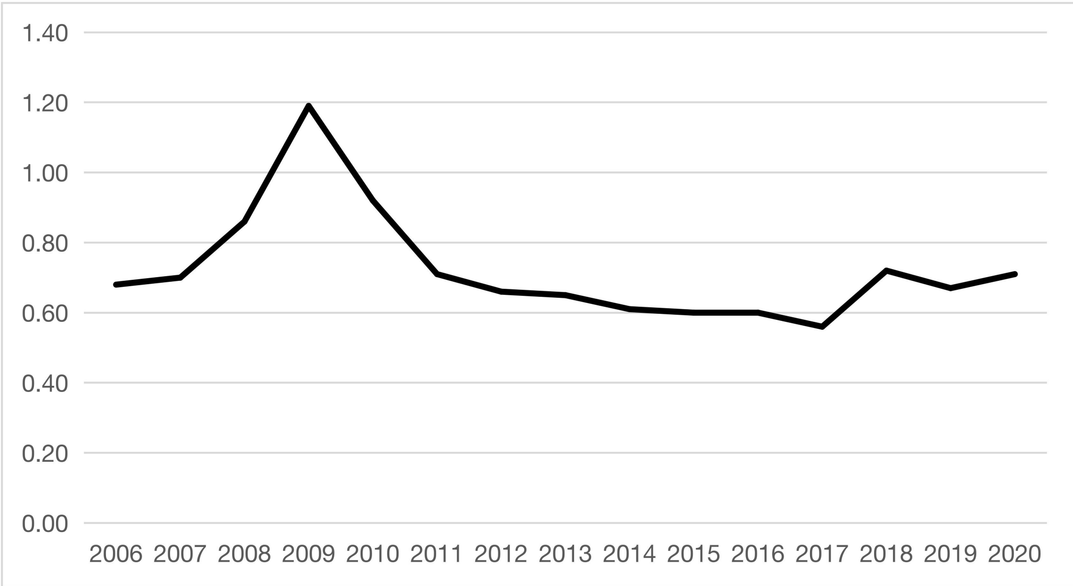


Fig 7 Adaptability of container handling capacity in Yangshan Harbor Area from 2006 to 2009

It can be seen from Figure 6 and Table 12 that with the continuous construction of Yangshan Harbor Area, the adaptability of container handling capacity in the area continued to rise from 2006 to 2009.In 2009, for the first time in 15 years, the container throughput in Yangshan Harbor Area showed a negative growth, down 4.6% compared with the same period. Moreover, the adaptability of container handling capacity in Yangshan Harbor Area exceeds 1 for the first time.

However, due to the lag of port planning and construction and the continuous increase of container throughput, since 2009, the adaptability of container handling capacity in Yangshan Harbor Area has been declining, and the decline rate has gradually slowed down. The lowest value was reached in 2017, and the adaptability of handling capacity was only 0.56, that is, 9.3 million TEU container handling capacity supported 16.55 million TEU container throughput, indicating that there was a gap of 7.252 million TEU in container handling capacity, exceeding 78 % of container handling capacity in the same year. The average berth utilization rate of Yangshan Harbor Area is as high as 178 %, indicating that Yangshan Harbor Area is overloaded and has a serious shortage of supply. According to the United States container adaptability 0.9, container design handling capacity needs to reach 14.897 million TEU in 2017. The 14.897 million TEU is 1.6 times the actual handling capacity of containers in 2017, which further illustrates the serious imbalance between supply and demand of container handling capacity in Yangshan Harbor Area.

On the whole, the existing navigation resources in Yangshan Harbor Area have failed to meet the needs of port production and development, and the port cannot be in a high load state for a long time, so the handling capacity of containers needs to be greatly strengthened.

