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Ogawa, Akinobu and Tsuchiya, Takahiro

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Takahiro Tsuchiya[1] and Akinobu Ogawa (ORCID: 0000-0002-7786-7169)[2]

[1]Associate Professor, Kyoto University of Advanced Science, Kyoto Japan. tsuchiya.takahiro@kuas.ac.jp

[2]Associate Professor, Niigata University, Niigata Japan. ogawa@econ.niigata-u.ac.jp

Corresponding Author: Akinobu Ogawa

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Abstract

This study investigates smart port development within the Guangdong–Hong Kong–Macao Greater Bay Area (GBA), a key project under China's expansive Belt and Road Initiative. This development is of paramount importance as it addresses the pressing need to modernize port infrastructure, thereby enhancing water transport efficiency and sustainability. Furthermore, it aims to bridge gaps in technology integration and policy implementation in the region, thereby contributing to overall economic growth and trade efficiency. The methodology employed in this research is comprehensive and robust. This study undertakes an in-depth review of policy documents, technological advancements, and case studies on smart ports across countries. Key data sources include the 14th Five-Year Plan, the GBA Development Plan, and specific Nansha Port District Phase 4 Terminal developments. Data analysis techniques are focused on evaluating the impact of Industry 4.0 technologies such as the Internet of Things, big data, artificial intelligence, and 5G on port operations. The findings of this research are promising, indicating remarkable progress in GBA's port modernization. Successful cases of modernization, such as Tianjin's 5G automated port, serve as beacons of hope. However, policy coordination and technology adoption in diverse ports is challenging. The study highlights the need for a unified strategy, i.e., a strategic move that can ensure seamless integration of smart technologies, thereby enhancing trade efficiency and spurring economic growth in the region.

Keywords: Smart Ports, Greater Bay Area, Belt and Road Initiative, Industry 4.0 Technologies, Port Modernization

1. Introduction

China's Guangdong–Hong Kong–Macao Greater Bay Area (GBA) initiative was proposed by Xi Jinping (General Secretary of the CPC Central Committee, President of the State). The GBA initiative is an integrated development project for the ports of Shenzhen, Hong Kong, and Guangzhou in South China, which are located at the nodes of the "Belt and Road" Initiative (Silk Road Economic Belt and 21st Century Maritime Silk Road) proposed by Xi Jinping (General Secretary of the CPC Central Committee) in 2013 and boast the second-highest container transport volume after East China, which includes the rapidly developing ports of Ningbo Zhoushan and Shanghai.

The GBA initiative involves the development of ports and harbors in the GBA.[1] Port development under the GBA initiative includes the establishment of an international shipping center (high-end services such as ship management, leasing, and ship finance) in the Hong Kong special administrative region (hereinafter Hong Kong) and the strengthening of comprehensive international shipping service functions (port navigation infrastructure) in Guangzhou and Shenzhen. The GBA initiative is characterized by the simultaneous revitalization of industries in the hinterland, including healthcare; the promotion of innovation through research and development; and the creation of a tourism hub. This initiative has led to the development of a huge economic zone equivalent to the population of the UK and promoted the clustering of industries to create a modern industrial system that is internationally competitive. Currently, the GBA initiative focuses on the development of port infrastructure, particularly smart ports. In May 2020, as part of the Chinese Government's vision to transform the GBA into a high-tech metropolitan area comparable to the Silicon Valley in California, US, the People's Bank of China, the central bank, and other financial supervisory authorities launched a comprehensive plan to facilitate cross-border transactions and investment in the region. Various measures have been undertaken to successfully implement the GBA initiative. However, several phenomena have

[1] The "Outline of the Guangdong–Hong Kong–Macao GBA Development Plan" was proposed by the Chinese government in 2019. This document states that port development is needed for the GBA. This Outline was prepared to strengthen the international competitiveness of port complexes in the Zhuhai Delta region.

hindered the relations between western countries and China, which is experiencing rapid economic and military growth. This is due to the current lack of research on China's political decision-making process, policy-making process, and policy structures (e.g., financial resources and initiatives). The same is true for the GBA. While the GBA is an important economic development initiative in South China—a nexus for China's foreign and domestic policy—the direction and intention of development and the policy structure pursued by the central government and the governments of the special administrative regions of Hong Kong and Macao are not always clear. Furthermore, the impact of the smart port initiative on other countries is unclear, and security concerns about the software employed in Chinese port infrastructure being used in the US have been reported (LaRocco 2024).[2] Therefore, this study attempts to explore the actual state of smart ports in the GBA, along with global trends in smart ports, and clarify the intentions and impact of the GBA initiative.

