An Empirical Analysis of Competitiveness of Yangshan Deep-Water Port: The Application of Intermodal Transportation and Automated Container Terminal

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Abstract: Regard to the highly competitive market in the globalized generation today, many ports need to upgrade their overall competitiveness. This research project focus on the competitiveness of Yangshan Deep-Water Port in terms of the application of intermodal transportation and automated container terminal. This research project will analyze the comprehensive competitiveness of Yangshan Port through relevant data obtained from interviews. In addition, relevant materials in academic papers will be collected to further support the collected information. The purpose of this project is to analyze methods and measures of Yangshan Port to improve its comprehensive competitiveness to further provide experience and methods that can be adopted by other ports.

1. Introduction

In the 1990s, the volume of port trade in Shanghai increased rapidly, however, it also encountered a problem - the water depth of the Yangtze Estuary Inlet Channel was too shallow, in other words, there was no deep-water berth. Therefore, Yangshan Deep-Water Port was built [1]. The Shanghai Yangshan Deep-Water Port is located at the mouth of Hangzhou Bay and passes through the Donghai Bridge in Nanhui District, Shanghai [2]. It is an international large container shipping port and the largest container shipping port in the world. It is the first outlying island port in China with a water depth of 15 meters. It solved the problem that Shanghai Port could not anchor the fifth and sixth container ships [3]. Yangshan Port covers an area of more than 25 square kilometers including four port areas. It is east port, south port, west port and north port, and is planned to construct in phases from 2002 to 2020. East port is a refined oil transfer base and LNG receiving station. South port is a reserved shoreline to ensure development planning beyond 2020. North port and west port are the container loading and unloading areas and also the core area of Yangshan Port. They contain more than 30 berths and can handle the world's largest super Panamanian container ship and giant tanker [4]. Opened in the year of 2005, Yang Shan Port is far younger than other large ports [5]. Yangshan Deep-Water Port is actually only part of the entire Shanghai Port system. It is still highly dependent on government and provincial and even state-owned state-owned enterprises. Yangshan Deep-Water Port has now contributed amazing throughput to global water resources. In 2010, all ports in Shanghai operated a total of 29 million TEUs, of which Yangshan Deep-Water Port had a container throughput of 10.1 million TEUs, accounting for 35% of Shanghai's container throughput [6]. This share increased from 15% in 2006 to 35% in 2010, indicating that Yangshan Port may dominate Shanghai TEU throughput in the future.

1.1 Problem Identification

Unlike most large ports, Yangshan Deep-Water Port is not a “naturally grown” port, which means it has been designed and built from the start to become one of the world's largest ports and multimodal transport centers. This background helps Yangshan Deep-Water Port avoid many of the drawbacks found in historic ports, such as the ineffective layout of transportation networks and complex facilities. By discussing the differences between Yangshan Deep-Water Port and the traditional port, this study can explore the further development path of modern ports and

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multimodal transport centers, and find a variety of unique measures and experiences from the rise of Yangshan Deep-Water Port, useful for other ports. And discuss their application conditions.

1.2 Research Objectives

The cargo operation field represents the most core part of a port. With a standard container throughput of 1.558 million and a cargo throughput of 14.3 million tons in only one month [7], there are various measures applied to reach this level of prosperity. The authors will focus on two factors that Yangshan Deep-Water Port is moving forward than most traditional ports, and have gained many advantages through Yangshan Deep-Water Port's multimodal transport and automated container terminals.

1.3 Intermodal Transportation

1.3.1 Background

After the globalization of trade, the traditional mode of transportation is no longer a viable solution, and other transportation methods and their combinations are needed. Among them, intermodal transportation is particularly prominent. The main reason is that the transportation of containers has proliferated over the past 20 years [8]. Initially, the main reason for containerization was to improve cargo safety, reduce processing costs, standardization and accessibility of multiple modes of transportation [9]. These advantages translate into cost-effective and efficient global door-to-door multimodal transport services that drive industry growth. Multimodal transport is defined as a specific type of multimodal transport in which goods are transported from origin to destination in the same multimodal transport unit (eg TEU container) and the goods are not handled by themselves when the mode changes [8]. Global multimodal terminals provide companies with the flexibility and economies of scale to use multiple models. Multimodal transport is a complex and cumbersome system transportation method, including strategic planning, tactical planning and operational planning [9].