From Table 12, we can also see that since 2010, there is a serious gap in the container handling capacity in Yangshan Harbor Area, and it increases year by year. At the end of 2017, with the completion and opening of Yangshan Harbor Phase IV, the container handling capacity of Yangshan Harbor Area has been alleviated to a certain extent. However, with the continuous growth of world trade and the continuous increase of container throughput, this cannot fundamentally solve the imbalance between supply and demand of container handling capacity of Yangshan Harbor Area. The handing capacity of Yangshan Harbor Area will soon fall into a state of supply shortage.

Tab 12 Adaptability of container handling capacity in Yangshan Harbor Area from 2006 to 2020

Year	Container throughput (Ten thousand TEU)	Container design handling capacity (Ten thousand TEU)	Adaptability	Gap (Ten thousand TEU)	Over design throughput
2006	323.6	220	0.68	103.6	47.10%
2007	610.8	430	0.70	180.8	42.00%
2008	822.7	710	0.86	112.7	15.90%
2009	784.8	930	1.19	-145.2	-15.60%
2010	1010.8	930	0.92	80.8	8.70%
2011	1309.8	930	0.71	379.8	40.80%
2012	1415.0	930	0.66	485.0	52.20%
2013	1436.4	930	0.65	506.4	54.50%
2014	1520.2	930	0.61	590.2	63.50%

2015	1540.7	930	0.60	610.7	65.70%
2016	1561.6	930	0.60	631.6	67.90%
2017	1655.2	930	0.56	725.2	78.00%
2018	1842.4	1330	0.72	512.4	38.50%
2019	1980.8	1330	0.67	650.8	48.90%
2020	2022.2	1430	0.71	592.2	41.40%

4.3 Supply and demand analysis of container handling capacity in Yangshan Harbor Area of Shanghai Port

According to the announced *Environmental Impact Assessment of Xiaoyangshan North Work Zone Planning Scheme in Yangshan Deepwater Port of Shanghai International Shipping Center,* the development and construction of Xiaoyangshan North Work Zone in 2025 will add 4.5 million TEU container handling capacity to Yangshan Deepwater Port. Therefore, in 2025, the container handling capacity of Yangshan Harbor Area is 20.1 million TEU, assuming that the port will operate with relatively high capacity utilization rate, we take the value of the adaptability of the handling capacity as 0.9, then, in 2025, the container handling capacity of Yangshan Harbor Area will meet the demand of 22.33 million TEU.

However, according to the quantitative prediction and analysis of the container throughput of Yangshan Harbor Area of Shanghai Port in the third chapter of this dissertation, the demand for container throughput of Yangshan Harbor Area in 2025 will reach 27.5 million TEU, far greater than the supply, with a difference of 5.17 million TEU and an excess of nearly 25 %. Considering the throughput capacity adaptability of 0.9, Chapter III predicts that the container throughput demand of Yangshan Harbor Area is 27.5 million TEU, in 2025, that is, the container handling capacity of 24.75 million TEU, in 2025 will be 1.73 times that in 2020, which also shows that there is serious imbalance between supply and demand of port transportation capacity, that is, the port design handling capacity is less than the actual throughput.

Although, after being put into use at docks, Chinese ports improve port capacity by increasing investment in non-berth elements, making the actual handling capacity of ports is usually higher than the design capacity. For example, the automatic equipment and control system are used in Yangshan Harbor Area Phase IV, and the unmanned automatic guide vehicle is used to transport containers, so that the actual handling capacity of the container terminal berth exceeds the designed handling capacity.

At the same time, dock berths use “maximum design capacity” rather than “design throughput capacity”, which also makes the port throughput capacity prediction higher than the design handling capacity.

However, in the case of a huge gap in container handling capacity, these factors make a small increase in container handling capacity, and can't solve the problem of insufficient capacity in Yangshan Harbor Area, also can't meet the needs of the development of port production and logistics in the port, once again illustrates the urgent task of improving the handling capacity of Yangshan Harbor Area. The insufficient supply of container handling capacity in Yangshan Harbor Area of Shanghai Port cannot be ignored.