This research examines the current challenges and opportunities in developing smart ports within the GBA in China.

2. Trends in Smart Ports

2.1. Smart Ports

In recent years, Industry 4.0 (Fourth Industrial Revolution) has attempted to introduce technologies such as the Internet of Things (IoT), big data, cloud computing, artificial intelligence (AI), and 3D printing in various fields. Similarly, ports integrated with Industry 4.0 technologies are called "smart ports," "port 4.0," or "fifth-generation ports."

For example, South Korea has developed a roadmap for smart port development, and China has been promoting smart port construction (Jun et al. 2018). Furthermore, Hong Kong and Singapore already possess fifth-generation ports (Lee and Lam 2016; Lee et al. 2018). Singapore has been developing an AI-based system for reducing navigational accidents since 2017 (Pham 2023).[3]

Smart ports in Europe include the Port of Hamburg and the Port of Rotterdam. The Port of Hamburg has reduced operating costs by 75% and port congestion by 15% by implementing a cloud communications platform focused on renewable energy and efficient energy use (Heilig and Voß 2017). At the Port of Rotterdam, the use of information communication technology (ICT) tools to estimate optimal arrival times has considerably reduced waiting times for ships (Pham 2023).

However, the concept of "smart ports" is not clearly defined; to clarify this concept, reviews and interviews of port officials (directors, managers, and professionals) have been conducted (De la Peña Zarzuelo et al. 2020; Behdani 2023; Belmoukari et al. 2023; Li et al. 2023; Pham 2023). Naturally, the definitions of smart ports presented in these studies are not entirely consistent, but the definition presented by Behdani (2023) comprehensively encompasses the elements discussed in other studies.

Behdani (2023) summarizes the following three directions to be pursued by smart ports: (1) business process automation, (2) coordination and integration among port facilities, and (3) data-empowered decision-making processes. In other words, smart ports are characterized by full automation of port services, networking of multiple ports and integration of ports and cities, and streamlining of port services based on big data.

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[2] Notably, 80% of the "ship-to-shore" cranes moving goods at US ports are made in China and the US government has claimed to "use Chinese software" in recent testimony (CNBC "STATE OF FREIGHT," March 13, 2024).

[3] The Maritime and Port Authority of Singapore developed the "sense-making analytics for maritime event recognition" system in 2017, which is an AI-based system for the port of Singapore, providing new capabilities to reduce navigation accidents.

However, only a few ports in the world are fully automated (International Transport Forum 2021), and concerns have been expressed that dockers' unions would not support the loss of jobs resulting from full automation (Bottalico 2022). Further automation would also expose ports to cybersecurity risks (De la Peña Zarzuelo 2020).

2.2. Smart Port–enabling Technologies

Behdani (2023) has comprehensively classified the technologies required for realizing smart ports into seven areas: robotics and automation; autonomous shipping/vehicles; IoT; 5G networks; blockchain and smart contracts; big data analytics; and simulation, virtual reality, and digital twin technology.

The integration of these technologies will facilitate smart traffic management (smart gate system, smart ships/barges, smart containers, and automated guided vehicles), smart trading (e-custom and smart seals), and smart infrastructure (smart energy/lighting, smart berth and buoys, smart parking, smart stacking, and automated berth and cranes).

Robotics and automation includes driver and license plate identification systems that automate gates. In fact, the Port of Rotterdam and the Port of Singapore have automated container number recognition through optical character recognition (OCR) (Mi et al. 2021). Autonomous shipping, or autopilot operation of ships and vehicles, which requires 5G networks, is essential for fully automated container shipping as it enables uninterrupted communication between surrounding ships, vehicles, traffic signals, and other infrastructural components. Furthermore, Heilig and Voß (2017) have listed GPS, radio-frequency identification, real-time location system, wireless sensor networks, and electric data interchange as necessary information technologies for smart ports, in addition to OCR and 5G networks.