1.3.2 Intermodal Transportation in Yangshan Port

Yangshan Deepwater Port can complete water-and-water intermodal transportation, water-and-rail intermodal transportation, and water-and-road intermodal transportation. However, from 2006 to 2011, the roadway accounts for 67.4% of the total container transportation of Yangshan Port, the waterway is 32.2%, and the railway is 0.4% [10]. It can be seen that in the Yangshan Port collection and distribution system, the development of waterway and railway is relatively lacking. Yangshan Port is connected to the interior by the Donghai Bridge. The Donghai Bridge is a standard highway with two-way six-lane plus emergency stop, which is the main channel for land transportation. With the opening of the Phase IV terminal of Yangshan Port, the capacity of the Donghai Bridge will tend to be saturated. Also, the meteorological conditions at sea will not guarantee the all-weather operation of the bridge [11].

Water-and-rail intermodal transportation is an economical, environmentally friendly and efficient methods of collecting and distributing [10]. However, the development of sea-and-rail intermodal transportation in Yangshan Port is also affected by the geographical conditions of the port area. Due to Yangshan Port is an offshore port, and the cost of land construction is relatively high, the railway-related departments are placed in the adjacent Luchao Port. This separation of ports and railways has resulted in increasing of transportation costs and reduction of efficiency [13]. However, the Chinese government highly promotes the development of water-and-rail intermodal transportation in Yanshang Port. It has been found that the container transported by railway has been already increased into 3.2% of the total container transportation of Yangshan Port in 2017 [14].

According to the Shanghai International Port Group, 85% of Yangshan Port's container throughput comes from the Yangtze River Delta Economic Zone [13]. Therefore, water-and-water intermodal transportation can be commonly used. However, Yangshan Port is located in the second-class sea area. According to Chinese law, riverboat cannot enter the second-class sea area. In addition, the development of inland waterways is affected by capital and historical factors and difficult to expand. Therefore, Yangshan Port uses the “water bus” to complete the water-and-water intermodal transportation. The “water bus” is a relatively small ocean-going ship [10]. Zhang [13] introduced the operation methods of the “water bus.” The “water bus” initially operated between Yangshan Port and Shanghai Port. The cargo at Yangshan Port was first transferred to Shanghai Port by “water bus” and then transferred from Shanghai Port to other inland river ports. However, after 2013, the “water bus” can operate between Yangshan Port and other river ports in the Yangtze River Delta [11]. It has been found that containers operated by Yangshan Port via water-and-water intermodal transportation accounted for 50.4% of total container throughput in 2017 [14].

1.4 Automated Container Terminal

1.4.1 Background

The modern container terminal is evolving into larger economies of scale. It will adopt new technologies and machinery and combine modern management practices [15]. Automation of operating facilities is a significant trend in current container terminal operations [16]. Currently, there are 32 automated container terminals built around the world. Since the mid-1980s, advances in automation discipline technology have led European and Japanese ports to take the lead in planning to develop automated container terminals. The world's first automated container terminal was put into operation at the ECT terminal in the Port of Rotterdam [17].

China's automated container terminal construction and development are currently in its infancy. In 2014, Xiamen Yuanhai Terminal began to renovate the No. 14 berth and part of No. 15 berth and built first fully automated container terminal in China [18]. In 2015, Shanghai Port and Qingdao Port publicly announced the beginning of planning and construction of automated container terminals [16]. In 2017, the fourth phase of Yangshan Deep-water Port was fully completed and put into operation. It is China's first fully automated container terminal and also the largest intelligent container terminal in Asia [19].

