Trends and Prospects of Port Digital Transformation

Xiang Li*

School of Transportation, Shanghai Maritime University, Shanghai, 201306, China

* Corresponding Author Email: 202010623082@stu.shmtu.edu.cn

Abstract. In the field of shipping, an increasing number of ports are transitioning from traditional manual container terminals to automated and intelligent container terminals. Automated container terminals are a new generation of ports that are based on modern infrastructure and powered by advanced information technology and port transportation. This article attaches importance to introducing the research background of automation and intelligence in container terminals and explains the application of advanced intelligent technologies and automation machinery. Next, it analyzes the current status of automation in container terminals, using four automated ports: TraPac Port, Long Beach Port in the United States, Nansha Port, and Tianjin Port in China. Finally, it discusses the challenges faced by automation and intelligence in container terminals and highlights the need for government support in terms of economy and policy.

Keywords: automated ports, advanced technologies, intelligent container terminals.

1. Introduction

With the progress of society and continuous technological development, the existing port development model and regional port competition model will both undergo significant adjustments [1]. Container terminals are beginning to develop towards intelligence and energy efficiency. The port is undergoing a transformation towards integrated development and innovation-driven growth, aiming to promote high-quality development and implementing an innovation-driven strategy with a focus on digitization and intelligence, promoting "new infrastructure" in the maritime industry [2]. In this trend, automated terminals have been put into use in some ports worldwide. Fully automated container terminals can reduce operating costs and production risks, improve operational efficiency and service quality, and are conducive to energy conservation, emission reduction, and environmental protection. They have become the direction for the future development of container terminals. In November 2019, the Ministry of Transport, the National Development and Reform Commission, and other nine departments jointly issued the "Guiding Opinions on Building World-class Ports" in China. By 2025, it is required to establish a preliminary comprehensive perception, pervasive interconnection, and intelligent system of port-vehicle coordination for some coastal container hub ports [3]. However, Due to the complexity of terminal production operations and the high coupling of various automated systems, there are more demanding requirements for the structural and functional design of the control systems for automated terminal equipment.

Currently, the following progress has been made in the digitalization of global ports:

(1) Port Information Systems: Many large ports have established comprehensive port information systems, achieving the digitized management of containers, cargo, vessels, and personnel. These systems integrate data and information from various stages, providing real-time monitoring and decision support.

(2) Automated Container Terminals: Some ports have introduced technologies such as automated stacker cranes and automated guided vehicles, realizing the automated operation of container yards. These automated container terminals reduce manual operations, improving operational efficiency and safety.

(3) Shipping and logistics platforms: Global ports are currently constructing and promoting shipping and logistics platforms that effectively connect vessels, cargo, and the logistics supply chain through the application of information technology. These platforms provide functions such as cargo

tracking, online booking, and information sharing, improving the visualization and coordination of the logistics process.

(4) Electronic port construction: Global ports are promoting the construction of electronic ports to simplify and expedite customs procedures and review processes, and improve clearance efficiency through electronic data exchange and online declaration methods.

(5) Application of Data Analysis and Artificial Intelligence in Port Operations: Domestic ports are actively exploring the application of data analysis and artificial intelligence in port operations. By analyzing big data and applying intelligent algorithms, it is possible to optimize ship scheduling, cargo transportation, and port resource management, thereby improving overall operational efficiency.

It is undeniable that global port digitization has made significant progress in the past few years, but it still faces challenges in certain areas. For instance, there is a need for further strengthening and addressing issues such as cybersecurity threats, data privacy protection, and standardization. This article will analyze the changes brought to ports by digitization and offer some suggestions to address the challenges related to digitization.

2. Analysis Of Port Transformation Status In China and Abroad

2.1. Analysis Of Port Transformation Status In China

China has made great progress in building digital ports. Its comprehensive mastery of key technologies related to the entire chain of automated port design, construction, equipment manufacturing, system integration, and management improves the efficiency of port operations. Currently, China has achieved a lot of innovative results in terms of overall port layout, handling techniques, intelligent gate systems, collaborative yard operations, Beidou and "5G" technology applications. Among them, Beidou system, the layout of the docks and the continuous updates of intelligent devices are the most representative features. In terms of positioning, traditional commonly used positioning methods mainly include magnetic nails, gridding lines, ultrasound, etc., which have problems such as difficult construction, large positioning deviation, and low positioning accuracy. The high-precision advantage of the Beidou system can effectively avoid the problems existing in the traditional positioning methods mentioned above [4]. For intelligent devices, China has successfully developed pioneered technologies such as the "one-click anchoring" for the entire track crane and the robot dismantling and locking system. In the layout of the dock’s hand, by combining local circumstances, China explored new automated port layout patterns such as "alongshore arrangement" and "U-shaped arrangement", and innovatively developed new types of harbor transport vehicles such as unmanned container trucks, artificial intelligence handling robots (ART), and intelligent guided vehicles (IGV).