To use 5G networks, general IoT technologies such as supported devices, software, and communication protocols are required. Blockchain, which can record various transactions on a distributed ledger, is necessary for employing smart contracts. Big data analytics can enhance the efficiency of port services by analyzing data obtained from terminal operating systems.

Big data analytics is used to analyze image data for realizing driver and license plate identification systems. Constructing a digital twin by integrating all types of data on ports and harbors can enable the digital simulation of bottlenecks and their impact, thus allowing for a virtual analysis of remedial measures before their real-world implementation. Digital twin construction can increase port safety; the ports of Antwerp, Abu Dhabi, and Rotterdam have already invested in the development of digital twin for port operations.

As we have seen until now, smart ports will be realized when all port infrastructure is connected to the network and various types of digital data are accumulated and utilized. Another feature of these ports is that they will be connected to other ports around the world. Such a network of ports could be highly vulnerable. Therefore, the prevention of cybercrime, i.e., cybersecurity, is crucial for smart ports (Alop 2019; Gunes et al. 2021; Ben Farah et al. 2022).

In Europe, where smart port development has been progressing, each country is pursuing smart port development from the bottom to the top, resulting in the duplication of smart ports within the region. At certain ports, labor unions are opposing automation projects. Meanwhile, in China, the Ministry of Commerce under the State Council has initiated a top–down approach to convert 13 ports to smart ports at the local government level. Therefore, the next section summarizes the progress of smart ports in China and analyzes smart port projects in the Guangdong–Hong Kong–Macao GBA.

3. Related Studies

This section summarizes previous research on port policy in the GBA. Some studies have considered the role of tourism in the economic development of the GBA (Leandro 2020; Chen et al. 2022; Duan and Lai 2022; Yuan et al. 2022), while others have evaluated the behavior of tourists visiting the GBA (Haiyang et al. 2022; Mou 2022) and the business cycle in the tourism industry (Cui et al. 2021).

Studies focusing on entrepreneurship in the GBA have identified the factors that enhance entrepreneurship based on interviews with women entrepreneurs as well as undergraduate and postgraduate students (Nowak 2020; Liu 2022) and the structure of entrepreneurship in GBA (Feng et al. 2020; Wu et al. 2022; Wang et al. 2023). Studies focusing on innovation include Ye et al. (2021), Sharif and Chandra (2022), and Ye et al. (2022); these studies have compared innovation policies in Hong Kong and Shenzhen (Sharif and Chandra 2022; Yu et al. 2022), and the interaction between the government and firms (Ye et al. 2022).

Xie et al. (2021), Mok (2022), Tang (2022), Xie et al. (2022), and Mok et al. (2022) investigated education within the GBA, inferring that higher education institutions should promote industry–university collaboration within the GBA. Mok et al. (2022) investigated the motivation of high-level personnel who have studied outside China to return to mainland China and provided policy implications for the acquisition and retention of high-level personnel, focusing on the GBA. Studies on transport networks within the GBA have highlighted the vulnerability of GBA's transport network (Chen M. et al. 2020; Song et al. 2022) and analyzed the impact of the development of the transport network on the region's economy (Liao et al. 2019; Chen J. et al. 2020; Chen Z. et al. 2020; Lin et al. 2020; Chang et al. 2021; Li et al. 2022; Yang et al. 2022; Fu et al. 2023).

Chen J. et al. (2020) measured the growth potential of major ports in the GBA—Hong Kong, Zhuhai, Shenzhen, and Guangdong—and found that Shenzhen has the highest overall growth potential and Zhuhai has the highest growth potential in terms of cargo throughput, suggesting that Hong Kong should focus on supplying shipping services such as marine insurance. Li et al. (2022) suggest that policy intervention is needed as free competition in proximate ports leads to inefficiencies such as excessive infrastructure development and ports should be integrated although each major port in the GBA have different governing authorities. Yang et al. (2022) also state that policy intervention is necessary to avoid excessive competition. The bottom–up nature of governance in Western European maritime clusters makes it difficult for multiple ports to work together on common objectives; conversely, the top–down nature of governance in the GBA is advantageous, with the roles of Hong Kong and other ports clearly distinguished for integrated development. Fu et al. (2023) state that for the integrated development of GBA, Hong Kong should specialize in supplying higher added value, such as marine insurance, rather than cargo handling. Thus, policy intervention is necessary to develop smart ports in the GBA, and it is necessary to change the role of Hong Kong, which has been the driving force of China's ports, and clarify the division of roles among ports in the GBA.