1.4.2 Fully-automated Container Terminal in Yangshan Port

Different types of handling equipment can constitute different container terminal systems. All terminals use gantry cranes, single- or double-trolley, either semi-automatically or automatically. Transportation between the quay and the stack can be carried out by trucks with trailers, Automatic Guided Vehicle (AGVs) or straddle carriers [16]. Although there are multiple combinations of devices, they can be divided into the following three categories:

- The fully automated terminal of “Double-trolley Quay Crane + AGV + Automatic Rail-mounted Gantry” mode.
- The semi-automated terminal of “Single-trolley Quay Crane + Straddle Carrier + Automatic Rail-mounted Gantry” mode.
- The semi-automated terminal of “Single-trolley Quay Crane + Container Truck + Rail-mounted Gantry with Outrigger Arm” mode.

Yangshan Port has selected a more mature technology of the fully-automated terminal of “Double-trolley Quay Crane + AGV + Automatic Rail-mounted Gantry” mode [20]. The Yangshan Port adopts a double-trolley quay crane. The front trolley is loaded and unloaded by manual confirmation. The rear trolley is used to automate the vertical transportation between the platform and the AGV. The final automated stacking process is done by ARMG [21]. Also, the ratio of water-to-water intermodal transportation in Yangshan Port is more than 50%. Thus, the automated stack will show a significant imbalance between landside and seaside operations [20]. Therefore, Yangshan Port adopts a hybrid arrangement with no cantilever and single-sided cantilever ARMG area. Only the seaside ARMG can realize the seaside operation in the no-cantilever area. The single side cantilever area can complete the seaside operation by AGV enters inside the area. Thus, the seaside and landside ARMG can realize the seaside operation [22].

1.4.3 The Competitiveness of the Fully-automated Container Terminal

Automated container terminals will bring a certain degree of competitiveness to the port.

Externally, the large-scale vessel directly leads to a reduction in the number of ports having enough capacity to accept those vessels. Also, the number of containers to be handled per flight has increased significantly. For example, in the past, containers carried by vessels to the port was mostly around 6000 TEU. However, the recent capacity of containers is more than 15,000 TEU. Although the large vessel is longer and broader, the increase in width is significantly higher than the increase in length. The "TEU number per meter" of a 15,000 TEU ship is 80% higher than a ship of around 6000 TEU. It means that container berths need to handle 80% more containers per meter than the original [17]. At this time, the loading and unloading efficiency of the port will be particularly important, and the advantage of the automated port is especially outstanding.

For the generic automated terminal, Leeper [23] stated that although the initial investment in automated terminals is higher than traditional terminals, automation has broad advantages, including improved profitability, improved quality and safety, and optimized workforce. Moreover, it is a necessary condition to increase productivity and reduce investment costs [23]. Wan, et al. [24] show that the application of automated container terminals in Singapore Port brings higher efficiency and higher performance. Liu, et al. [25] analyzed and evaluated four different types of automated container terminals through simulation. By analyzing throughput, vessel turnaround time, vehicle turnaround time, berth occupancy and dwell time in the yard, the performance and cost of traditional terminals can be significantly improved through automation [25]. By analyzing several major factors affecting the operational performance of the container terminal treatment facility, Yang and Shen [15] found that the combination of automated container terminals and multimodal transport can make port operations better.

For Yangshan Port, it has different advantages from the general automated terminal. Qui and Hsu [26] found that in AGV systems, the layout of the vehicle network has a significant impact on system efficiency. According to the characteristics of its port, Yangshan Port seamlessly connects the relevant facilities of AGV with the automated operation area. It solves the problem of concentrated traffic flow at the AGV battery exchange station of the mostly automated container terminal, greatly reduces the waiting time of the AGV queue, improves the battery replacement efficiency of the AGV, and reduces the traffic impact on the working area [20]. Also, Yang and Shen [15] stated that the green ports are widely sought after by the shipping industry. Yangshan Port's lithium battery driver AGV was independently developed by Zhenhua Port Machinery Company, and it can work for 12 hours under full power [27]. It allows Yangshan Port to minimize carbon emissions and reduce the environmental impact of exhaust and noise.