In this case, there will be a shortage of resources and insufficient supply capacity in the Yangshan Harbor Area of Shanghai Port, which will lead to port congestion and even the phenomenon of locks delay and pressure box. The port production efficiency will be reduced and the consequences will be very serious, which is mainly manifested in the following aspects:

a）Direct impact on the economic benefits

First, port congestion affects the efficiency of port operations, leading to the high stacking density of the port yard, bringing periodic pressure to the dock production operations, resulting in prolonged time for ships to affiliate the port, also leads to traffic congestion around Yangshan Harbor Area, while increasing the cost of ship integrated transport. For example, COSCO rents a container ship of 12,000 TEU for about $ 18,000 per day. If one week is delayed due to port congestion, only rent is a huge loss, let alone other costs, such as berthing, fuel, labor costs, etc. Second, in the case of port congestion, the port production capacity is insufficient, terminal operation machinery to the maximum extent, additional operation equipment and personnel, and commandos, which not only increases the operation cost of the port, but also increases the difficulty of port production management.

In addition, the high utilization rate of berths in Yangshan Harbor Area on the one hand increases the waiting cost of shippers, and on the other hand, it raises the price of port services, which greatly increases the cost of social logistics, which will restrict economic development to a certain extent.

Moreover, the high utilization rate of berths in Yangshan Harbor Area increases the waiting cost of cargo owners on the one hand, and on the other hand, raises the price of port services, which greatly increases the cost of social logistics and restricts economic development to some extent.

b) Cause port congestion and even spread to surrounding ports

Port congestion will inevitably increase the operating cost of the shipping company, when the port congestion to a certain extent, the shipping company would rather choose to cancel the ship affiliated plan, or transfer to the surrounding port, especially for the shipowners who have high timeliness for the delivered goods, they prefer to handle the goods quickly. Therefore, the port congestion will spread to the surrounding ports. In particular, the port congestion beginning at the hub port will be like a chain reaction, which will affect the Asian ports, and have an adverse impact on the global shippers. For example, in 2017, serious congestion occurred in the third phase of the Yangshan Harbor Area of Shanghai Port, which spread to Qingdao Port, Ningbo-Zhoushan Port, and even major ports in Asia. In 2020, the average utilization rate of berths in Yangshan Harbor Area was up to 141.41%. The high berth utilization rate also means that the industrial chain is fragile. Once the wind blows, it will be unexpected and fall into serious congestion, and the surrounding ports will also be affected.

c) Direct loss to the cargo owner

Port congestion not only has a negative impact on the port itself and the shipping company, but also affects its upstream and downstream industries. When the port congestion is serious, the backlog of goods, the congestion time will even miss the sales time of goods and make the goods unsalable and increase additional transportation costs.

When the port congestion is serious, it causes the backlog of goods, and the congestion time is long will even lead to missing the sales time of goods, resulting in unsold goods, additional transportation costs, etc.

d) Other influences

The long congestion of the port will gradually become the 'bottleneck' restricting the development of the port, threatening the navigation safety of Yangshan Harbor Area, which not only brings trouble to the normal transportation of the carrier, but also brings great inconvenience to the normal business activities of the cargo owner. In addition, port congestion can cause the loss of port supply and marine business-related system disorders. From another point of view, the rising freight rates and container freight price caused by port congestion seriously damage the normal operation of the shipping industry and logistics supply chain.

5 ANALYSIS ON THE COUNTERMEASURES FOR THE CONSTRUCTION AND DEVELOPMENT OF YANGSHAN HARBOR AREA OF SHANGHAI PORT

The supply-demand relationship of the port container handling capacity is of great significance to the development of Yangshan Harbor Area of Shanghai Port. From the prediction of the container throughput of the Yangshan Harbor Area in the next five years, the container throughput of the port will continue to maintain an upward trend in the next five years. From the analysis of Chapter IV, the existing container handling capacity level in Yangshan Harbor Area does not meet the development needs of container throughput. Moreover, according to the previous announcement of *the Environmental Impact Assessment of Xiaoyangshan North Work Zone Planning Scheme in Yangshan Deepwater Port Area of Shanghai International Shipping Center*, knowing that the Xiaoyangshan North Work Zone in 2025 will add 4.5 million TEU to the container handling capacity of Yangshan Harbor Area, and this will further increase the pressure of Yangshan Harbor Area container handling capacity, affecting the development of the port.