Based on the aforementioned studies, there is a lack of accumulated research on port development in China's GBA. Therefore, this study aims to clarify this issue.

4. Smart Ports in China

4.1. China's Five-Year Plans and Smart Port Initiative

This section investigates the relationship between China's Five-Year Plans and the Smart Port Initiative. In recent years, China has made substantial progress in the development of smart port technology and infrastructure, aiming to establish global advantage in this sector. For example, China has built the world's first fully automated 5G port in Tianjin, with the highest efficiency and productivity. In China, since the implementation of the "9th Five-Year Plan" (1996–2000), the State Council, National Development and Reform Commission, Ministry of Natural Resources, and other departments have

issued a series of development policies that support and regulate the port industry and outline the direction of smart port ("wisdom port" in Chinese) development as well as port modernization.

During the 9th Five-Year Plan, the central government proposed focusing on the construction of numerous large ports. During the periods of the 10th and 11th Five-Year Plans, national policy gradually evolved to intensify port construction, expand port throughput, and establish and improve a modern transportation system. Furthermore, the 12th and 13th Five-Year Plans specify that the country needs to increase the size and level of modernization of its ports and build an efficient network of ports through division of labor and cooperation.

During the most recent "14th Five-Year Plan" (2021–2025), major provincial governments have established development goals for the smart port industry. Furthermore, the country noted the need to build a modern integrated transportation system and accelerate the construction of world-class ports. Currently, China is accelerating the construction of an integrated transportation system, and ports are an important part of water transportation. To promote their intelligent development, the country has announced several policies to boost the smart port industry.

For example, the "Guiding Opinion on the Development of Smart Ships (智能航运发展指导意见)" proposes to establish appropriate environmental conditions for the testing and demonstration of smart ships, smart aviation insurance, and smart supervision by 2025. This opinion indicated that several key technologies that limit the development of smart shipping (wisdom shipping) will be surpassed, the country will become a global innovation center for smart shipping development, the core technologies of smart shipping will be relatively and comprehensively mastered by 2035, and the establishment of smart shipping technology standards will be comparatively complete. By 2050, a high-quality smart transportation system will be realized that will play an important role in building transportation capacity.

The "14th Five-Year Plan" (Modern Integrated Transportation System Development Plan) targets the development of the ports of Dalian, Tianjin, Qingdao, Shanghai, Ningbo Zhoushan, Xiamen, Shenzhen, and Guangzhou while simultaneously promoting the intelligent transformation of existing container terminals. This plan emphasizes accelerating the construction of next-generation automated terminals in Tianjin Beijiang C Section, Shenzhen Haixing, Guangzhou Nansha Phase 4, and Qinzhou.

Accordingly, provinces and cities are developing smart port policies based on their circumstances. Specifically, Hebei, Liaoning, Tianjin, Shandong, Zhejiang, Jiangsu, Hubei, Fujian, Guangdong, Hainan, Guangxi, Sichuan, Chongqing, and other provinces, autonomous regions, and municipalities under their jurisdiction have formulated plans based on their respective regional policies.

4.2. "Outline of the Guangdong–Hong Kong–Macao GBA Development Plan" and Smart Ports

China has proposed a plan to develop and expand the GBA in an integrated manner. The "Outline of the Guangdong–Hong Kong–Macao GBA Development Plan" established by China in February 2019 is positioned within the framework of the "Belt and Road" Initiative, which is aimed at the integrated development of South China, the starting point of the "Maritime Silk Road." After the construction of smart ports in the GBA was specified in the "Blueprint and Action Plan for Promoting the Joint Construction of the Silk Road Economic Belt and 21st Century Maritime Silk Road" released by the Chinese government in March 2015, the Chinese government and the governments of Hong Kong, Macau, and Guangdong Province signed the "Guangdong–Hong Kong–Macau Cooperation Evolution through the Cooperation Framework for the Construction of the Guangdong–Hong Kong–Macao GBA" in July 2017, leading to the enactment of the Outline in February 2019.