2. RESEARCH Methods

2.1 Research Design and Strategy

The appropriate research strategy is intended to guide researchers in a more systematic way to answer his own research problems [28]. The qualitative method strategy will be mainly used for this research project; thus, the primary data shall be analyzed primarily to ensure the accuracy of the outcome of the research. Also, the research will be supported by the secondary data. The research design for this paper is to investigate the competitive advantage of Yangshan Deep-water Port.

2.2 Sampling Strategy

There are five steps are required to follow to determine the sampling strategy, which are,

1. The determination of the sample population
2. The determination of the sample frame
3. The determination of the design of the sample
4. The determination of appropriate sample size
5. Execute the sampling process

Due to the limitation of the resources, the sampling method selected in this paper is non-probability sampling. This is convenient for sampling. Convenient sampling refers to the most convenient person or unit that can be obtained. This sampling method is particularly useful in a qualitative study on the condition that resources are limited [29].

2.3 Data Collection

The primary data for this research is gathered by a structured interview. It is conducted by phone call or video call with the manager of Yangshan Port or experts conducting academic research on Yangshan Port. The beforehand questions of the interview. The secondary data for this paper is gathered from previously collected sources such as articles, e-News and some papers from different authors.

2.4 Data Analysis method

All the collected data will be analyzed and further explained as each data is critical to determining the final outcome of the research [30]. The data for this paper will be presented in both descriptive way and numbers way. The collected data in a descriptive way must be presented in an expressive manner to help the reader truly understand the results of the research. The data collected in numbers way will further help express inferential statistical analyses as well as provide readers with a more intuitive understanding [31].

In order to investigate the competitiveness of Yangshan Deep-Water Port with the application of intermodal transportation and automated container terminal, content analysis method will be used. This project will organize and separate the collected data and find the most mentioned content in the interview. Count the content and check if it fits the research direction of this project. The suitable content will be collated and analyzed. Secondary data is used to further support primary data. Therefore, the secondary data will be looked up in the relevant articles, e-News and some papers after the analysis and collation of the primary data.

3. Data Analysis and Findings

This chapter aims to provide an in-depth analysis of the findings in relation to the primary and secondary data collected for this paper. The primary data collection and analysis would be solely based on the conducted interviews while the secondary data will be based on selected articles, journals, and newspapers which will serve to evidence the primary data collected.

3.1 Primary Data

3.1.1 Primary Data Analysis for Intermodal Transportation

Regarding the data collected through the interview, the main collection and distribution method of Yangshan Port is still road transportation. In 2016, in Yangshan Port, 58% of the cargos were transported by roadway to their destination. However, almost all bulk carriers' cargos are entered or left Yangshan Port by the roadway [32]. This is the reason why roadway accounts for such a large proportion of total cargo traffic. 36% of the interviewees said that the most critical mode of intermodal transportation in Yangshan Port is water-and-water intermodal transportation. In 2014, containers entering or leaving Yangshan Port via water-and-water intermodal transportation accounted for 51% of the total container throughput of Yangshan Port. However, containers entering or leaving Yangshan Port by road-and-water intermodal transportation accounted for only 45.2% of the entire container throughput [33]. Those above water-and-water intermodal transportation highly relies on the "shuttle bus" to a large extent. The "shuttle bus" has been introduced in Section 2.1.2. The service of "shuttle bus" started in 2005. It was originally designed to solve the problem that river vessels cannot enter the sea, and the inland waterway near the Yangtze River is too narrow [13]. 54% of the interviewees indicated that the operating cost of "shuttle bus" and the fees charged to customers are seven times lower than road transport and five times lower than rail transport. It is even twice lower than without secondary transport [10]. Interviewees provided the following reasons. The first reason is that "shuttle bus" is operated jointly by the Shanghai International Port (Group) and two shipping companies under it. Therefore, it is managed, operated and charged uniformly, and there is no vicious competition. Secondly, the "shuttle bus" did not aim for profit at the beginning. It is treated as a powerful measure to develop the supporting services of the Yangshan deep-water port and optimize the port environment. Thirdly, it can reduce the time of the corresponding customs clearance. Fourthly, the collection and transportation of waterways are satisfied with the “ecological logistics” required by the international shipping organizations. It greatly reduces energy consumption, exhaust emissions, and noise pollution. Finally, under the Chinese government's policy of supporting Yangshan Port to be the largest international container port in Southeast Asia, the “shuttle bus” received a certain subsidy from the Chinese government, which made it cheaper. Among the interviewees, 45% holds that the rational utilization of the “shuttle bus” and the relatively low price make Yangshan Port more competitive than other ports.