Therefore, in order to adapt to the increasing demand for container throughput in Yangshan Harbor Area and improve the container handling capacity of the port, Yangshan Harbor Area needs to make strategic layout in the following aspects in the future construction and development.

5.1 Improve the port infrastructure and strengthen the construction of the collection and distribution system

Long-term experience has proved that port container handling capacity is positively correlated with the level of port infrastructure. With the large-scale ocean vessels becoming an irresistible trend, the port infrastructure requirements are getting higher and higher, such as deep-water berths, large anchorage, and so on. The planned land area of Yangshan deep water port area is more than 20 square kilometers, and the deep-water shoreline reaches more than 20 kilometers, and its development potential is huge.

Therefore, Yangshan Harbor Area should take advantage of itself, balance the whole port resources, rationally plan the port layout, actively promote the upgrading of port equipment, technology updates, software upgrades and yard expansion. In order to enhance the container handling capacity and ability to serve large ships in Yangshan Harbor Area, and prepare for the future container throughput demand and meet the ship strategy of shipping enterprises, it should also strengthen the port infrastructure construction, including the number of container terminals, handling capacity, dock yards, fairway depth, etc..

In the international shipping system, ports have already broken through the traditional positioning, carrying a variety of materials, financial resources, human forces, information distribution and other important responsibilities. Port collection and distribution system is a link between the port and the source of goods, all kinds of information flow, capital flow and logistics. The ability of port collection and distribution directly determines the efficiency of the overall operation of the port. In recent years, East Sea Bridge as the only land collection and distribution channel in Yangshan Harbor Area of Shanghai Port, has been overloaded, and relatively serious congestion has appeared in some time periods. At the same time, with the gradual construction of the north side of Xiaoyangshan, the port area will increase the container handling capacity of 8 million TEU in the future, which will more seriously affect the traffic capacity and operation efficiency of Yangshan Harbor Area.

In order to alleviate the congestion of the East Sea Bridge and the tension of the port area, promote the overall operation efficiency of the Yangshan Harbor Area, and achieve the purpose of cost saving, first of all, we should actively promote the construction of water, highway and railway collection and distribution system in Yangshan Harbor Area, vigorously develop sea-rail inter-modal transportation, speed up the construction of Shanghai-to-Nantong railway, actively promote the railway into the port area, and improve the railway network. Secondly, we should actively promote the river-sea intermodal transport, build a “interconnected, accessible and efficient” Yangtze River Delta inland waterway network, vigorously promote the planning and construction of waterway projects such as Hang-Ping-Shen and

Su-Shen inland port line, and promote the upgrading of regional water transport systems.

At the same time, relying on Yangshan Harbor Area, Waigaoqiao Port Area, Pudong and Hongqiao International Airports, as well as railway, highway and inland freight stations, logistics bases are established to promote the development of container multimodal transport, so as to improve the traffic capacity and form a logistics transportation system with smooth internal transport. Promoting the construction of collection and distribution system is an important way to improve the container handling capacity and promote the development of port container throughput.

5.2 Accelerate the construction of intelligent ports and improve the port service level

The improvement of the comprehensive strength of the port will inevitably make the port's container handling capacity develop rapidly. With the development opportunity of "The Belt and Road" and "Maritime Power", Yangshan Harbor Area of Shanghai Port needs to innovate the port shipping service mode, further optimize and improve the management system and mechanism, and introduce relevant professional talents.