2.1.1 Tianjin Port

On October 17, 2021, after 21 months of construction, the intelligent container terminal of Section C in Tianjin Port Beijiang Port Area was officially put into operation. Fig.1 shows the C section of the intelligent container terminal in Tianjin Port Beijiang Area. Since 2019, Tianjin Port has been gradually achieving the automation upgrade and transformation of the entire container yard rail bridge, the large-scale operation of unmanned electric container truck fleets, and the full-process automation upgrade and transformation of traditional container terminals. It has successfully developed a "5G+L4 level autonomous driving" unmanned or minimally manned smart port, achieving a fully unmanned mode for horizontal transportation. The port's 76 vehicles have been operating in a full load state for over 12 months, with a total mileage of millions of kilometers. By implementing automation and intelligent equipment and solutions, the working schedule of gantry cranes at Tianjin Port has been reduced from 2 hours to 10 seconds, increasing efficiency by more than 10%. The target for direct berthing rate has increased by 5%, and the average waiting time for external trailers has been shortened by 5 minutes. Through refined management, the allocation of port resources will be further optimized, reducing overall operating costs by 10%. Without the need for new terminals or berths,

the port's operational capacity will be further enhanced, achieving true cost reduction and efficiency improvement through digital transformation. Additionally, the port has also solved the issue of the takeover rate, which is now lower than one in a thousand [5]. Tianjin Port has provided a Chinese solution for the automation construction of other traditional ports.



Fig. 1 Xinhua News Agency, Tianjin Port's "Smart Zero Carbon" Terminal, 2022-10-14 [6]

2.1.2 The Fourth Phase of The Fully Automated Terminal at Nansha Port in Guangzhou

The Phase IV fully automated terminal at Guangzhou Port Nansha Port Area is located at the mouth of the Pearl River, connecting the river network within the Pearl River system and the deep-water seaport in Nansha Port Area. The port officially started operations on July 28, 2022. It is the first newly constructed automated terminal in the Guangdong-Hong Kong-Macao Greater Bay Area and a fully automated terminal for intermodal transportation by rail, river, and sea. At the forefront of the Nansha Phase IV terminal, the gantry crane accurately grabs the containers on the ship according to the instructions automatically issued by the information system, and automatically places them on the unmanned intelligent guided vehicle (IGV). As Fig.2 shows, the IGV automatically plans the route and transports the containers to the yard through intelligent algorithms, The rail-mounted gantry crane automatically aligns and grabs the containers, placing them in the designated positions. The entire production process flows smoothly, marking the successful joint commissioning of the first fully automated terminal in the Guangdong-Hong Kong-Macao Greater Bay Area - Guangzhou Port Nansha Phase IV project. In contrast to the previous automated docks that used magnetic nail navigation, which involved laying magnetic nails on the dock floor and using RF antenna-equipped vehicles to navigate along the magnetic nail tracks, the Nansha Phase IV project adopts the world's first "single small vehicle automated shore crane, Beidou navigation unmanned intelligent container truck, horizontal layout of the yard for side loading and unloading, and fully automated port" Guangzhou Solution, which is a system that is completely independently developed with intellectual property rights in China.



Fig. 2 Xinhua News Agency, Guangzhou Nansha Port Phase IV fully automated terminal has commenced operation, 2022-07-28[7]

2.2. Analysis of Port Transformation Status in America

In America, there is a divergence between foreign-owned terminals, primarily operated by foreign carriers, and domestically-owned terminals operated by US operators. The former are heading towards the direction of automated terminals, while the latter are moving towards semi-automated terminals.

Representative examples of automated terminals in American ports include the TraPac terminal in Los Angeles operated by NYK Line, the container terminal in Long Beach operated by OOCL, the Global Container Terminal (GCT) in Bayonne, New Jersey operated by Maher Terminals, and the Virginia International Gateway (VIG) terminal in Virginia operated by Maersk. The following text will attach importance to the introduction and analysis of TraPac Port and the Long Beach Container Terminal.

2.2.1. TraPac Port

The TraPac Terminal is the first automated container terminal in the United States. The Phase 1 project was completed in 2007, the Phase 2 project went into operation in November 2015, and the Phase 3 project began operating in 2016.