On the other hand, 45% of interviewees pointed out that the superior geographic location and linkage with the rest port of the Yangtze River Delta Economic Zone made Yangshan Port more competitive. Yu [34] pointed out that 65-80% of container throughput of Yangshan Port comes from the Yangtze River Delta region. Also, a large part of it is transported through the Yangtze River. Therefore, Yangshan Port and the rest port of the Yangtze River Basin have carried out a certain degree of water-and-water intermodal transportation. Interviewees pointed out that the linkage area is centered on Yangshan Port and is divided into short radius and medium radius. The short radius linkage refers to the water-and-water intermodal transport between Jiangsu Port, Zhejiang Port and Port of Waigaoqiao. The medium-radius linkage refers to the water-and-water intermodal transportation with the rest of the Yangtze River Basin. 45% of interviewees believe that small radius linkage is currently the primary and efficient source of containers. 18% of the interviewees also pointed out that the medium-radius linkage is also significant since it involves more ports and has more potential development space. However, this competitive advantage is based on the efficiency and low cost of the “shuttle bus.” Also, 27% of interviewees indicated that this advantage also needs to be supported by high-quality inland waterway. Although the inland waterway in the Yangtze River Basin is very convenient and the corresponding infrastructure is relatively complete, most of the waterways are still in a natural state and require further development by the Chinese government [34]. In 2003, Wang [35] proposed the potential container transportation advantage in the Yangtze River Delta region and the inland waterway in the Yangtze River basin should be renovated. Therefore, the interviewed managers indicated that the Chinese government is planning to repair the 2,100-kilometer waterway in the Yangtze River Basin comprehensively and will officially start in 2023, which will further enhance the competitiveness of Yangshan Port. Finally, 72% of the interviewees pointed out that there are still some challenges in achieving the sea-and-rail intermodal transportation in Yangshan Port. The reason for this problem has been explained in Section 2.1.2. The Chinese government and the Shanghai International Port (Group) are vigorously improving the sea-and-rail intermodal transportation in order to make collection and distribution system of Yangshan Port more efficient. Specific measures and results will be explained in the secondary data.