The port also needs to promote the application of the new-generation of information technologies such as big data, cloud computing, digital twinning and artificial intelligence. Then the port should copy the Yangshan Phase IV automation construction experience to other traditional Yangshan container terminals, strengthen the intelligent construction of the core module of container terminal.

At the same time, from the aspects of yard, the automation transformation of traditional container terminals is promoted in an orderly manner, so that the efficiency of container handling capacity in the port area is further improved, so as to break through all kinds of bottlenecks that restrict the efficiency of automatic terminals, and further improve the actual handling capacity of the Yangshan Harbor Area.

While improving the port hardware strength, Yangshan Harbor Area should also pay attention to improving its own soft power. The port area should make full use of the advantages of the special integrated bonded area, strengthen the interaction with the industry within the region, actively develop the port industrial service function, enhance the radiation level of shipping service, and improve the comprehensive service ability of the port.

Meanwhile, Yangshan Harbor Area should actively innovate the customs supervision system, solve the problem of port congestion, create an international first-class port business environment, and improve the operation efficiency of the port area, so that the port container handling capacity can meet the needs of future container throughput development.

5.3 Speed up the development process on the north side of Xiaoyangshan, relieve pressure on the deep-water wharf on the south side of Xiaoyangshan

According to the analysis in Chapter 4, we can see that the supply capacity of Yangshan Harbor Area is insufficient, which cannot meet the needs of the development of port production. At the same time, the south side of Xiaoyangshan Harbor Area tends to be saturated. In order to solve this problem, SIPG should accelerate the construction of the north side of Xiaoyangshan. According to the planning scheme of the northern side of Xiaoyangshan, it can be known that its development and construction would add 8 million TEU to the Yangshan Harbor Area. Therefore, accelerating the construction of the north side of Xiaoyangshan by SIPG can effectively increase the container handling capacity of Yangshan Harbor Area, thereby reducing the waiting time for ship loading and unloading. This can greatly alleviate the pressure of insufficient supply in Yangshan Harbor Area, improve port handling capacity and production efficiency, so as to meet the increasing demand for container throughput in the future.

With the development of the Yangtze River Economic Belt and the construction of Zhoushan river-sea intermodal transport center, more and more container ships are berthing in Yangshan Harbor Area. The shallow water shoreline on the north side of Xiaoyangshan can be used to build a river-sea combined transport terminal with shallow draft, so that the smaller tonnage of river-sea combined transport ships do not need to occupy the Yangshan Deepwater Port terminal on the south side of Xiaoyangshan, and the container's “transfer from one platform” can be completed.

At the same time, Yangshan Deepwater Port can free up more space to receive large ships from all over the world, to avoid the phenomenon of port pressure. Yangshan Harbor Area needs to make full use of the advantages of regional berths, so as to greatly improve its operational efficiency and the actual handling capacity.

5.4 Promoting port alliance cooperation, complementing resource advantages

At present, the Yangshan Harbor Area of Shanghai Port is competing and cooperating with Ningbo-Zhoushan Port in terms of container port throughput, port hinterland supply, infrastructure services, cargo transit resources, talent technology and policy support. Compared with Ningbo-Zhoushan Port, Yangshan Harbor Area has some advantages such as policy and technology, but also has some disadvantages such as container throughput, collection and distribution network system construction. In order to meet the rapid growth of container throughput in Yangshan Harbor Area in the future and realize regional balanced development, Yangshan Harbor Area can choose to complement the advantages of Ningbo-Zhoushan Port, adhere to the rational division of labor and dislocation development, and cooperate to improve the throughput capacity. According to their own actual conditions, the two ports need to take the initiative to play their own advantages.

In the process of cooperation, they should maximize their benefits, take the initiative to reduce their inferior business, and achieve strong cooperation and mutual benefit, so as to optimize the allocation of resources between the two ports. They also should further promote the development of port integration, deal with the division of labor and cooperation between the ports in the Yangtze River Delta, promote the upgrading and intensive development of ports, so as to form a unique and interdependent port group, jointly face the growth demand of container throughput, and improve the international competitiveness, so that they can effectively reduce port congestion, reduce ship waiting time, improve port throughput and operation efficiency.