The terminal utilizes the operation process of "Automated Straddle Carrier + Automated Rail Mounted Gantry Crane". Its transportation system adopts the solution of "Energy Storage System + Pure Electric Heavy-duty Trucks". The energy storage system charges the trucks continuously for 24 hours, enabling the fully automated zero-emission operation of the pure electric trucks.

The terminal's automated radiation detection system is used to monitor the containers being transported on the tracks, ensuring the smooth delivery of the containers and significantly improving operational efficiency and cargo transportation speed.

2.2.2. Long Beach Port

Meanwhile, the automation renovation of the Middle Harbor terminals at the Port of Long Beach is part of an ongoing expansion project with a total investment of $1.3 billion. The Port of Long Beach has successfully implemented automation in its container terminals, making it one of the most technologically advanced freight facilities in the world. Located in the heart of the port, the Long Beach Container Terminal is equipped with nearly all-electric and zero-emission equipment, aiming to improve cargo flow and significantly enhance air quality in this rapidly growing era of the second

busiest seaport in the United States. All vessels docking at the terminal are required to connect to shore power upon arrival, allowing them to shut down their diesel engines and connect to the shore's electrical grid. All major buildings have energy and water-saving features that meet the strict Gold-level standards of Leadership in Energy and Environmental Design (LEED). With an annual capacity of 3.3 million standard containers, LBCT alone can become the sixth busiest seaport in the United States, capable of transporting twice the cargo of the two terminals it replaces while emitting less than half the air pollution. The trade growth facilitated by this terminal has created 14,000 permanent new jobs in Southern California. Additionally, LBCT employs union workers who operate fully electric ship-to-shore cranes, supported by control center operators and technical maintenance personnel.

3. Problems and challenges brought by port digitization

The digitalization of ports has resolved numerous traditional issues, but it also faces several challenges. Here are a few key problems:

(1) Technological barriers: Port digitalization requires extensive support from advanced technologies such as the Internet of Things (IoT), artificial intelligence (AI), big data, and cloud computing. However, these technologies may encounter technical difficulties during implementation, such as data security, system integration, and network connectivity.

(2) Data sharing and privacy concerns: Port digitalization requires the sharing of data among various stakeholders, including cargo owners, ship owners, freight forwarders, warehouses, and logistics companies. Currently, most port companies have developed department-level applications and data based on terminal companies. The management of information technology is fragmented, lacking overall and systematic integration. The functional modules of each system have little connection with each other, leading to a severe information silo phenomenon. However, some departments have more in-depth considerations regarding information security and the responsibility for information leakage, which hinders smooth information exchange between business departments and lacks mechanisms and shared platforms for coordination [8]. So establishing appropriate data protection and security mechanisms is crucial.

(3) Cultural and organizational transformation: The digitization of ports requires more than just the introduction of technology; it also necessitates comprehensive cultural and organizational transformation. Many traditional port and logistics companies may lack awareness and capabilities for digital transformation and thus require employee training and optimization of organizational structure.

(4) Legal and policy environment: The digitization of ports also requires legal and policy safeguards. For example, regulations related to data ownership, privacy protection, network security, and the digital economy need to align with the development of digitization.

(5) The shortage of skilled professionals in the field and the talent management system: Traditional port companies lack a well-established training path and mechanism for cultivating digitally proficient professionals, resulting in a long-term delay in the analysis of digital talent team structure and talent development. This lack of professionals who understand both technology and business hinder the effective resolution of the strong dependence of various types of port operations on information technology. As a result, port companies face challenges in achieving breakthrough efficiency in their digital transformation efforts [8].

4. Suggestions

In regards to the digitalization of our country's ports, the following suggestions can be considered:

(1) Strengthening technological research and innovation: Increase investment in research and application of key technologies such as the Internet of Things, artificial intelligence, big data, and cloud computing.Promoting data sharing and standardization. For example, establish a unified data-

sharing platform and standards to promote data sharing and interoperability among various stakeholders in ports. This will drive innovation and maturity in digitalization technologies for ports, promoting the development of digitalization.