3.1.2 Primary Data Analysis for Automated Terminal in Yangshan Port

Regarding the data collected through the interview, it has been found that the fully-automated container terminal of Yangshan Port is still in the run-in and trial operation period. However, it has already brought a certain degree of competitiveness to Yangshan Port. As aforementioned in Section 2.2.2, Yangshan Port has selected a more mature technology of the fully-automated terminal of “Double-trolley Quay Crane + AGV + Automatic Rail-mounted Gantry” mode [20]. 27% of interviewees said that the main reason for choosing this technology is that this model is also adopted in fully automated container terminals of Qingdao Port and Xiamen Port. Therefore, previous experience can be obtained to improve the automated terminal of Yangshan Port. 36% of interviewees pointed out that the biggest competitive advantage of automated container terminal is that they will bring extremely high efficiency to the terminal, and there will be very few handling errors. Secondly, Yangshan Port is a young and brand-new terminal. There is no problem of renovation and reconstruction. Therefore, the design team is given a lot of space to create and innovate. This will be further explained in the secondary data. Also, 36% of the interviewees indicated that the transportation pressure of the Donghai Bridge was significantly reduced after the fully automated terminal of Yangshan Port was put into operation since more cargo was selected to transfer by the “shuttle bus” via the automated terminal. On the other hand, the pressure on the warehouse is significantly reduced. The fully automated terminal can reasonably arrange the transfer speed of the AGV by computer and monitor the inventory of the warehouse around the clock. This reduces the situation of too much or too little ca ago in the warehouse or yard. However, 27% of the interviewees said that the fully-automated terminal of Yangshan Port is only in the trial operation stage, and all equipment, systems, and personnel in the port are still in the run-in period. Since the opening of the port in December of 2017, it will be closed for two weeks every three months to collect data and train relevant personnel. Also, the AGV independently developed by Zhenhua Heavy Industry will conduct data updates every year for the first three years of operation. The reason is that the driverless technology still needs a lot of measured data to perfect the system.

However, Nam and Ha [36] studied container terminal automatic processing systems using advanced technologies and applied these systems to terminals in Korea. The results show that automation does not always guarantee excellent performance (e.g., higher productivity) - it depends on terminal characteristics such as high labor costs [36]. However, the labor population is huge in China. As a result, labor costs are significantly reduced compared to ports in Europe or the Americas [37]. This means that automated terminal may not bring competitive to Yanshang Port. For this point, all interviewees who have worked in the port pointed out that although labor costs in China are low, few people are willing to participate in port-related work. The following reasons have been given. First, wages are too small compared to manufacturing and food processing industries. For Yangshan Port, regular dock workers only have a salary equivalent to AU$700 for a month. However, the processing industry and the manufacturing industry have wages of AU$1400 for a month. Second, the job risk is quite high. In 2017, there were 200 people injured at work in Yangshan Port. Third, the flow of personnel was frequent, and often more than one over fourth of the people left this job before the training period had finished. In 2016, Dalian Port, Tianjin Port, Qingdao Port recruited dock-related workers, and finally only received 60% of the planned enrollment. Finally, there is a lack of fresh blood. Among those who are employed, only 10% are under the age of 25 years old, and 60% are 40-45 years old. Therefore, low work efficiency cannot meet the requirements of customers, and further lead to the loss of customers. This has become a disadvantage. However, the fully automated terminal perfectly solves this problem and makes the terminal more competitive. In addition, XX% of interviewees pointed out that environmental protection is also major competitiveness of Yangshan Port. Interviewees pointed out that the fully automated terminal of Yangshan Port fully considered environmental factors during construction and operation. During the construction process, the impact on the surrounding ecological environment will be minimized. China's self-developed AGV is driven by lithium batteries, which significantly reduces carbon emissions and noise pollution. Especially in the international, the environmental protection index of the port has a great impact on the competitiveness of the port. Customers are more willing to choose a port with a high environmental protection factor.

3.2 Secondary Data

3.2.1 Intermodal Transportation

In the secondary data, Zhang and Hu [38] stated that the “shuttle bus” business of this period is still in the development stage, and there are many problems in terms of fees and operations, such as unstable flights, high rate of empty ships of “shuttle bus” and so on. However, since 2010, the container throughput of Yangshan Port has increased by nearly 10% every year. The reason is that the efficiency of the “shuttle bus” has been greatly improved. Shanghai Port is also more experienced in the operation and management of the “shuttle bus” [38]. The repair of the inland waterway in the Yangtze River Basin has also begun. Lu et al. [11] stated that the inland waterway from Yangshan Port to Suzhou Port had been refurbished.