5.5 Transfer part of the container cargo in transit for domestic trade to surrounding ports

The expansion space of Yangshan Harbor Area of Shanghai Port is very limited. To avoid excessive utilization of port capacity, it should be considered to gradually transfer domestic trade, Yangtze River transit, coastal transit and offshore routes to nearby ports, such as Taicang Port of Suzhou and Zhoushan Port of Ningbo. Because from a more long-term point of view, in such a high land cost of international metropolis-Shanghai, the expansion of large container terminals is not economical.

Therefore, Professor Xu Jianhua (2017) believed that Shanghai should learn from London as a high value-added shipping center, build exchanges without sticking to throughput. The title of the world’s largest container port, has been transferred from New York / New Jersey Port to Rotterdam Port. Since the 1990s, it has been rotated between Hong Kong Port and Singapore Port. Since 2010, Shanghai has been the world's largest container port. However, from the aspects of industrial structure, port-city relationship, environmental governance and urban traffic, Shanghai is not necessarily suitable to be the world's largest container port. Port congestion costs too much, so that container throughput in Shanghai Port should be gradually diverted to Taicang Port and Ningbo-Zhoushan Port, in order to share the pressure of container throughput in Yangshan Harbor Area. Therefore, by transferring part of the container goods transited by domestic trade to the surrounding ports, the pressure on the handling capacity of Yangshan Harbor Area is reduced from the demand side, so as to alleviate the congestion in Yangshan Harbor Area.

6 CONCLUSION AND PROSPECT

As an important part of port planning, port container throughput prediction has affected the port planning and decision-making of government departments and it also helps the port find its problems and the causes of the problems. The purpose of this paper is to apply the grey system to the prediction of port container throughput through author's study and research, and to help the port management and construction be more effective by analyzing the supply and demand relationship of container port throughput. In this paper, the Yangshan Harbor Area of Shanghai Port is taken as the research object and its prediction model is established based on the variation characteristics of container throughput in the Yangshan Harbor Area. Through the study of reliable prediction methods, the prediction results are derived. In terms of the comparison and analysis conducted on the container handling capacity of Yangshan Harbor Area, some countermeasures and suggestions are put forward for the future development and planning of Yangshan Harbor Area.

6.1 Conclusion

a) Through the prediction and analysis of container throughput in Yangshan Harbor Area of Shanghai Port, it can be concluded that the container throughput of Yangshan Harbor Area is expected to has a steady growth trend in the future. Moreover, the GM(1,1) model is used to predict the container throughput of Yangshan Harbor Area in 2025 and the prediction result is 27.5 million TEU.

b) According to the data, the container throughput capacity planned for the Yangshan Harbor Area of Shanghai Port in 2025 is 20.10 million TEU. Due to the flexibility of container throughput capacity adaptability, the planned handling capacity can support the transportation demand of 22.33 million TEU. The difference between demand and supply of container throughput capacity is about 5.17 million TEU, exceeding nearly 25%, which means demand is much larger than supply. The lack of supply capacity in Yangshan Harbor Area will cause the overloaded use of natural resources and wharf supporting facilities. It also aggravates the pressure of collection and distribution system in Yangshan Harbor Area, resulting in problems such as wharf congestion in Yangshan Harbor Area.

c) Aiming at the problem that container supply is less than demand in Yangshan Harbor Area of Shanghai Port, this paper puts forward the following countermeasures and suggestions: Improve port infrastructure and strengthen the construction of collection and distribution system. Speed up intelligent port construction and improve port service level. Speed up the development process of the north side of Xiaoyangshan, alleviate the pressure of deepwater wharf in the south side of Xiaoyangshan. Promote port alliance cooperation to achieve complementary advantages of resources. Transfer part of the domestic trade transit container cargo to surrounding ports.