In the Outline, as noted in the Introduction, the GBA includes Hong Kong, Macau, and the cities of Guangzhou, Shenzhen, Zhuhai, Foshan, Huizhou, Dongguan, Zhongshan, Jiangmen, and Zhaoqing (the "nine Pearl River Delta cities") in Guangdong Province. The region covers a total area of 56,000 km^2 and has a population of 86 million (as of 2020).

In addition to Hong Kong and Macau, the GBA includes Shenzhen was designated as a special economic zone in 1980, making it one of the most economically liberal regions in China. The preface of the Outline emphasizes the development of the "one country, two systems" concept. In other words, the project aims to ensure the sustainable growth of Hong Kong and Macau by promoting cooperation between Hong Kong, Macau, and mainland China while taking advantage of the two special administrative regions, thereby contributing to the prosperity of the Chinese economy.

The preface is followed by a description of the significance of building the GBA. Furthermore, cooperation between Hong Kong, Macau, and the Chinese mainland is emphasized; the opportunity for Hong Kong and Macau compatriots to enter the Chinese mainland will ensure the sustainable growth of the two regions. This is followed by references to boosting the international competitiveness of the Chinese economy and promoting the "Belt and Road" Initiative. The preface suggests that the main focus is not necessarily on economic growth but on cooperation or integration between Hong Kong, Macao, and mainland China and that the establishment of the GBA is positioned as a means of achieving this.[4]

Although the GBA boasts an economic scale comparable to global bay area cities of New York, San Francisco, and Tokyo, the social systems (such as immigration control and customs) of Guangdong, Hong Kong, and Macau under the "one country, two systems" concept do not allow for the smooth movement of people and goods. Furthermore, cities other than Hong Kong and Macau are likely to face slow economic growth.

In the Outline, specific policies and their directions are presented, based on the aforementioned preface, along with their importance and current status. The policies are wide-ranging (extremely exhaustive and unclear in terms of priorities). However, they can be broadly divided into four categories: (1) innovation creation, (2) infrastructure construction and connectivity (including information infrastructure), (3) coordination or linkage of social systems, and (4) preservation of ecosystems.

Although the interrelationship between the abovementioned four categories is sometimes vague, it is clear that the idea of eliminating bottlenecks for further development by promoting integration in the GBA in terms of hardware and software is essential for the innovation creation.

In terms of innovation creation, the initiative aims to innovate in areas such as big data and nanotechnology through the development of innovation facilities and collaboration between industry and academia, including the participation of Hong Kong and Macau universities and research institutes in science and technology projects in mainland China. To promote such collaborations, it is essential that people and goods are able to move smoothly within the area.

Therefore, the construction of railroads, airports, and highways and their interconnection are related to building and connecting infrastructure. Notably, this construction also enables the interconnection of information infrastructure as well as passenger and cargo transportation, allowing for the development of a network covering the entire GBA region whose security will be ensured through real-time monitoring and other measures.

In addition, since securing human resources is extremely important for innovation creation, cities other than Hong Kong and Macau are encouraged to learn from their experience in this regard. Furthermore, by linking the education systems of Hong Kong and Macau with those of mainland China, young people in Hong Kong and Macau are encouraged to study in mainland China. Other examples of linkage or consolidation of social systems include scenarios in which residents of Hong Kong and Macau apply for civil service examinations in mainland China; Hong Kong and Macau residents living in Guangdong Province are treated the same as mainland Chinese residents in terms of social security; patriotic education is provided for young people in Guangdong, Hong Kong, and Macau; and judicial cooperation among these regions is strengthened.

The development of an ecological protection barrier and the realization of a low-carbon

[4] The Chinese Communist Party/State Council has announced details of its plan to "fuse and develop" Fujian Province and Taiwan situated on the "opposite shore" on September 12, 2023, which may share a fundamental purpose with the GBA.

economic development model within the GBA are presented as specific policies that can be implemented. As already mentioned, it is difficult to determine the higher-level goal from the following two objectives: innovation creation and collaboration between Hong Kong, Macau, and mainland China. Furthermore, to enable innovations, it is necessary to attract human resources not only from mainland China but also from all over the world. To achieve this, Hong Kong and Macau must take advantage of their ties with western countries; however, the more they promote social and cultural integration with mainland China, the more they will lose their advantage.