Moreover, China launched the following two policies in 2013 and 2014 [33]:

- Reduce the transit cost of ships, increase the transit throughput of Yangshan Port, and increase the port size

- Through preferential policies to attract ships to transit in China, increase port throughput, speed up the time-consuming process for shippers to obtain tax rebates, and accelerate the flow of corporate funds.

This further enhances the competitiveness of the intermodal transportation to Yangshan Port. Qiang [39] further state there are still lots of aspects can be improved in water-and-water Intermodal transportation. For example, the specification of vessels and the elimination of old vessels can shorten the time of operation including vessel operation, entry and exit, and loading and unloading. The corresponding relaxation policy can provide certain relief for the collection of vessel fees [39]. The renovation and maintenance of the inland waterway are also being implemented gradually. It mainly refers to the renovation method and experience of the Port of Rotterdam for its inland waterway [33].

On the other hand, Yangshan Port is also vigorously developing sea-rail combined transport. He, et al. [40] proposed that it is possible to establish fixed-point train transportation and to locate the main transportation market in areas with inland transportation distances greater than 500 km, such as the western part of China. It is also necessary to improve the corresponding railway supporting facilities of Luchao Port and set up relevant departments of Luchao Port within Yangshan Port as soon as possible to make the railway-related services more convenient. Hua [41] pointed out in his article that the scheduled train transportation has been initially implemented in Yangshan Port. Moreover, in 2015, the proportion of railway freight transportation increased to 3.1%. This has a significant improvement from the initial 0.8% [41]. This increasing means that the collection and distribution system of Yangshan Port is more and more complete and closer to the world's first-class container hub port.

3.2.2 Automated Container Terminal

For secondary data of automated container terminals in Yangshan Port, it is hard to find the articles that involve the analysis of the performance of the automated container terminal in Yangshan Port. The reason is that the automated container terminal of Yangshan Port was put into use in December 2017 and it is unable to obtain sufficient data to analyze the influence. Thus, this part of the project will focus on the innovation of Yangshan Port's fully automated container terminal and the environmental protection methods. Yangshan Port's fully automated container terminal has mainly innovated and improved the working area of the AGV and the container yard. Yangshan Port separates the manual work area from the automated work area to avoid interference between the two operations [20]. Combined with the land and the traffic conditions outside the port, the layout of the separate gates of “East and West Exit” was proposed to make port traffic more efficient and convenient [42]. A new mode of “pre-check, diversion and release” three-level inbound intelligent gate layout was designed to strengthen the management of vehicles. According to the different operation modes of the AGV’s automation operation area, maintenance area and test area, the “interaction area” at the intersection of the three areas is designed. This interactive area realizes the common layout of the AGV test area, maintenance area, and machine repair area, and solves the safety problem of man-machine hybrid operation, automatic and non-automatic operation mode conversion. The designed traversing AGV battery replacement station mode significantly reduces the waiting time for AGV queuing, improves the battery replacement efficiency of the AGV, and reduces the traffic impact on the working area in front of the terminal [20]. In theory, the total container capacity of Yangshan Port has increased to 25 million TEU per year. Although Yangshan Port does not have so many sources of goods, for the time being, it has the potential to handle 25 million TEU containers. This is also the potential competitiveness of the fully automated container terminal to Yangshan Port.

Excepting the contribution of AGV to environmental protection mentioned in Section 2.2.3, Cai, et al. [43] design the ship-water saving system, rainwater collection system, and wastewater recycling system. It improved the comprehensive utilization of water resources. In this design, the available sewage in the port area is fully utilized. While reducing the impact of sewage on the surrounding ecology, it improves the utilization of water resources [43]. Full consideration of environmental protection will make Yangshan Port more competitive.