6.2 Prospect

Due to the influence of author's ability level, limited time and lack of practical work experience, there are still some problems exist and worth further study, which are summarized as follows:

a) Considering subjective flexibility, this paper establishes GM(1,1) model to predict the development trend of container throughput in Yangshan Harbor Area, however, it does not dig out the influence of other factors on container throughput except time factor. For the future study, the research direction can dig deeper into the impact of some factors on the container throughput of Yangshan Harbor Area, the law of seasonal fluctuations in the annual range or the impact of the COVID-19 on the container throughput of Yangshan Harbor Area.

b) GM(1,1) model has advantages in short-term trend prediction, however, its accuracy is not stable for medium- and long-term prediction. In the following research. Other research methods can be considered to optimize the parameters of GM(1,1) model comprehensively and the optimal model can be determined by comparison. For example, the combination model is established by combining genetic theory model to solve the problem of instability of GM(1,1) model for medium and long term prediction accuracy. Nevertheless, by combining the Markov prediction model to establish a combination model to solve the GM(1,1) model is only suitable for the data sequence problem with obvious change trend and small fluctuation.

c) The actual container handling capacity of Yangshan Harbor Area of Shanghai Port will be greater than the designed throughput capacity to a certain extent, however, the specific value cannot be determined for the excess part.

d) In terms of a few researches have done by scholars on the issue of supply and demand of container throughput in Yangshan Harbor Area of Shanghai Port, the collection of data and the collation of knowledge is certainly adversely affected.

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APPENDIX A MODELING PROCESS OF THREE EXPONENTIAL SMOOTHING METHOD

The three exponential smoothing forecasting method is a time series forecasting method, which is based on the moving average forecasting method with a certain time series for forecasting. Exponential smoothing prediction is divided into multiple types, such as single exponential smoothing, secondary exponential smoothing, and three exponential smoothing.

Based on the characteristics of port throughput forecast, this paper adopted the three exponential smoothing forecast method. The main feature of exponential smoothing forecast is that the weight of the recent data is relatively large, and the weight of the long-term data is relatively small, and it shows the characteristics of gradual change.

The modeling process of the three exponential smoothing index should start with the smoothing index. The basic formula of exponential smoothing method is :

$$S(t+1) = ay(t) + (1-a)S(t)$$

Where $S(t)$ is the predicted value (smooth value) of t ; $y(t)$ is the actual value of t ; a is smooth coefficient $(0 \leq a \leq 1)$.

Three exponential smoothing forecast is combined with one exponential smoothing, using model parameters to assign different exponential smoothing coefficients. The prediction formula is:

$$f(t+T) = a_t + b_t T + c_t T^2$$

Where T is forecast period, a_t, b_t, c_t are model parameter.

The three exponential smoothing prediction method is calculated as follows :

$$S(t)^{(1)} = ay(t-1) + (1-a)S(t-1)^{(1)}$$

$$S(t)^{(2)} = aS(t)^{(1)} + (1-a)S(t-1)^{(2)}$$

$$S(t)^{(3)} = aS(t)^{(2)} + (1-a)S(t-1)^{(3)}$$

$$a_t = 3S_t^{(1)} - 3S_t^{(2)} + S_t^{(3)}$$

$$b_t = \frac{a}{2(1-a)^2}[(6-5a)S_t^{(1)} - 2(5-4a)S_t^{(2)} + (4-3a)S_t^{(3)}]$$

$$c_t = \frac{a^2}{2(1-a)^2}[S_t^{(1)} - 2S_t^{(2)} + S_t^{(3)}]$$

The initial value of smoothing is generally based on experience. When the number of samples is less than 10, we generally take the average of the previous three periods of sample data as the initial value; When the number of samples is between 10 and 20, we generally take the average of the previous two periods as the initial value; When the number of samples is greater than 20, the first period of data is generally taken as the initial value.

$$S_0^{(1)} = S_0^{(2)} = \frac{y_1+y_2}{2}$$