(2) Strengthening security and privacy protection: By benchmarking the finance and mobile communication industries, the security system for digital and automated construction in ports can be enhanced and the industries can be referenced for the digital and informational construction of other infrastructure facilities. From a comprehensive perspective on global network attack behaviors, ransomware attacks mainly target enterprises and institutions that operate continuously for 24 hours, such as gas stations, hospitals, and ports. However, attacks on financial institutions such as banks are relatively less frequent, mainly due to the fact that the latter often adopt multiple data protection measures. Establishing a comprehensive digital security mechanism for ports, including secure storage and transmission of data, network security protection, and privacy protection, to ensure the safety and reliability of port digitization is necessary. Implementing data-centric security throughout the entire lifecycle is crucial. This means focusing on data and applications during the design, development, testing, deployment, and maintenance stages. It is also important to strengthen external attack defense and internal data leakage auditing to prevent external hackers from stealing sensitive data and internal data leaks, which is essential for effectively safeguarding core data security [9].

(3) Promoting organizational and cultural transformation: By strengthening collaboration with shipping companies, actively exploring new opportunities hidden in new situations, and continuously trying various forms of cooperation, the deep and solid development of port and shipping integration be promoted. It can also expand the survival and development space of port enterprises by expanding the port's capacity and developing hinterland areas, in order to better adapt to market changes [10]. At the same time, it will enhance digital transformation training and guidance for ports and logistics companies, improving employees' awareness and application capabilities of digital technologies, and driving organizational and cultural change to support port digitization.

(4) Enhancing the legal and policy environment: Formulating regulations and policies that are suitable for the digital development of ports, clarifying issues such as data ownership, privacy protection, and network security, to provide legal and policy support for the digitalization of ports. Establishing a sustainable mechanism for "data application," to start with environmental monitoring data and collaborate with specialized post-treatment methods. This will effectively enhance the capacity for environmental governance [11].

(5) Increasing investment and policy support: The government plays a crucial role in creating an ideal environment and providing policy support for technological innovation and talent development. The collaboration between the port and government agencies will continue to deepen, as we work together to explore the diversified application of next-generation information technology in the port industry. This will accelerate the optimization and integration of the entire industry chain, enhance the overall service capabilities of the industry, and achieve cooperation, development, and mutual benefit [12]. So, governments should strengthen financial and resource support for digitalization projects in ports to enhance the feasibility and benefits of port digitalization.

In summary, port digitalization plays a crucial role in the development of China's ports and logistics industry. It requires joint efforts from all parties to strengthen cooperation and innovation, address challenges in technology, data, culture, law, and investment, and promote the rapid development of port digitalization in our country.

5. Conclusion

With the growth of global trade and the increasing complexity of logistics supply chains, ports require more efficient, sustainable, and intelligent operational methods to meet market demands. Digital technology presents tremendous opportunities and advantages for port operations. However, this article only offers suggestions for existing issues and may not be applicable to all ports. Different ports in different regions have different limitations and face different challenges and difficulties. In

the future, specific analysis should be conducted for each individual port to implement their respective digitalization plans. With further support from government policies, technological breakthroughs, and cooperation from port enterprises, the shipping industry will usher in its own digital era and these difficulties will gradually be overcome, bringing greater opportunities and advantages for the digitalization of ports.

References

[1] Duan Chaohui. 'Wisdom' solves the current port development problems. China Ship Survey, 2017 (08): 44-47.

[2] Yan Jun. Thoughts on improving the digital development level of China's ports. Transport enterprise management, 2023, 38 (04): 3-5.

[3] Li Zhe. Port intelligent construction. Communication enterprise management, 2021, (03): 58-61.

[4] Wu Haile, Chen Yang, Jia Laiguo. Application of Beidou System in Smart Ports. Satellite Applications, 2020, (07): 22-27.

[5] Li Hui. Application of big data technology in intelligent management of port shipping. Pearl River Shipping, 2023, (10): 20-22.

[6] Xinhua News Agency. Tianjin Port's "Smart Zero Carbon" Terminal, 2022-10-14, https://www.gov.cn/xinwen/2022-10/14/content_5718240.htm#1

[7] Xinhua News Agency. Guangzhou Nansha Port Phase IV fully automated terminal has commenced operation, 2022-07-28, https://www.gov.cn/xinwen/2022-07/28/content_5703261.htm#

[8] Zhang Yimin. Problems and development paths in the construction of digital ports. China Ports, 2022, (04): 5-8

[9] Yellow truss. Proactively addressing information security challenges in the era of digital ports. China Ocean Shipping, 2022, (11): 41-42.

[10] Ma Pingping. China 's port development status and future trend analysis. Continental bridge vision, 2023, (05): 33-34 + 37.

[11] He Haobo, Zhu Shiliang, Chang Jin. Digital intelligent green port system construction. China Port, 2022, (11): 54-56.

[12] Wu Junfeng. China 's smart port digital transformation trend and innovation platform construction. China Ports, 2021, (10): 20-23.