3.3 Findings

The proportion of road transportation has been correspondingly reduced, and the proportion of water and water multimodal transportation has been greatly improved, making the distribution system of Yangshan Port more efficient and environmentally friendly. The repair of the inland waterway in the Yangtze River Basin has also begun. At the same time, Yangshan Port is also developing water and iron combined transport to make the multimodal transport system more perfect. On the other hand, the linkage development with other regions of the Yangtze River Delta Economic Zone is also a major advantage, providing Yangshan Port with strong economic support. Container cargo in the Yangtze River Delta Economic Zone accounts for 85% of the container throughput of Yangshan Port, and most of them choose water transport. Therefore, Yangshan Port uses the “shuttle bus” to improve the efficiency of cargo transportation in the Yangtze River Delta region and reduce costs.

Like other fully automated container terminals, it brings extremely high efficiency to the terminal, which is the most critical competitiveness. In addition, Yangshan Port is a very young port that draws on the experience of China's fully automated terminals to make its operations more efficient. Innovations and improvements in the AGV workspace have made Yangshan Port's work more efficient and convenient. The environmental protection of the port is one of the biggest competitive advantages of the port in recent years. The fully automatic terminal of Yangshan Port is fully powered by lithium batteries, which greatly reduces carbon emissions and noise pollution. The rational application of sewage is also in line with the concept of ecological logistics.

Only a few percentages of Chinese workers are willing to participate in port-related work because wages are too low compared to manufacturing and food processing industries. Port work risks are higher than jobs at the same wage level. Port security measures are constantly improving, but many people still have disabilities or deaths due to work-related injuries every year. Although the initial investment in automated ports is large, it can effectively solve labor shortages and safety problems. This makes the automation port very competitive in Chinese ports, and it has become one of the competitiveness of Yangshan Port.

4. Implications and Conclusions

4.1 Outcomes of the Research

In summary, multimodal transport and automated container terminals have indeed brought competitiveness to Yangshan Deep-Water Port. The Yangshan Deep-Water Port multimodal transport system is becoming more and more mature and is expected to see the world's super ports. Although the development of sea-rail combined transport is very difficult, Yangshan Deep-Water Port is doing its utmost to improve. On the other hand, the Yangtze River Delta Economic Zone has provided strong economic support and a large amount of goods for Yangshan Deep-Water Port. The implementation of port linkage has further enhanced the comprehensive competitiveness of Yangshan Deep-Water Port in the Yangtze River Delta Economic Zone and the world.

Although the automation terminal is in its infancy, it also brings more efficient container loading and unloading speed to Yangshan Deep-Water Port. This also indirectly eased the pressure on the road transport of the East China Sea Bridge. It has laid a solid foundation for Yangshan Deep-Water Port to further enhance the port competitiveness in the future, because the fully automated terminal is the main direction for the future construction and development of the terminal. Environmental protection is now an inevitable trend in the future development of the port. Yangshan Deep-Water Port regards environmental protection as an important condition for cargo transportation and building inspection. This is in line with the concept of “ecological shipping” proposed by the international shipping industry. It is also important to know that Yangshan Port is the bonded port area in China. Although this is not mentioned in the data analysis, it is also one of the core competitiveness of Yangshan Port. It eliminates customs procedures for all transit goods, which increases the efficiency of international transit, saving time and costs. Therefore, the efficient and convenient international transit transport has become one of the core competitiveness of Yangshan Port.

4.2 Implications of the Research

The following application was obtained through the project. According to the special geographical location and water conditions of Yangshan Deep-Water Port, Shanghai International Port (Group) Co., Ltd. proposed a "shuttle bus" method, which effectively solved the problem that riverboats could not enter the sea and the inland waterway was too narrow. This can be adopted by other ports with similar geographical conditions. As an offshore port, Yangshan Deep-Water Port can provide experience for countries that are building maritime ports in the future, such as railway transportation. Establishing a port near a specific economic zone can not only promote economic development in the region, but also improve the overall competitiveness of the port. The fully automatic terminal is still a relatively advanced technology, so it is necessary to decide whether the technology will bring comprehensive competitiveness to the port according to the specific conditions of the port.

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