Moreover, it is unclear how well the cities within the GBA can work together as local governments may compete with each other for economic growth. As Tsuchiya and Ogawa (2023) have summarized, most studies on the GBA do not question its economic results, but given the existence of such a dilemma—while cities within the GBA are expected to become more economically linked, they are also competing for economic growth—it is not necessarily inevitable.

For example, while describing the overall strategy, the Outline clearly states that the flow of people, goods, and money should be facilitated to promote cooperation between Hong Kong, Macau, and other cities. In terms of innovation creation, which is a priority for the GBA, the Outline recommends policies that will enable the smooth flow of human resources, capital, information, technology, and other elements within the region. While infrastructure development and interconnectivity are essential to achieve this integration, simplification or elimination of customs clearance and border entry procedures are equally important.[5]

Although traffic between mainland China and Hong Kong, which had been restricted due to the spread of the COVID-19 infection, was normalized in February 2023, it is still necessary to obtain a border entry permit. For some countries, visa exemptions for entry into mainland China remain suspended. The Chinese government announced the resumption of visa waiver measures on September 29, 2023. However, at least for Japan, these measures are not expected to be resumed at this time, and when applying for a visa, Japanese residents must visit one of the application centers in Tokyo, Nagoya, or Osaka.[6]

Therefore, local Japanese companies, which are said to have little interest in the GBA, are also concerned about border entry procedures. For example, the high-speed railroad connecting Guangzhou and Hong Kong (Guangzhou South Station to West Kowloon Station) has greatly reduced the time required to travel between Guangdong Province and Hong Kong, but border entry procedures can be time-consuming. They need to travel back and forth between Guangzhou, where their factories are located, and Hong Kong, the center of financial transactions.

The Outline states that the government will improve the ease of use of transit passes for residents of Hong Kong and Macau to and from mainland China, facilitate visa applications for residents of cities other than Hong Kong and Macau, and explore policies to facilitate the entry of foreigners. However, no clear actions regarding the six-day visa waiver for foreigners entering Guangdong Province from Hong Kong and Macau have been undertaken at the current time.[7] Considering the restrictions imposed on the movement of human resources, the extent to which innovation creation can be promoted remains unclear.

Cargo can be imported into mainland China without tariffs through the Guangdong Free Trade Pilot Zone in Shenzhen, which has already made the movement of cargo smoother compared with that of people. However, Hong Kong has experienced a greater decline in the number of cargo due to the loss of

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[5] For example, Sam, Chief Strategist at Hong Kong's Baihui Securities, says, "Even if online meetings are available, important negotiations and other matters will not proceed without face-to-face meetings" (Nihon Keizai Shimbun, October 22, 2022).

[6] Moreover, as of October 2023, it took three hours to apply for and three hours to receive a passport with a visa affixed (in the case of the Tokyo Visa Center).

[7] A 6-day regional visa waiver for foreigners entering Guangdong Province from Hong Kong and Macau has been announced for October 2023. Travel must be arranged through a travel agency in Hong Kong or Macau and must constitute a group tour of two or more people.

its advantage of being a free port, with port cargo volume handled in April–June 2023 being 14.9% y/y.[8] Therefore, it can be said that at present, the Guangdong Free Trade Pilot Zone and Hong Kong are competing for cargo.

Therefore, we discuss the current status and challenges of smart port construction in the Yuehua Bay Area below, using the Guangzhou Nansha Port District Phase 4 Terminal as a case study while considering the innovation environment survey in Hong Kong (end of August to early September 2023) and in Shenzhen and Guangdong (late October 2023).

4.3. Smart Ports in the GBA: Guangzhou Nansha Port District Phase 4 Terminal

The history of ports in the GBA has been summarized by Ding et al. (2023). The GBA includes nine cities—Guangzhou, Shenzhen, Zhuhai, Foshan, Huizhou, Dongguan, Zhongshan, Jiangmen, and Zhaoqing—two special administrative regions—Hong Kong and Macau. China's reform and opening up in 1978 led to the establishment of four special economic zones, including Shenzhen in 1980, and 14 coastal liberated cities, including Guangzhou in 1984. This triggered the formation of an economic model that combined Hong Kong's high degree of economic freedom and Guangdong's location in mainland China.

In the 1970s, Hong Kong was positioned as the bulk cargo port for containers and Guangzhou as the bulk cargo port for coal, crude oil, etc. However, when the central government and Guangdong Province formulated the "Guangdong Province Coastal and Zhuhai Delta Harbor Layout Plan" after 1990 when the transport capacity for these cargoes started becoming insufficient, container transport gradually shifted to the Port of Shenzhen. In the 2000s, when the transportation capacity limitations of the Port of Shenzhen became evident, a plan to construct the Nansha Port Area at the Port of Guangzhou was initiated, and the first-phase berth in the Nansha Port Area was completed in 2004. The Port of Nansha meets diverse needs of transportation by sea, river, and road; after the completion of this first-phase berth, the Port of Guangzhou's Nansha Port District has played a major role in container transportation in the GBA.

In the Guangzhou Port Nansha Port Area, the first four terminals were completed in 2004, the second terminal started service in 2007, the third terminals in 2014 and 2017, and the fourth terminal on July 28, 2022. Nansha Phase 4 Terminal, the newest container terminal in the Guangzhou Port District's Nansha Port Area, is the first fully automated terminal in the GBA. Furthermore, a rail service line has been laid to integrate marine and rail transportation and link the inland and coastal areas (Figure 1).

[8] From the JETRO Business Brief (September 14, 2023).

Fig. 1 Signage showing the integration of the inland and coastal areas at the Nansha Phase 4 Terminal

The most important infrastructure enabling full automation of the Nansha Phase 4 Terminal includes the unmanned gantry cranes and unmanned intelligent guided vehicles (IGVs) that enable remote control operations (Figure 2). The gantry crane automatically loads the onboard container onto the IGV according to the instructions issued by the information system, and the IGV automatically transports the container on board to the yard according to the navigation of China's satellite positioning system, "Beidou." This automation reduces personnel by 70% and enhances safety during operations.

Conventional automation employs navigation by magnetic markers, and the installation and maintenance of magnetic markers is expensive as it is not easy to change routes. The IGV, developed by Haige Communications in cooperation with the Port of Guangzhou and Zhenhua Heavy Industries to eliminate this bottleneck, will autonomously formulate routes and transport containers to the container yard. Additionally, the automated gantry crane and IGV, which combines the Beidou positioning system and 5G communications, is a proprietary system for which China has intellectual property rights (Li 2024).

Another port that, similar to the Nansha Phase IV berth, is fully automated with the use of IGVs is the Beijiang C Zone of Tianjin Port (Zou et al. 2022).

Fig. 2 IGV at Nansha Phase 4 Terminal

Systems have been integrated at Terminals 1, 2, and 4, and a facial recognition system has been introduced at the gates (Figure 3). However, the Nansha Phase 4 Terminal is a smart port noted for its automated terminal operations (Figure 4); it cannot be said to be a smart port in the broader sense as it lacks connection with other domestic and international ports.

As has been the case with Hong Kong and Shenzhen, it will be necessary to develop new ports when existing ones approach the limit of their container carrying capacity. However, at least in the Nansha Port Area, there is scope for further development. The development of a fourth terminal has already started (Figure 5).

Fig. 3 Container terminal gate with facial recognition system

Fig. 4 Sign indicating the Phase 4 Terminal with “Automated Wharf” written on it

Fig. 5 Construction site at Longxue Island in the Nansha Port Area, where further development is underway

5. Discussion

5.1. China's Smart Port and "Belt and Road" Initiatives

China is developing its proprietary smart port management and control systems and decreasing its dependence on foreign countries. This includes the domestic technology development of autonomous trucks, complex software systems, and other critical components. China's Smart Port Initiative is part of its "Digital Silk Road strategy," which aims to integrate Industry 4.0 technologies such as 5G, AI, big data, and cloud computing into port infrastructure investments under its "Belt and Road" Initiative.[9]

Robinson (2023) reported that Huawei is providing smart port technology to the Middle East and North African countries, including Oman, Saudi Arabia, and the UAE. Additionally, Huawei is developing a next-generation "intelligent port brain" smart port system at the Port of Tianjin and promoting automation and AI using ICT. This push for smart port technology is seen as a way for China to strengthen its trade dominance and use these digital partnerships to collect sensitive data.

Thus, China's Smart Port Initiative appears to be an important part of the country's strategy to acquire technological and economic dominance over the global trade and logistics network. By developing domestic smart port capabilities and exporting these technologies to the rest of the world, China seeks to position itself as a leader in next-generation port infrastructure.

The keystone of China's smart port concept is the GBA initiative. The GBA is located at the nexus of the "Belt and Road" Initiative's "Silk Road Economic Belt" (a land route via Central Asia) and

[9] Victoria Bela, China stakes global dominance in race to build intelligent ports, January 30, 2024. <https://www.scmp.com/news/china/science/article/3250341/china-stakes-global-dominance-race-build-intelligent-ports>

the “21st Century Maritime Silk Road” (a sea route via the Indian Ocean). Therefore, the development of smart ports in the GBA is crucial for integrating port infrastructure investments under the “Belt and Road” Initiative.

5.2. Port Interconnection and Challenges of Smart Port Development in the GBA

Container freight rates increased sharply in response to the COVID-19 pandemic. This was attributed to a decline in container production and shortage of port workers, which caused containerized cargo to stagnate in ports. Therefore, given that containerized cargo is expected to increase in the future, there is an urgent need to develop large and smart ports with automated cargo handling operations; the GBA, which includes the ports of Guangzhou, Zhuhai, Shenzhen (Figure 6), and Hong Kong, aims to interconnect these ports and transform them into smart ports.

In addition to the Pearl Harbor Bridge connecting Hong Kong and Macau and the Humen Bridge and Humen Two Bridge connecting Guangzhou and Dongguan, the Shenzhen–China Link (comprising two bridges and an undersea tunnel) was built to connect Shenzhen and Zhongshan and was completed on November 28, 2023. The interconnection of ports is steadily progressing, with the Shenzhen–China Expressway reducing the travel time between Shenzhen and Zhongshan to approximately 30 minutes. Furthermore, an automated wharf has been in operation in District 4 of the Nansha Port area of the Shenzhen Port since July 2022.

Nansha Port District 4 concentrates on advanced technologies such as Beidou positioning, 5G communications, AI, and automated driving, all of which have been domestically produced, from facility construction to system implementation.[10] The automated wharf, which uses a commercial high-precision satellite/inertial fusion positioning system specifically designed for ports, has relatively low installation and maintenance costs unlike conventional automated wharfs that require the installation of magnetic markers.[11]

The Outline states that the construction of key platforms will be accelerated in Shenzhen Qianhai, Guangzhou Nansha, and Zhuhai Yokqin; moreover, Guangzhou Nansha, Hong Kong, and Macao will become windows to the outside world, thereby becoming model zones for fostering innovation creation, building a financial services platform, and developing into high-quality living areas.

However, while construction continues on the Pearl River side of Longxue Island, where District 4 is located, several rural areas in the Nansha District give the impression that such plans are absent throughout the region. Meanwhile, the integration of Hong Kong and Macau with mainland China has been improved, and the GBA is expected to continue to drive China’s development in the future. Furthermore, port development in mainland China is progressing; however, the extent to which the integration of Hong Kong and Macau with China will contribute to the development of the GBA remains unclear. Mainland China may replace the functions of Hong Kong and Macau and reduce the degree to which the GBA is opened up to the outside world.

As the COVID-19 pandemic subsides and economic activity resumes in earnest, with China’s economy simultaneously entering a phase of stagnation, the extent to which the GBA and the Smart Port initiatives can be resumed and integrated into the development process will be an issue to be considered in future.

5.3. Future Challenges

[10] From People’s Daily Online Japanese edition (July 29, 2022).
[11] This system is being built by Haige Communications in cooperation with Zhenhua Heavy Industries; from People’s Daily Online Japanese edition (May 28, 2021).

Future challenges include further elucidating port development in China, particularly the financial burdens of the GBA in the South China region, and the initiatives of the central government, local governments, and private sectors. This aspect has not been extensively discussed in previous studies on the GBA. Empirical surveys and literature reviews can help clarify the actual conditions of the GBA.

Fig. 6 Panoramic view of the Nansha District of Shenzhen Port

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